Markus Salomon
Till Markus *Editors*

Handbook on Marine Environment Protection

Science, Impacts and Sustainable Management

Volume 1 and Volume 2

Springer

Handbook on Marine Environment Protection

Markus Salomon • Till Markus
Editors

Handbook on Marine Environment Protection

Science, Impacts and Sustainable Management

Volume 1 and Volume 2

Springer

Editors
Markus Salomon
German Advisory Council on the Environment
Berlin
Germany

Till Markus
University of Bremen
Bremen
Germany

ISBN 978-3-319-60154-0 ISBN 978-3-319-60156-4 (eBook)
https://doi.org/10.1007/978-3-319-60156-4

Library of Congress Control Number: 2017963547

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

The deteriorating state of our ocean is directly linked to continuous and intense anthropogenic influences. Some of the most evident impacts on the marine environment include the overexploitation of marine resources, the introduction of harmful substances (including fertilizers, plastic, and materials from marine pollution accidents), ocean warming and acidification due to the release of carbon, shipping on a massive scale and underwater noise, as well as physical disturbances to coastal and benthic habitats. One of the key conclusions of the inaugural World Ocean Assessment published in 2015 was that humankind is racing against time to start managing the ocean in a more sustainable way. It is likely that continuous unsustainable use of the ocean resources and space will trigger an irreversible pattern of deterioration. Thus, the fate of the ocean depends on our ability and willpower to leave the destructive path of development and find solutions that would allow us to combine the growing use of ocean services to humankind with science-based management, protection, and restoration of the marine environment.

Fortunately, the efforts of the oceanographic community to raise the awareness of decision-makers and the public at large about the state and fate of the ocean have resulted in the inclusion of the Sustainable Development Goal 14 (SDG14) in the Agenda 2030. SDG14 resoundingly declares the ambition of nations to conserve the ocean and use it sustainably. SDG14 strives to halt ocean pollution and unsustainable exploitation of fishing resources. It also advocates to manage marine and coastal ecosystems using approaches that are scientifically sound and to address the impacts of ocean acidification. In addition, it urges for the advancement of ocean research capacity. Practical implementation of these goals, however, is a daunting challenge. Also, one should not forget that ocean acidification is the "other side" of the climate change problem. Implementation of SDG14 will require goodwill, economic investment, effective and efficiently enforced policies, and a greater understanding of the ocean physical, biological, and chemical processes. Ocean science—previously a field dominated by the sense of scientific discovery—urgently needs to be transformed into science-based service of environmental management. Observations and good data are a prerequisite for such service. But oceanographers should also start acting as honest brokers of their knowledge. They should effectively capture public opinion and achieve the necessary influence over policy and decision-makers in such a way that their recommendations can be implemented.

Humans have significantly influenced or altered nearly all terrestrial ecosystems and are rapidly expanding their activities in the oceans. While regularized *land* use is the norm, similar practices for the ocean have yet to be fine-tuned. Maritime spatial planning is already becoming a legal requirement in some parts of the world, and by the year 2030 it is expected to cover half of the area of world's exclusive economic zones. Yet in order to govern the protection and use of offshore and coastal space and resources sustainably and efficiently, we must develop the "know-how." Acquiring the necessary experience by acting independently and learning through mistakes would be too slow, too costly, and too risky. Rather, we need to engage in gathering and promoting collective knowledge, starting from the foundations to existing best practices. Doing so is the modest ambition of this comprehensive publication. The first chapter commences with a brief account of underlying science, while subsequent chapters review the impacts of marine and land-based activities on ocean ecosystems and investigate the possible risks of future activities. In the concluding chapters, an incredibly useful and innovative review is presented of how the knowledge can be both transformed into existing governance structures and further driven towards the goal of truly sustainable management.

I would like to thank the editors and all contributors to this book for their crucial inputs in fostering a deeper understanding of the marine environment and in promoting the sustainable use of our ocean. I hope that this book will be well received and widely used around the world, and I trust that numerous editions will follow that collate all the latest knowledge, experience, and best practices from all corners of the world.

Vladimir Ryabinin
Executive Secretary, Intergovernmental
Oceanographic Commission of UNESCO,
Assistant Director-General, UNESCO,
Paris, France

Preface

Scientists, the public, and governments are all concerned about serious threats to the world's marine environment. Excessive pollution, overexploitation, and climate change, to name just a few factors, have led to fundamental changes in marine ecosystems. Such changes have brought negative consequences such as the loss of biodiversity, the disruption of food-webs, the destabilization of ecosystems, and a continuous decline of fisheries resources.

Identifying and better understanding the pertinent drivers, causes, and effects, and then developing and implementing governance strategies towards sustainability, has proven far from simple. Over the last half-century, numerous efforts have been undertaken in many areas and sectors to reduce anthropogenic pressures on the seas. Such attempts can be described as a trial-and-error search process in which managers have faced a multitude of unforeseen challenges and obstacles along the way. The urgent need to reduce anthropogenic pressures has stimulated and advanced marine management and conservation-related research activities both in the natural and social sciences. Accordingly, ocean management and governance today does not begin from scratch and the quest for viable management solutions is no longer like "fishing in an empty sea." A substantial body of knowledge now exists about the relevant natural and social processes, governance mechanics, success stories, and best practices for targeting different marine environmental issues. In our view, this is a clear signal that a sustainable use of our seas and its resources is possible.

The quantity and quality of publications and journals related to marine environmental management is continuously growing. Almost all journals and publications, however, are dedicated to very specific scientific, management, and conservation questions. What we found to be missing was a clear, accessible, and comprehensive treatise on the topic—one highlighting and explaining complexities, pitfalls, and success stories of sustainable marine management. The goal of this book is to fill that gap and supply a state-of-the-art overview of the field of marine environmental protection, including both scientific and management aspects.

The target audiences of the handbook are students and advanced academics involved in this research area, experts who need to start working on specific aspects in marine environmental protection or management, administrators and practitioners (particularly from developing countries), and stakeholders, as well as nonprofessionals interested in the protection and sustainable use of seas and oceans and their resources.

The handbook comprises an array of contributions from leading experts in their field, ranging from all disciplines of natural sciences to economists, lawyers, and political scientists. Most of the experts are academics or government officials, while some are from the business sector. Among the important qualities the authors bring to this publication are academic expertise, experience, wisdom and mastery, the ability to elucidate, and the enthusiasm to reflect.

The handbook contains 54 chapters which are divided into two different volumes. The first volume provides the natural science background and starts with an introduction to the functioning of the marine environment, and to the main divisions of the oceans and their specific characteristics and properties, especially of the coastal areas (due to their important role in the use of marine resources by humans). Following this is an insightful examination of the marine ecosystems and foodwebs, the way they are connected with each other, the services they deliver to human beings, and their resilience to human impacts. It continues with a comprehensive overview of all the main human uses of the seas—their structures, design, and degree as well as the impacts and threats on the marine environment for which they are responsible. Volume one ends with an outlook on important management requirements from the perspective of a natural scientist.

The second volume addresses governance and management aspects regarding the protection of marine environments. First, developments and drivers of ocean uses are explained. To this end, a short history of ocean use is discussed. In addition, the main drivers for the exploitation of the oceans as well as underlying management challenges are outlined. Thereafter, the handbook guides the reader towards the theme of ocean governance. Here, the functioning of the existing institutional, political, and legal system is highlighted, both at the global and regional level. Moreover, a general overview of management principles, strategies, and instruments is given. Volume two also provides state-of-the-art insights into current management efforts over several different single sectors. The last chapter of the handbook provides a similar service regarding select cross-sectoral topics which are currently being targeted within the international scientific, political, and legal community.

As will become apparent in greater detail throughout this book, the desire to protect our oceans has gained substantial political attention. Highly complex sectoral regimes have developed over the last five decades, governing shipping, fishing, and mining activities in particular. Of more recent origin and mainly at a regional level, cross-sectoral ocean policies and regulations increasingly promote a systematic and coordinated management approach. Very recently and at a global level, the United Nations' Sustainable Development Goal Nr. 14 of its Agenda 2030 has reiterated the need to engage in the conservation of our oceans and urges humankind to "conserve and sustainably use the oceans, seas and marine resources." Despite all this notable and promising progress, there is still a long way to go before our maritime heritage can be said to be truly protected. This book strives to gather and sum up the ideas, the strategies, and the experiences that can help to carve out that path.

As a final note we would like to thank all the authors and all those who have also contributed in many ways to make this book possible. We are deeply grateful that they have joined us on this journey. May this endeavor contribute to restoring and maintaining the beauty of our marine environment.

Berlin, Germany Markus Salomon
Bremen, Germany Till Markus

Contents

Volume 1

Part I Natural Science Basics

1 **Introduction into Physical Oceanography** 3
Rebecca Hummels

2 **Ecological Organization of the Sea** 37
Birte Matthiessen, Franziska Julie Werner, and Matthias Paulsen

3 **Marine Ecosystem Services** 67
Markus Salomon and Henriette Dahms

Part II Impacts of Sectoral Marine Activities

4 **Impact of Fishing Activities on Marine Life**. 79
Gerd Kraus and Rabea Diekmann

5 **Mariculture** 97
Thomas A. Wilding, Kenneth D. Black, Steven Benjamins, and Iona Campbell

6 **Shipping**. 115
Alan Simcock

7 **Impacts of Coastal Developments on Ecosystems** 139
Christian Winter

8 **Offshore Oil and Gas Production and Transportation** 149
Stanislav Patin

9 **Exploitation of Offshore Wind Energy**. 165
Jens Lüdeke

10 Dredging for Navigation, for Environmental Cleanup, and for Sand/Aggregates 189
Craig Vogt, Eugene Peck, and Gregory Hartman

11 Environmental Risks of Deep-sea Mining 215
Philip P. E. Weaver, David S. M. Billett, and Cindy L. Van Dover

12 Dumped Chemical Weapons 247
Jacek Bełdowski

13 Marine Climate Engineering 261
David P. Keller

Part III Impacts of Land-Based Activities

14 Agriculture 279
Oene Oenema, Qian Liu, and Jingmeng Wang

15 Land-Based Industries 297
Elisabeth Schmid

16 Land-Based Wastewater Management 311
Stephan Koester

17 Tourism 327
Alan Simcock

Part IV Pollution from Diffuse Sources

18 Climate Change: Warming Impacts on Marine Biodiversity 353
Helmut Hillebrand, Thomas Brey, Julian Gutt, Wilhelm Hagen, Katja Metfies, Bettina Meyer, and Aleksandra Lewandowska

19 Ocean Acidification 375
Peter Thor and Sam Dupont

20 Pollution with Hazardous Substances 395
Katja Broeg and Norbert Theobald

21 Pollution with Radioactive Substances 413
Hartmut Nies

22 Eutrophication 429
Justus E. E. van Beusekom

23 Marine Litter 447
Stefanie Werner and Aleke Stöfen O'Brien

24 Input of Energy/Underwater Sound 463
Olaf Boebel, Elke Burkhardt, and Ilse van Opzeeland

25 Introduction of Non-indigenous Species 487
Ralph Kuhlenkamp and Britta Kind

Volume 2

Part V Social Drivers, Developments, and Perspectives of Increasing Ocean Uses

26 A Short History of the Use of Seas and Oceans 519
Sunhild Kleingärtner

27 Factors Behind Increasing Ocean Use: The IPAT Equation and the Marine Environment 533
Troels J. Hegland

Part VI General Aspects of Management and Governance of Human Activities

28 Challenges and Foundations of Sustainable Ocean Governance . . . 545
Till Markus

29 Institutional Framework for Marine Environmental Governance . . 563
Pradeep Singh

30 International Principles of Marine Environmental Protection 585
Gerd Winter

31 Overview of Management Strategies and Instruments 607
Carolin Kieß

32 Future Prospects of Marine Environmental Governance 621
Pradeep Singh and Aline Jaeckel

Part VII Traditional Marine Management Topics

33 The International Legal Framework for Conservation and Management of Fisheries and Marine Mammals 637
Andrew Serdy

34 Aqua- and Mariculture Management: A Holistic Perspective on Best Practices 659
Marc H. Taylor and Lotta C. Kluger

35 Offshore Oil and Gas Exploitation 683
Henning Jessen

36 Sustainable Shipping 695
Ciarán McCarthy and Bénédicte Sage-Fuller

37 Management of Hazardous Substances in the Marine Environment 715
Mikael Karlsson and Michael Gilek

38 Origin and Management of Radioactive Substances in the Marine Environment 733
Hartmut Nies

39 Waste/Litter and Sewage Management 755
Aleke Stöfen-O'Brien and Stefanie Werner

40 Coastal and Ocean Tourism 773
Stefan Gössling, C. Michael Hall, and Daniel Scott

Part VIII Emerging Management Topics

41 The Greening of Ports.................................... 793
Bénédicte Sage-Fuller

42 Offshore Windfarms 811
Greg Severinsen

43 Wave and Tidal Energy 827
Kate Johnson and Sandy Kerr

44 Deep-Seabed Mining....................................... 843
Philomene Verlaan

45 Marine Biodiversity: Opportunities for Global Governance and Management Coherence 855
Daniela Diz

46 Marine Protected Areas: Global Framework, Regional MPA Networks and a National Example 871
Henning von Nordheim

47 Marine Environmental Protection and Climate Change.......... 891
Birgit Peters

48 Management of Non-indigenous Species and Invasive Alien Species 905
Wolfgang Köck and Bjørn-Oliver Magsig

49 Integrating Sectoral Ocean Policies......................... 919
Markus Salomon and Miriam Dross

50 Marine Scientific Research.................................. 933
Anna-Maria Hubert

51 An Emerging Environmental Issue: Marine Discharge of Mine Tailings 953
Craig Vogt and Jens Skei

52 Managing and Regulating Underwater Noise Pollution 971
Till Markus and Pedro Pablo Silva Sánchez

53 Marine Geo-Engineering 997
Harald Ginzky

54 Marine Spatial Planning.................................... 1013
Mathias Schubert

Part I
Natural Science Basics

Chapter 1
Introduction into Physical Oceanography

Rebecca Hummels

Abstract The fundamental basis to understand the distribution and variability of abiotic variables within the oceans such as e.g. temperature and salinity are the underlying physical dynamics. These dynamics depend on the setting of the ocean basins and external forcing mechanisms. In this chapter water mass characteristics and their formation processes are described as well as fundamental principles, which set the oceans into motion. These fundamentals are the premise to understand possible future climate changes, the distribution and evolution of marine ecosystems and related economic interests and conflicts.

Keywords Physical oceanography • Water mass properties • Water mass formation and spreading • Wind driven circulation • Geostrophy • Waves • El Nino

1.1 Introduction

Over 70% of the Earth's surface is covered by the oceans. These enormous water bodies contain 97% of the Earth's water and hence are a principal component of the hydrological cycle. The oceans can store and redistribute large amounts of heat and therefore play a fundamental role for the natural mean climate state as well as climate variability of the whole planet. Furthermore, the oceans cover about 90% of the Earth's biosphere serving as the largest habitat on the planet and are the source of many ecosystem services. Despite the fact that the oceans serve as the largest habitat on the planet and thereby have an impact on economic factors e.g. in terms of fisheries, marine ecosystems are up to now only poorly understood (Mathiessen, Werner and Paulsen, Chap. 2). The development of marine ecosystems is dependent on several abiotic variables such as e.g. temperature and salinity, the current field or the availability of oxygen and nutrients. The distribution and variability of these

R. Hummels
GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany
e-mail: rhummels@geomar.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_1

abiotic factors crucially depend on the circulation within the ocean, which is determined by fundamental physical principles. These physical principles include processes on largely different scales in space and time covering the range from basin-wide to millimeter and millennial to seconds. In order to understand the fundamental physical principles at play in the oceans, the distribution and variability of these abiotic variables needs to be assessed from observations and then has to be related to the dynamical processes involved. This sometimes also requires the use of numerical simulations. Observing the different parameters within the oceans at an adequate temporal as well as spatial resolution is a severe challenge to oceanographers considering all the different scales of interest and the vast as well as remote areas of the oceans. However, only if the important processes are understood and adequately implemented in numerical ocean simulations, reliable predictions about future ocean and climate changes as well as the future evolution of marine ecosystems and related economic impacts will be possible.

1.2 Description of the Oceans

The current spatial set-up of the ocean basins has been set by tectonic forces and processes and is continuously changing at very slow speed. The outermost shell of the earth, the lithosphere, is not a uniform cover, but broken up into several tectonic plates. All oceanic basins were formed from volcanic rock that was released from fissures located at the mid-oceanic ridges (Fig. 1.1, yellow/green

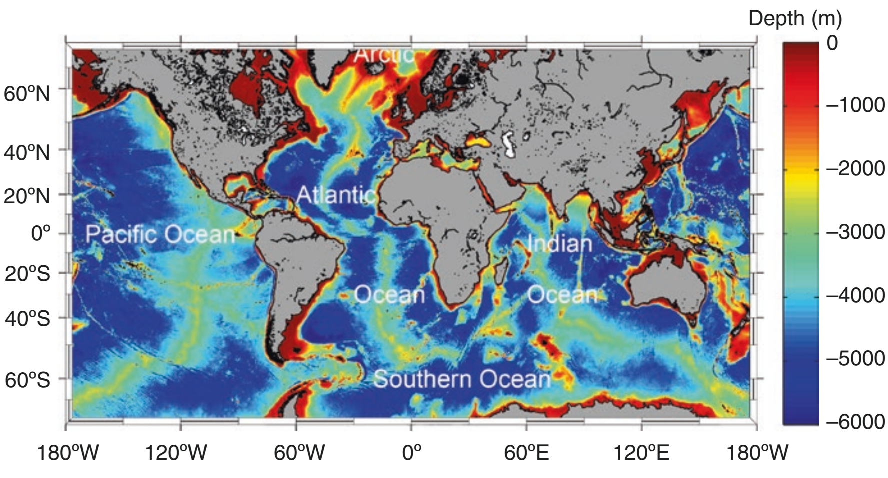


Fig. 1.1 Global seafloor topography obtained from www.topex.ucsd.edu/marine_topo/ (Smith and Sandwell 1997). The color shading ranges from *red*, shallow areas to *blue*, deep areas. *Red areas* bordering continents are the continental shelf areas, whereas *yellow* and *greenish areas* represent continental slope and continental rise. The ocean floor is shown in *blue* and covers about 30% of the Earth's surface

areas). The mid-oceanic ridges are diverging margins of tectonic plates, where enhanced volcanic activity forms new oceanic crust, which slowly drifts apart (seafloor spreading) at a speed of about 0–100 mm/year. On the contrary, at convergent boundaries one tectonic plate is forced below the other and material is lost into the earths' mantle, which is accompanied by strong earthquake and volcanic activity. At these converging boundaries very deep oceanic trenches, like the Mariana Trench (10,971 m), are formed.

Due to the oceanic topography resulting from the tectonic motions, the world ocean is divided into five ocean basins, which are in descending order by area the Pacific, the Atlantic, the Indian, the Southern and the Arctic Ocean (Fig. 1.1). Several marginal seas are affiliated to the respective oceans, whereas a marginal sea is defined as a sea partially enclosed by islands, archipelagos, or peninsulas, but adjacent to or widely open to the open ocean at least at the surface. Below the surface it can be disconnected from the ocean basin by submarine ridges, e.g. the Mediterranean Sea is a marginal sea of the Atlantic Ocean.

The individual ocean basins are further subdivided into different characteristic topographic areas: The continental shelf (red areas in Fig. 1.1) borders various landmasses, is quite shallow (average 130 m depth) and has a rather gentle slope. Shelf areas differ in their width ranging from tens of meters to a maximum of about 1300 km. Beyond the shelf area, the continental slope and continental rise follow (yellow areas in Fig. 1.1), before the ocean floor (blue areas in Fig. 1.1) hooks up. The continental slope is characterized by a steep slope dropping from the shallow shelf areas to about 2000 m depths over a range of 20–100 km and marks the edge of the continents. Although the shelf and the continental slope are under water they are considered part of the continents. The boundary between the shelf and the continental slope is called the continental shelf break. At the base of the continental slope, the continental rise connects the slope and the ocean floor with a shallower inclination more comparable to the shelf areas then to the continental slope area. The ocean floor itself is covered with approximately 10,000 volcanoes and seamounts, the exact number of these features is still quite unknown. In fact, topographic maps of the Mars or the moon are more complete than maps of the marine topography of the Earth. This is due to the fact that water absorbs and refracts light so well that the deep ocean is opaque even to the "eyes of most satellites". However, combining information on the Earth's gravity field and sea surface height as well as all available sonar-based ocean depth information a rather detailed map of the ocean floor could be constructed (Fig. 1.1, Smith and Sandwell 1997).

The different topographic areas described above are if paired with specific physical conditions favorable for the development of marine ecosystems. As an example, if the coastal/shelf areas are in regions of *upwelling* favorable winds, the nutrient-rich waters promote the development of high biological productivity, which in turn can be an important economic factor for the adjacent countries.

However, all these different topographic environments share the common substance seawater, which reacts to the physical setting of the specific environment and serves as the habitat for the different marine species. This common substance seawater shows more variability though then one might think, which will be explained in the following.

1.3 Characterization of Seawater

Before pointing out some characteristics of seawater, it is noteworthy to say a few words about plain water: Water (H_2O) is the only chemical substance on Earth, which naturally appears in all three common states of matter (solid, liquid and gas). It consists of two hydrogen atoms, which are covalently bonded to a single oxygen atom. As the water molecule is not linear and the oxygen atom has a higher electronegativity than hydrogen atoms, it is a polar molecule with an electrical dipole moment. This means that the water molecule is charged positive at one end and negative at the other end and depending on the surrounding temperature these dipoles align themselves according to their charge. This attribute of the water molecule is the fundamental premise for some characteristics of water. First of all water is a good solvent especially for salts (seawater), sugars, acids, alkalis and some gases, especially oxygen and CO_2. Second, water can form an unusual large number of intermolecular hydrogen bonds. This ability leads to some additional characteristics of water: high values in surface tension, viscosity, specific heat capacity, heat of evaporation etc. as well as the density maximum at 4 °C. The density maximum is a kind of counterintuitive characteristic of water. Most substances have a larger density in their solid state of matter than in the liquid state. For water, the solid state is ice, which is lighter than liquid water at 4 °C and hence floats at the surface. This is the reason why a lake can have a frozen surface in winter, but below water at 4 °C is still liquid and serves as a shelter for fish. In this case the ice cover insulates the liquid water below from further atmospheric cooling.

For climate not only the liquid (water) and solid (ice) states of water are important. In form of water vapor in the atmosphere it is responsible for about two thirds of the natural greenhouse effect, which supports life on earth. Without the natural greenhouse effect the surface temperature of the Earth would be at about −18 °C instead of the actual about +14 °C we are facing nowadays. However, the additional anthropogenic release of other gases contributing to the greenhouse effect such as e.g. CO_2 brings an imbalance to the greenhouse forcing. This results in a further increase of the average surface temperature on Earth known as the global warming effect. Nevertheless, other characteristics of the water molecule, especially the high values in heat capacity and heat of evaporation allow water to buffer large temperature fluctuations and thereby moderate the effect of global warming and the Earth's climate in general.

The main difference between pure water and seawater is that in seawater a lot of salts are dissolved. The addition of salts changes the conductivity of seawater compared to pure water and actually nowadays conductivity measurements are used to estimate the salinity of a seawater sample. In fact, as a relation between the conductivity of a standardized seawater sample and the seawater sample in question is used, the commonly used salinity scale in oceanography does not have any unit. Typical values for salinity within the oceans range from 34 to 38 in the open ocean, less than 20 in brackish water like the Baltic Sea and over 38 in regions of high evaporation like the Mediterranean Sea. However, the idea of the conductivity relation is based on the assumption that the relative proportion of the different salts is similar in every region of the ocean. As a matter of fact this is not the case and the most modern salinity scale, the absolute salinity scale in units g/kg from TEOS-10 (Thermodynamic Equation Of Seawater—2010, www.teos-10.org) accounts for these differences.

Generally salinity is a chemical characteristic of seawater. Due to its influence on the density of seawater though it has implications for the physics as well. Differences in seawater density can drive large-scale motions in the oceans. Therefore the density of seawater is an important metric for oceanographers.

The density (ρ) of seawater depends on temperature (T), salinity (S) and pressure (P) of the respective seawater sample and is estimated with an equation of state $\rho = f$ (S, T, P) in units kg/m^3. The density of fresh, liquid water is 1000 kg/m^3 at 4 °C, whereas the additional salt, colder temperatures and the pressure effect let seawater density range from about 1020 to 1045 kg/m^3. To avoid the rather large numbers and small relative differences, oceanographers display density values often as sigma values (σ), which are simply ρ values subtracted by 1000. An exemplary set of T, S and P profiles and the resulting density profile in the Atlantic at 23°W on the equator is shown in Fig. 1.2. Here, additional curves for temperature and density, the *potential temperature* (θ) and the *potential density* (σ_θ) are included, which are frequently used in oceanography. The latter quantities account for the pressure effect due to the overlying water body and are used when temperatures/densities of different depth layers are compared.

A typical oceanic temperature profile has its largest values at the surface, whereas these surface values crucially depend on the geographic region of the profile or more precisely the solar radiation from the atmosphere at that location (tropical surface temperatures are a lot larger than polar surface temperatures). In most cases these “maximum” values extend over a certain depth range called the mixed layer depth (MLD). As the name already states the MLD is a well-mixed layer in terms of temperature and salinity, and hence also density differences within the ML are small. Below the MLD the thermocline continues, where temperature drops rather rapidly, whereas beyond the thermocline the temperature decrease is less strong.

Salinity profiles are rather different throughout the ocean, whereas surface values are also crucially dependent on the atmospheric forcing at the surface. In regions of high precipitation surface values are accordingly low and in regions of strong evaporation salinity at the surface is relatively high. Surface values of salinity can also be influenced by river run-off, for example the vast amount of freshwater that is brought into the ocean by the Amazon river.

The density profile is per definition a result of the T, S, and P values. Typically it has the lowest values at the surface, which should monotonically increase, if the water column is stably stratified. This means that if water with a larger density should be found on top of water with lighter density, this will lead to instability and mixing. Generally, the pycnocline (the depth layer of strong density variations) coincides with the thermocline as the strong temperature variations in this depth layer dominate the variability in density. Accordingly the definition of the MLD is sometimes based either on the temperature profile or on density.

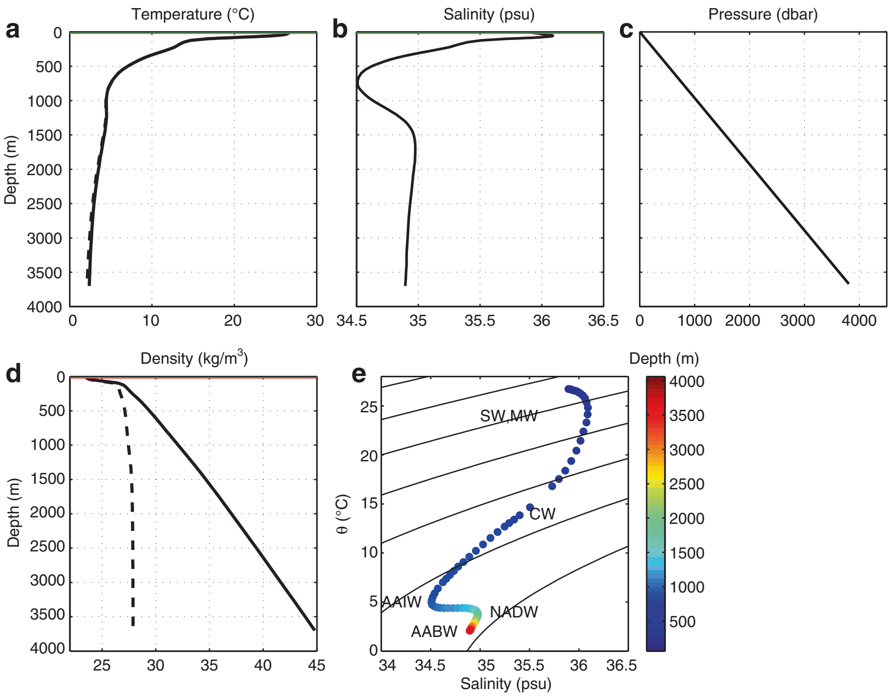


Fig. 1.2 Exemplary profiles of (**a**) temperature, (**b**) salinity, (**c**) pressure and (**d**) density against depth at 0°N, 23°W in the tropical Atlantic from the World Ocean Atlas (https://www.nodc.noaa.gov/OC5/woa13/woa13data.html). In (**a**) and (**d**) the in-situ temperature/density (*solid*) as well as the potential temperature/density (*dashed*) referenced to surface pressure are shown, in (**d**) σ values are depicted. (**e**) θ − S diagram, where θ is plotted against salinity; the *color-coding* indicates the depth of the individual observations and characteristic water masses are indicated, where SW depicts surface water, MW mode water, CW central water, AAIW Antarctic Intermediate Water, NADW North Atlantic Deep Water and AABW Antarctic Bottom Water. The *black contour lines* denote lines of σ_θ with a spacing of 1 kg/m^3

However, both definitions of the MLD use some kind of threshold criterion such as: the MLD is defined as the depth at which T has dropped by e.g. 0.2 °C compared to the surface/a near-surface value or ρ has increased by 0.03 kg/m^3 (de Boyer Montegut et al. 2004).The different characteristics in T, S and P as well as different concentrations of oxygen, carbon dioxide, light availability and nutrients set the environment for all the different kinds of marine species, which partly have adjusted to a certain range of these properties (Matthiessen and Werner, Chap. 2). Should the properties change, e.g. via global warming, acidification etc. the marine species can be forced to migrate to a different environment and/or adapt to the changing conditions. If they are not able to adjust in any way, their further existence will be endangered.

The MLD is also an important characteristic for biological activity as it sets a kind of physical barrier for different species. On the one hand, properties are rather different within the MLD than below the thermocline/pycnocline: availability of

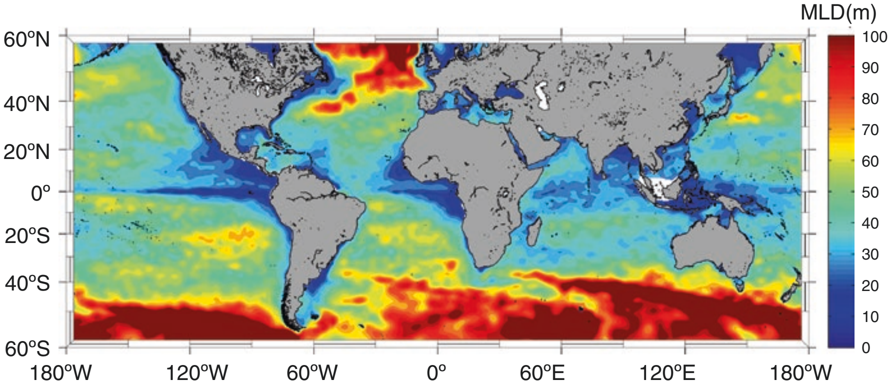


Fig. 1.3 Average annual Mixed Layer Depth (MLD) from the MIMOC climatology (Schmidtko et al. 2013) available at http://www.pmel.noaa.gov/mimoc/. Subpolar to polar regions have generally larger MLDs as the upper water column is uniformly cold, whereas in tropical regions the intense solar heating creates a thin, very warm surface layer, which is separated by a strong thermocline from the waters below

nutrients, light and oxygen, which are not necessarily abundant at depth. On the other hand, organisms must be able to pass the barrier of strong stratification (meaning strong density variations), which can be an issue especially for very small and light organisms. An overview over the average annual MLD is shown in Fig. 1.3.

Differences in density can drive large-scale motions in the ocean, which are due to their forcing mechanism termed thermohaline driven motions. The most prominent example for this is the so-called global overturning circulation. This overturning circulation is sometimes described as a global conveyer belt, which connects *convection* sites at high latitudes, e.g. in the Labrador Sea, where deep water is formed with areas at low latitudes, where water is enlightened through e.g. mixing, thereby returning towards the surface and further transported back to the *convection* sites (Fig. 1.4).

However, density differences or the stratification of the water column cannot only drive large-scale motions, but are also important for smaller scale phenomena. Without going into too much detail here, internal (gravity) waves are basically oscillations of layers of the same density (isopycnals), where the frequency of the oscillation as well as the vertical and/or horizontal propagation depend on the ambient stratification.

Note that the dependency of seawater density on pressure implies that seawater is compressible. This enables sound waves to travel through the ocean. Sound waves are themselves not important for the dynamics of the ocean, but their existence in seawater are the fundamental premise for various measurement techniques.

The paragraphs above were all concerned with differences in T and S, and hence density and the effects these differences can cause within the ocean. The question is where do these differences in T and S come from especially at greater depths in the ocean? How are water masses formed and how do they spread within the oceans?

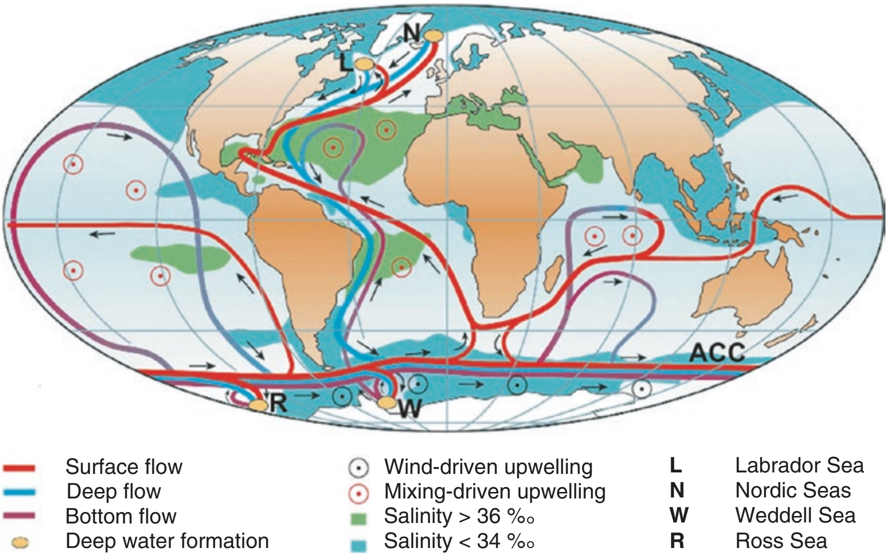


Fig. 1.4 Simplified schematic of the global overturning circulation. Deep water formation sites at high latitudes are indicated with *bold letters*. The cold and deep branch of the overturning circulation is marked as *blue paths*, the warm water return flow in the upper layers is indicated in *red*. Wide-spread zones of mixing are distributed all over the entire ocean (*red circles*), while wind-driven upwelling (*black circles*) is confined around the Antarctic Circumpolar Current (ACC). Sketch from Kuhlbrodt et al. (2007)

1.4 Water Mass Formation and Spreading

Water masses are formed at the surface in certain regions of the ocean. Some of these water mass formation regions are already indicated in Fig. 1.2e, where some water masses are pointed out e.g. "Antarctic" Intermediate Water. A water mass is formed, when water with certain T and S characteristics, which are imprinted at the surface by ocean-atmosphere interactions, gets injected into the thermocline and thereby is disconnected from the ML and surface. As the water mass is disconnected from the surface it preserves its T and S characteristics at least to some extent and spreads along isopycnals namely layers of constant density. Spreading along isopycnals is favorable in terms of energy conservation, as no work against the stratification has to be performed.

Temperature characteristics at the oceans surface are mainly set by the solar radiation, which varies with the location on the globe and the season. For salinity characteristics precipitation, ice melting and river runoff lower salinity, whereas evaporation and ice formation increase salinity. Depending on which of these processes dominate within the water mass formation region, the T and S characteristics of the water mass are set.

The processes, which then "inject" or "push" the water from the surface into the ocean interior are mainly *convection* and *subduction*:

Convection is a mainly thermohaline driven process, where surface water gets denser than the water below and therefore starts to sink. There are mainly two different kinds of convection referred to as open ocean *convection* and shelf *convection*, which contribute to the formation of deep and bottom waters. As the terms already indicate these processes take place in different oceanic settings, open ocean vs. shelf.

The subpolar North Atlantic is a region, where open ocean *convection* takes place and North Atlantic Deep Water (NADW) is formed. As the formation of NADW is an important contribution to the global overturning circulation mentioned above, its formation is explained here in more detail:

Open ocean *convection* is favorable in the Labrador Sea, because a set of physical premises is met within this area of the ocean. First, the circulation within the Labrador Sea is anticlockwise (referred to as a cyclonic circulation in the Northern Hemisphere). This kind of circulation is related to a density field, where isopycnals are elevated in the center of the circulation patch. This "doming" of isopycnals means that layers with a weak stratification are close to the surface, where they are exposed to the atmospheric forcing. A small density increase at the surface will therefore lead to *convection* and hence sinking of these waters. Second, the Labrador Sea is an area, where on the one hand ice formation takes place and on the other hand especially during the winter months the ocean is subject to a large heat loss. This large heat loss is driven by cold and dry winds blowing from the Canadian continent over the warmer ocean. Both of these processes ice formation and heat loss increase the density of the surface waters and hence deep *convection* begins. In the Labrador Sea *convection* can reach as deep as 2000 m (see Fig. 1.5) forming

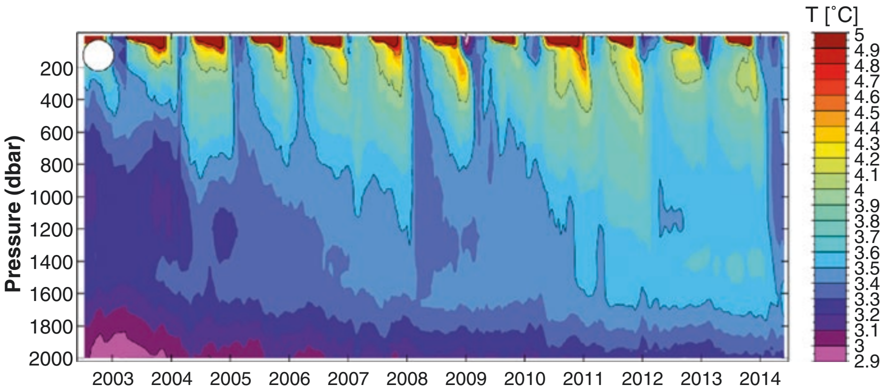


Fig. 1.5 Time series of potential temperature in the western to central Labrador Sea derived from Argo float data. The seasonal cycle is evident in the upper layers with warm temperatures in summer and cooling within the winter. In years of strong deep convection winter temperatures are nearly uniform throughout the water column (e.g. 2005, 2008, 2014) (Kieke and Yashayaev 2015)

Labrador Sea water (Marshall and Schott 1999), which is one flavor of NADW. This water mass leaves the Labrador Sea together with the even denser flavors of NADW, namely the Denmark Strait Overflow water and the Iceland Scotland Overflow Water, within the Deep Western Boundary Current (DWBC) and is exported to the south. Despite slight differences among the NADW "flavors", NADW is generally characterized by cold temperatures, high salinities and high oxygen concentrations (Figs. 1.2e and 1.6a–c). It is still of ongoing research how much NADW stays within the DWBC on its way south and how much of it takes interior pathways (Bower et al. 2011; Getzlaff et al. 2006; Rhein et al. 2015). However, NADW can be found throughout the Atlantic (Fig. 1.6). When it reaches the Southern Ocean, it gets distributed into all other ocean basins via the Antarctic Circumpolar Current (ACC). Within the Antarctic Divergence (between 50°S and 60°S) the wind forcing is set up in a way that it causes a divergent flow at the surface (*Ekman transport*), which leads to an upward movement of water for compensation. This means that isopycnal layers are tilted towards the surface and some fraction of NADW is forced to move upwards. This *upwelled* NADW serves after water mass conversions at the surface through e.g. strong precipitation and influx of melt water as source for the formation of Antarctic Intermediate water (AAIW).

In terms of the global overturning circulation another aspect of ongoing research is whether the global overturning is "pushed" by the formation of deep water as described above or "pulled" by mixing within the ocean, which enlightens deep water and brings it back towards the surface. In terms of the latter idea, that the

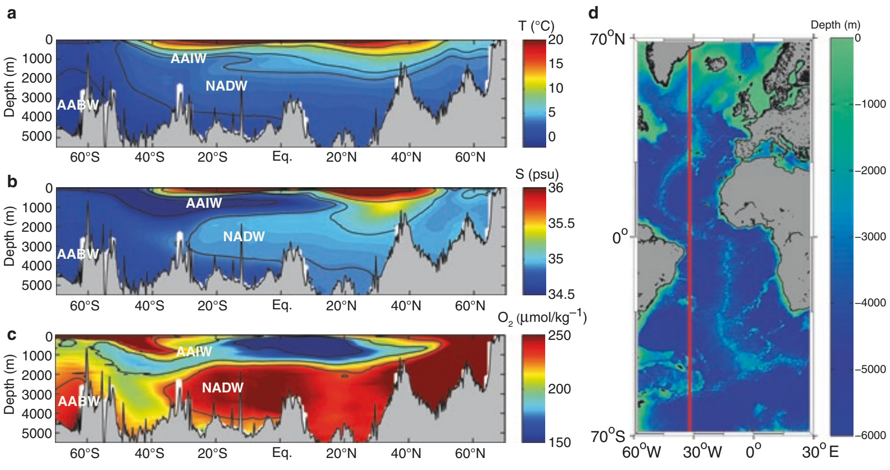


Fig. 1.6 Latitude-depth sections through the western Atlantic from the World Ocean Atlas of (**a**) temperature, (**b**) salinity and (**c**) oxygen; (**d**) shows the location of the section. Antarctic Intermediate Water (AAÌW) is characterized by low temperature, low salinity and high oxygen. North Atlantic Deep Water (NADW) has low temperature, high salinity and high oxygen concentration, whereas Antarctic Bottom Water (AABW) is characterized as very cold, fresh and a high oxygen concentration. Data from the World Ocean Atlas available at https://www.nodc.noaa.gov/OC5/woa13/woa13data.html

overturning circulation is pulled by mixing theories diverge on the aspect whether this mixing is evenly distributed over the entire ocean (Munk 1966) or might be concentrated in a specific region, e.g. wind driven mixing across tilted isopycnals within the Antarctic divergence (Toggweiler and Samuels 1998).

Shelf *convection* takes place around Antarctica and is driven by a density increase of the surface waters mainly related to ice formation. When sea ice is formed, salt is released from the freezing water to the surrounding water, which thereby gets denser. Note that dissolved salt changes the freezing point of seawater, which drops at a salinity of 34.5 to −1.9 °C instead of the freezing point of 0° for fresh water. This means that seawater has to be cooled even stronger than fresh water before sea ice can be formed. The extremely dense water, which is then produced during the formation of sea ice, cascades down along the shelf, where it gets even colder and forms Antarctic Bottom Water (AABW), the densest and coldest water mass of the world ocean. AABW is characterized by extremely low temperatures, lower salinity than deep water and high oxygen concentrations (Figs. 1.2e and 1.6a–c).

The formation of deep and bottom waters, which then spread around the world ocean, is very important for the ventilation of the deep ocean interior. For marine species living at great depths the deep and bottom waters are their source of oxygen and nutrients.

Subduction is another water mass formation process, which is related to the wind forcing at the surface. For this process water is actively "pushed" into the ocean interior and then spreads along the corresponding density surface. *Subduction* takes place over large areas of the subtropics and produces e.g. central and mode waters. The wind forcing has to be such that the surface currents converge and water is pumped downwards into the ocean, which is referred to as *Ekman pumping*. Another mechanism for *subduction* is that water, which originates within the ML of a certain region, is horizontally pushed (advected) into a region of shallower ML. Hence, in this other region that water mass is beneath the ML and therefore disconnected from the surface.

However, independent from the formation process, water masses spread along isopycnals after they are disconnected from the surface and the atmospheric forcing. Along their spreading pathways all water masses mix to some extent with surrounding waters and the oxygen is consumed by marine species. Hence, the distinct characteristics in T and S as well as other tracers like e.g. oxygen will be "washed" out the further away the water mass is traced from its formation region.

1.5 Measurement Techniques for Water Mass Properties

Pointing out all the differences in T and S of seawater and indicating the importance of the resulting density differences, raises the question: how do we know about all of these different characteristics and how do these characteristics change?

The basic knowledge about water masses and stratification were obtained using Nansen bottles with reversing thermometers. A water sample could be taken at a specific depth and analyzed with respect to salinity or other substances in question and the reversing thermometer gave the temperature at the same depth. Nowadays, electronic sensors mounted on the CTD probe (*C*onductivity, *T*emperature, *D*epth, Fig. 1.7) are used to provide information about temperature and salinity at a very high vertical resolution and accuracy. The CTD probe can be operated from a ship with a large winch over an electric cable. Often additional sensors such as oxygen, nitrate, fluorescence and turbidity are mounted on the CTD as well as a rosette of so-called Niskin bottles. The bottles are used to take additional water samples at specified depths for further analysis as well as the calibration of the electronic sensors. This instrument provides vertical profiles of the water column until about 6500 m depths with a high accuracy (a few thousands for temperature and salinity), which is necessary in order to assess climate variability also in the deep ocean.

However, as already mentioned, monitoring the vast and remote areas of the oceans is not possible with CTD observations from research vessels at the desired temporal and spatial resolution. In order to improve the resolution of hydrographic observations, programs like e.g. Argo were implemented. Argo is an international collaboration of up to 30 different contributing countries with the goal of maintaining 3000 active autonomously profiling floats measuring temperature and salinity distributed all over the world ocean. The deployments within Argo started in 2000 and continue up to date with a rate of 800 new floats per year. The profiling floats drift at a depth of about 1000 m for a period of 10 days. After these 10 days they sink to 2000 m depth and immediately rise to the surface, while recording profiles of temperature and salinity. At the surface the Argo float (Fig. 1.8) communicates with a satellite and transmits its data to the data centers before it sinks back to its parking depth of 1000 m. This cycle is repeated until the batteries are empty, which is typically the case after 2–5 years. In recent years more and more Argo floats are supplemented with additional sensors for oxygen and other biologically relevant parameters to increase the spatial and temporal coverage of these poorly resolved parameters.

In addition to these passively floating devices, the operation of underwater gliders is getting more common among the oceanographic community. Gliders are autonomous underwater vehicles, which use their wings and changes in their buoyancy to translate vertical into horizontal motion. This locomotion is not very fast (around 20 km/day), but it is very effective in terms of saving battery power, where the consumption of energy of the glider is comparable to the consumption of a small electric bulb for a bike. Hence, gliders can be sent on missions of several weeks and months and can cover a relatively large spatial distance of several thousand kilometers. Over this large distance most gliders operate up to a depth of about 1000 m following an up and down, saw-tooth like profile through the water column at a very high temporal resolution (Fig. 1.9). Several different sensors can be mounted on a glider depending on the variables of interest. As the communication with the glider is established via a satellite connection every time the glider surfaces its flight path can be adjusted depending on the phenomena it is supposed to observe. As an example the glider ifm11 of GEOMAR was programmed to measure several parameters directly "cutting" through a mesoscale eddy in the Northwestern tropical Atlantic (Fig. 1.9).

At the oceans surface the temporal as well as spatial coverage of temperature and recently also of salinity observations has been greatly improved using satellite

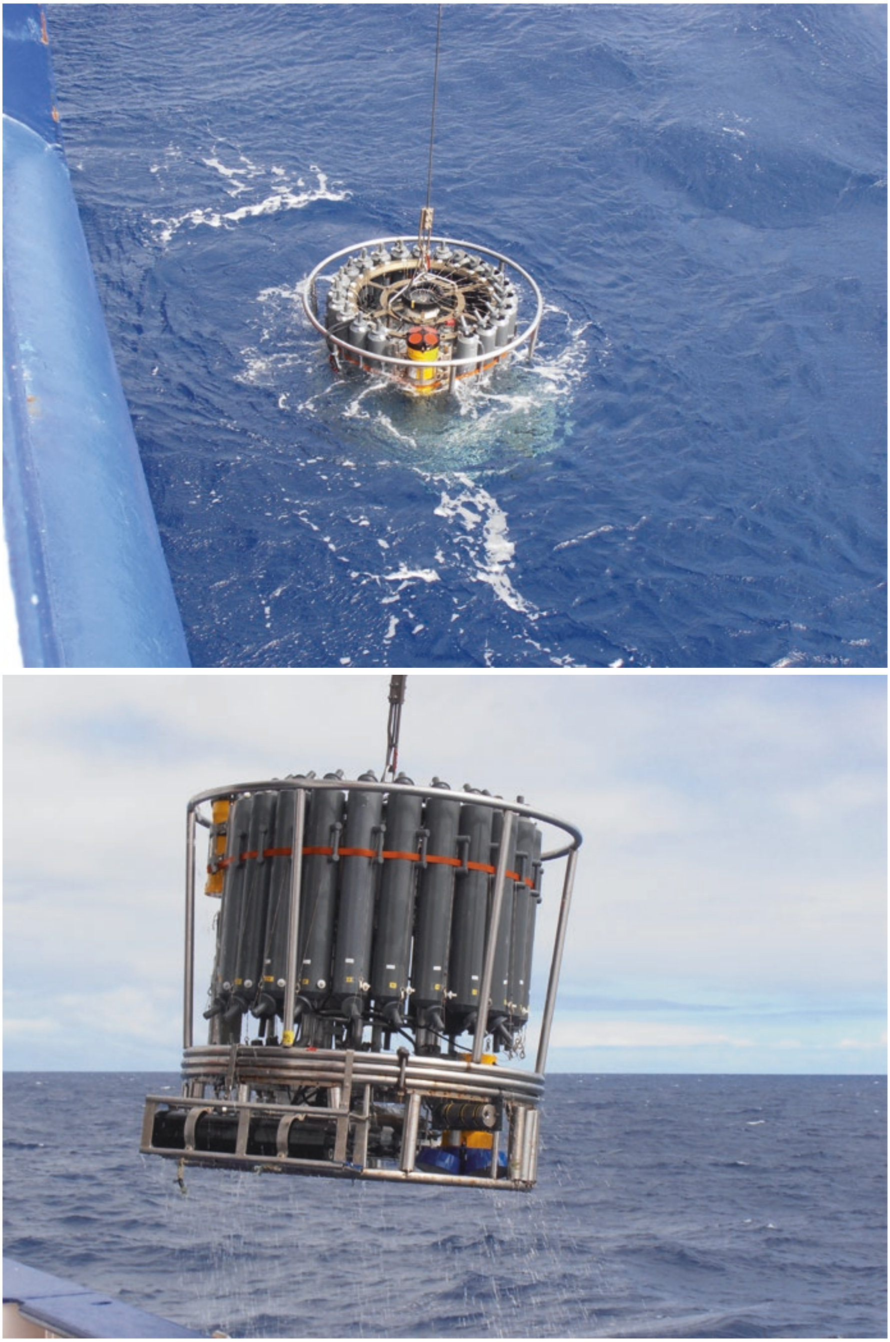


Fig. 1.7 Recovery of a CTD mounted below a carousel of Niskin bottles with water samples. The CTD was operated from the German research vessel R/V Maria S. Merian in November 2012 (photos: Florian Schütte)

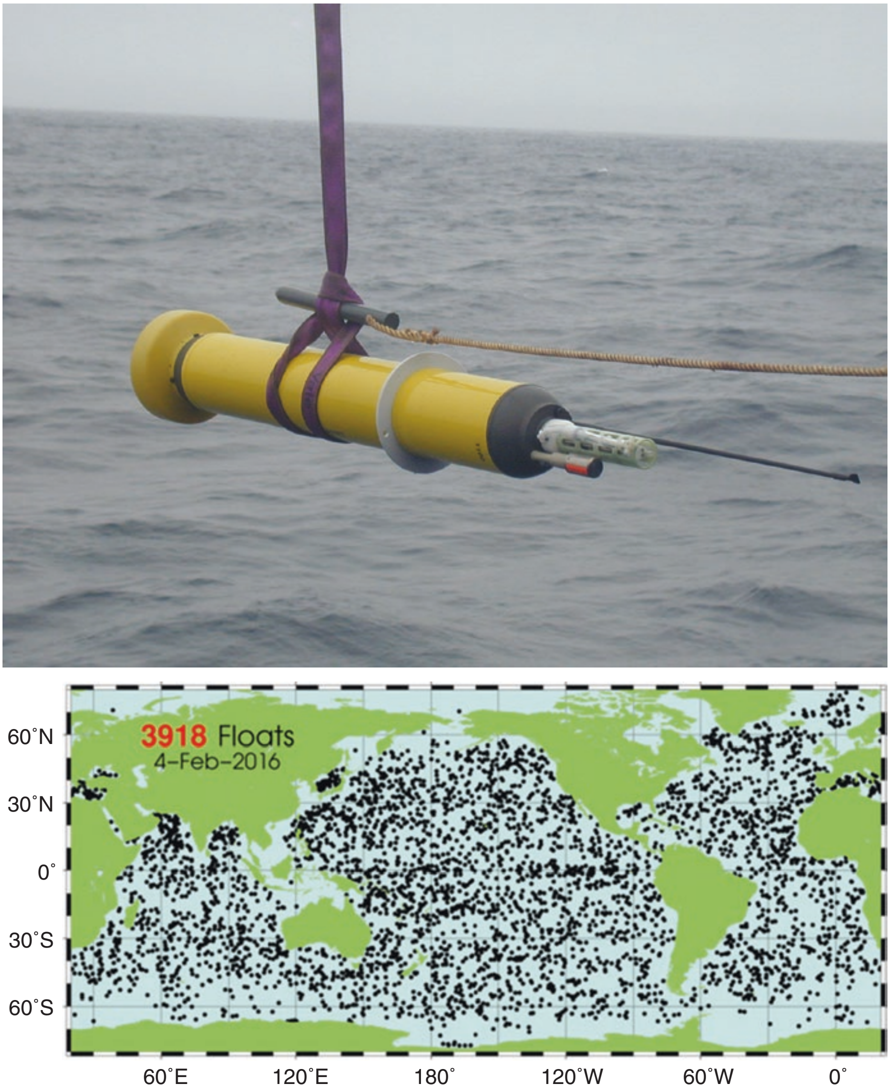


Fig. 1.8 *Top*: Launch of an APEX Argo float as an example of an autonomously profiling float (photo: Mario Müller); *bottom*: Global map of float position from the Argo array on the 4th February 2016. For an up-to-date picture visit www.argo.ucsd.edu

observations from microwave and infrared radiometers, which either passively register the microwave/infrared emission of the Earth's surface or actively illuminate their target and register the backscattered signal. The first satellite mission delivering sea surface temperature (SST) observations was launched in 1997 and since then various satellite missions have been launched. The advantage using microwave radiometers is that the observations are not limited due to the cloud cover. Using the combination of the different satellite data sets and other observations

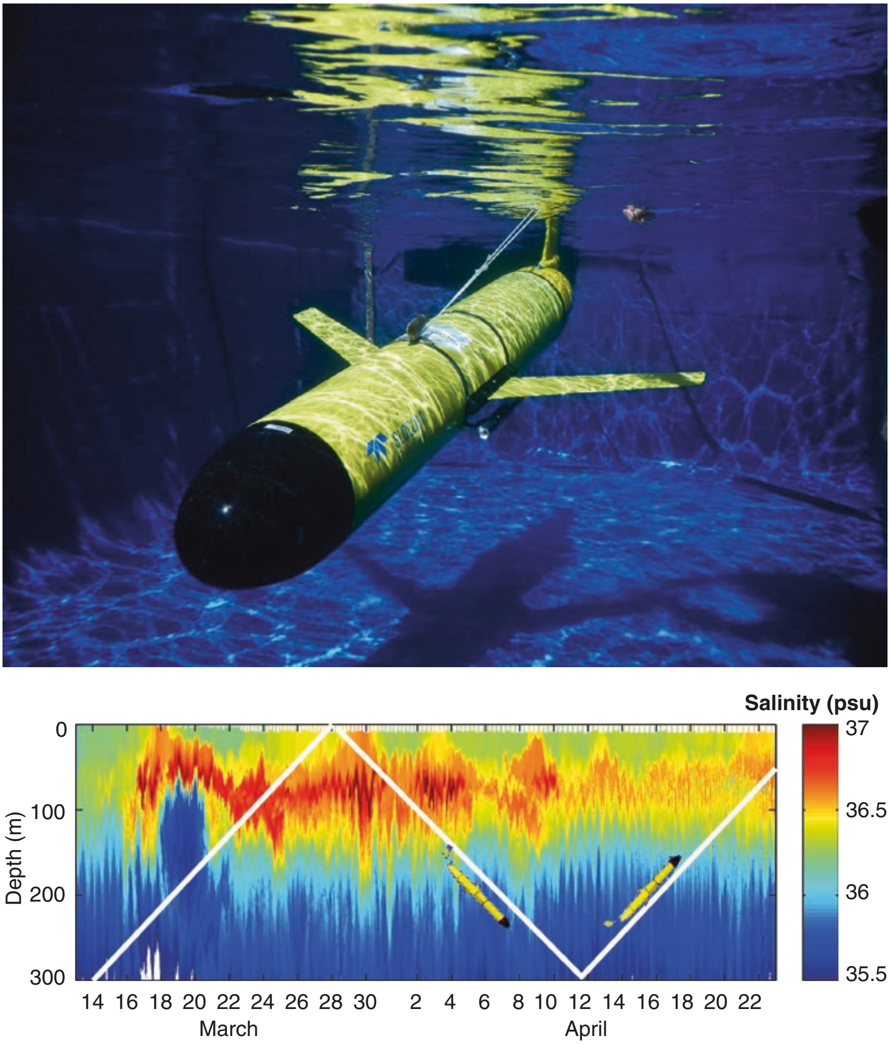


Fig. 1.9 *Top*: Picture of a Slocum glider (photo: Helena Hauss). *Bottom*: Sketch of the saw-tooth like flight path of a glider overlaying a salinity time series of the glider ifm11, deployment 1 from GEOMAR during March and April 2010. The glider mission took place within the Northwestern tropical Atlantic around 17.5°N, 24.5°W and cut through a subsurface mesoscale eddy characterized by low salinity observed between the 17th and 21st March 2010. For visualization of the flight path 1.5 diving cycles are indicated, however, for the entire section displayed here, the glider performed 996 profiles/dives

of SST, daily maps of SST at a spatial resolution of 1/4° in latitude and longitude are produced (www.remss.com).

Another type of microwave imagers is used to observe sea surface salinities, which was launched for the first time in 2009. Since then similar products as for SST are also available for sea surface salinity (SSS). SST maps do not only deliver

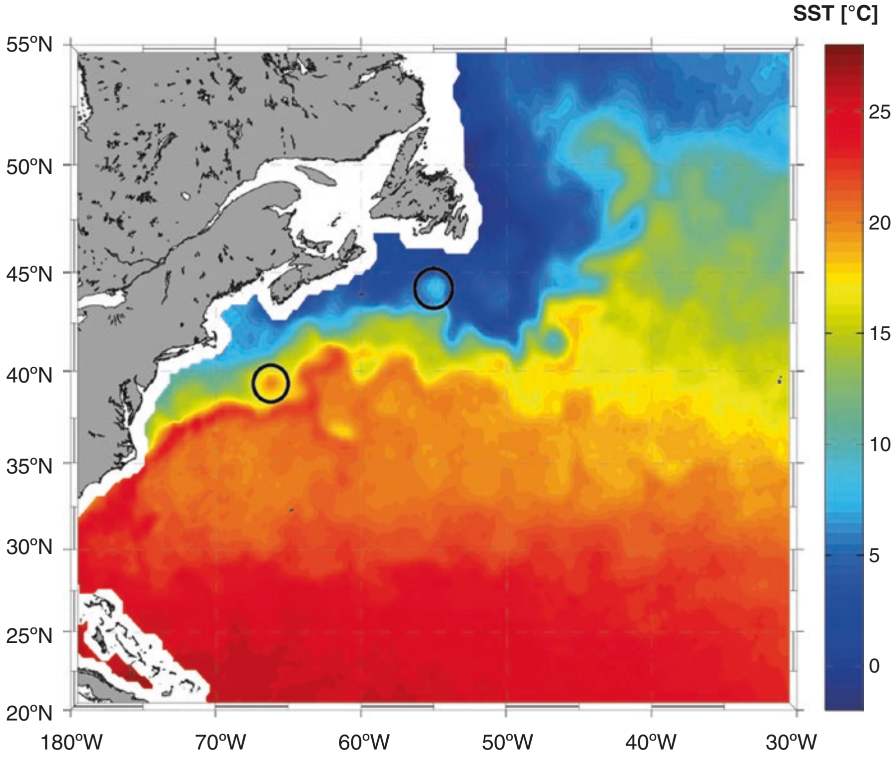


Fig. 1.10 SST snapshot using data from a combined SST product available at www.remss.com/measurements/sea-surface-temperature for the North Atlantic Ocean displaying the meandering path of the Gulf Stream. The Gulf Stream path is visible as the warm SST front spreading north-eastward and while meandering shedding off warm and cold core eddies (rotating water bodies of about 100–200 km in diameter marked with *black circles*)

fascinating snapshots related to the dynamics of the oceans such as the meandering of the Gulf stream (Fig. 1.10), but also helped to improve the understanding of e.g. *El Nino* and other climate relevant phenomena.

All these different kinds of observations of the oceans are collected at different data centers around the world, quality controlled and freely provided for public use for further analysis and research. They are also used to construct climatologies of the different parameters in the ocean describing its average state (see for example Fig. 1.6) as well as providing a reference against which changes can be assessed.

1.6 How the Wind Moves the Ocean

The other main driver of the ocean circulation system besides of the atmospheric forcing in terms of heat and freshwater fluxes at the oceans surface is the wind input. The wind driven circulation is by far more energetic than the thermohaline driven circulation, but is confined to the upper water layer of the ocean up to about 1000 m. In general, it is not necessarily possible to associate a certain oceanic feature to one forcing mechanism of the ocean alone, e.g. the Gulf Stream is part of the global thermohaline overturning circulation and part of the wind-driven Subtropical Gyre. However, in the following the main aspects of how the wind moves the ocean will be pointed out.

When the wind blows over the surface of the ocean, it sets the uppermost layer in motion by transferring some of its momentum to the surface layer. Due to friction or the drag of wind and water this moving surface layer then sets the layer below into motion and so forth. The speed of these layers decreases with depth/distance to the source of momentum. The entire layer, which is affected by the wind input can vary between about 50 and 200 m and is e.g. dependent on its stratification.

Every motion on earth, which is sufficiently slow or travels a sufficient distance, will be influenced by the rotation of the earth: The *Coriolis force* is a fictitious force and acts on objects, which move relative to a rotating reference frame. Sounds complicated, but the overall effect is that air or water, which moves over a long enough time and distance, will "feel" the *Coriolis force* and will be deflected to the right (left) in the Northern (Southern) hemisphere. When the drag between wind and water at the surface and the *Coriolis force* are in balance, oceanographers speak of the *Ekman balance* (Ekman 1905). The solution of the associated equations explains that the surface currents are directed at a 45° angle to the wind and decrease within the so-called Ekman layer (the layer directly affected by the wind input). At the same time the direction of the wind induced flow is slightly shifted from layer to layer, resulting in the so-called Ekman spiral (see Fig. 1.11). This Ekman spiral can

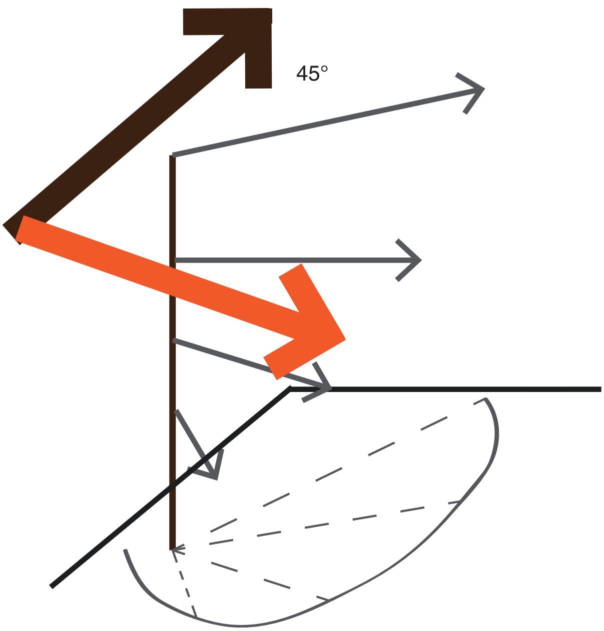


Fig. 1.11 Ekman spiral. The surface current (*uppermost thin grey arrow*) is directed at an angle of 45° to the surface wind (*thick black arrow*). With increasing depth the flow (*thin grey arrows*) is further shifted to the right (*left*) in the Northern (Southern) Hemisphere and its magnitude decreases. The integral transport (*thick red arrow*) over the entire Ekman layer is directed at an angle of 90° to the right (*left*) in the Northern (Southern) hemisphere

only rarely be observed within the open ocean, as it would e.g. require the wind input to be steady over a certain period of time. In addition, other assumptions underlying the Ekman theory are not necessarily valid simultaneously within the open ocean. However, the integrated effect over the entire Ekman layer yields in a net transport (*Ekman transport*) at 90° to the right (left) of the surface wind in the Northern (Southern) hemisphere and proportional to the strength of the wind. This net *Ekman transport* is an important feature, when trying to understand further aspects of the wind driven circulation.

Hence, to further understand the concepts of the wind driven circulation it is instructive to look at the global wind system (Fig. 1.12). It gets obvious that the global system can be divided into a few main bands, which are the trades dominating the tropics and subtropics roughly between the equator and 30°N/S (blowing from east to west), the Westerlies dominating the mid latitudes roughly between 30° and 60°N/S (blowing from west to east) and the polar easterlies prevailing from about 60° to the poles (blowing from east to west).

As an example to understand the governing dynamics of the wind driven circulation, the mechanisms setting up the Subtropical Gyre regime in the North Atlantic will be explained. Subtropical gyres are large-scale rotating circulation systems, which dominate the surface circulation of the oceans within the subtropics (between about 10° and 45°) in the Northern and Southern hemisphere. The rotation direction is clockwise (anticlockwise) in the Northern (Southern) hemisphere.

At the Northern edge the Subtropical Gyre of the North Atlantic is bordered by the Westerlies and at the Southern edge the wind field is dominated by the Northeast Trades (Figs. 1.12 and 1.13 left panel).

As explained above the net transport in the surface layer induced by the wind (*Ekman transport*) is 90° to the right within the Northern Hemisphere and hence

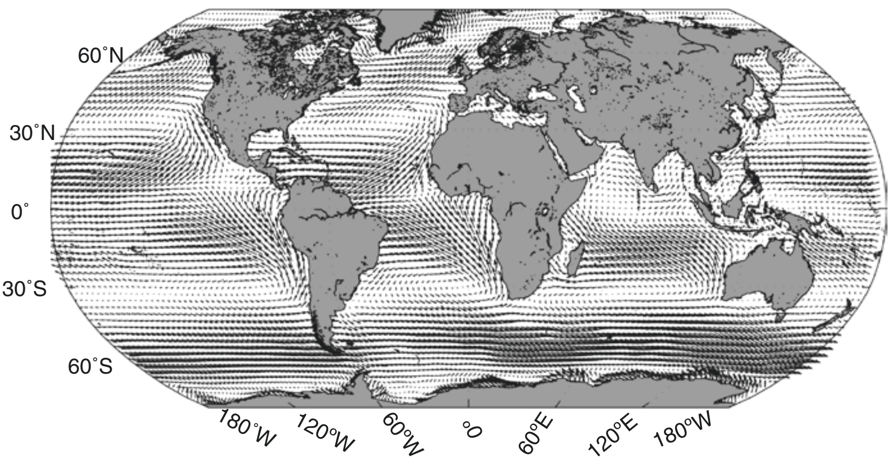


Fig. 1.12 Annually averaged global wind field from NCEP/NCAR long term monthly means of surface winds (http://www.esrl.noaa.gov)

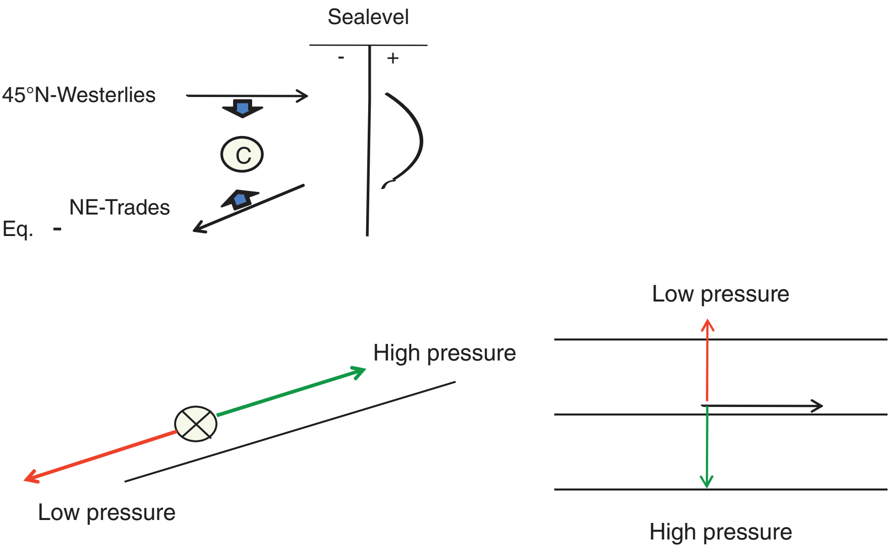


Fig. 1.13 *Top*: Simple schematic of the wind field within the Subtropical Gyre regime together with the associated Ekman transports (*blue arrows*) and the resulting convergence of water ©, which elevates the sea level in the center of the Gyre (shown *right*) and thereby creates a pressure gradient. *Bottom*: Schematics of the geostrophic balance from different angles. The pressure gradient force (*red arrows*) balances the Coriolis force (*green arrows*) and the resulting geostrophic current (*black arrows*) is parallel to isobars with the high pressure to the right (*left*) in the Northern (Southern) hemisphere

southward for the Westerlies and northward for the Northeast Trades (Fig. 1.13 top left). This causes a convergent flow (C) between the wind systems, which results in a "bulk" of water in the center of the gyre. The resulting effect is that a pressure gradient between the "bulk" of water in the middle and the surrounding water is set up. This pressure gradient sets up the conditions for another oceanographic concept termed *geostrophy*.

For compensational effects, water will flow from the area of high pressure to the area of low pressure, along the pressure gradient (Fig. 1.13 bottom). Due to the Earth's rotation, the effect of the *Coriolis force* will come to play again and will deflect the flow to the right (left) in the Northern (Southern) hemisphere. When the *Coriolis force* and the pressure gradient force are in balance, a *geostrophically* balanced flow results (Fig. 1.13 bottom). This flow is at a right angle to the pressure gradient and at the same time at a right angle to the *Coriolis force*. Hence, the *geostrophic* flow resulting from the circular bulk of water in the middle of the gyre results in a somewhat circular flow around the bulk, the Subtropical Gyre.

Above, the *Ekman balance* was introduced as the balance between frictional forces and the *Coriolis force* within the boundary layer of the ocean. As a result of this balance, pressure gradients develop due to the variations in the wind field. These pressure gradients then form a *geostrophic* flow reaching into the interior of the ocean (up to about 1000 m), when the pressure gradient force is in balance with the *Coriolis force.* If these two concepts are combined, hence considering the balance of frictional forces, the pressure gradient force and the *Coriolis force,* the Sverdrup balance (Sverdrup 1947) results. Evaluation of this equation system results in the formulation of a streamfunction for the flow basically only dependent on the wind field. Hence, when an idealized wind field for the Subtropical Gyre is assumed (Fig. 1.14 left), the resulting streamfunction of the Sverdrup relation is nearly sufficient to explain the rotational gyre circulation (Fig. 1.14 right). However, the Sverdrup theory cannot close the circulation at the western boundary, which has to be justified with continuity. Further consideration of bottom friction (Stommel 1948) or lateral friction (Munk 1950) can be used to close the circulation at the western boundary and even explain the intensification of the flow at the western boundary (in case of the North Atlantic Subtropical Gyre the energetic Gulf stream).

The wind input at the surface can not only drive *geostrophic* surface currents as described above, but is also responsible for subsurface current features e.g. at the equator: As the *Coriolis force* vanishes at the equator, the *geostrophic* balance

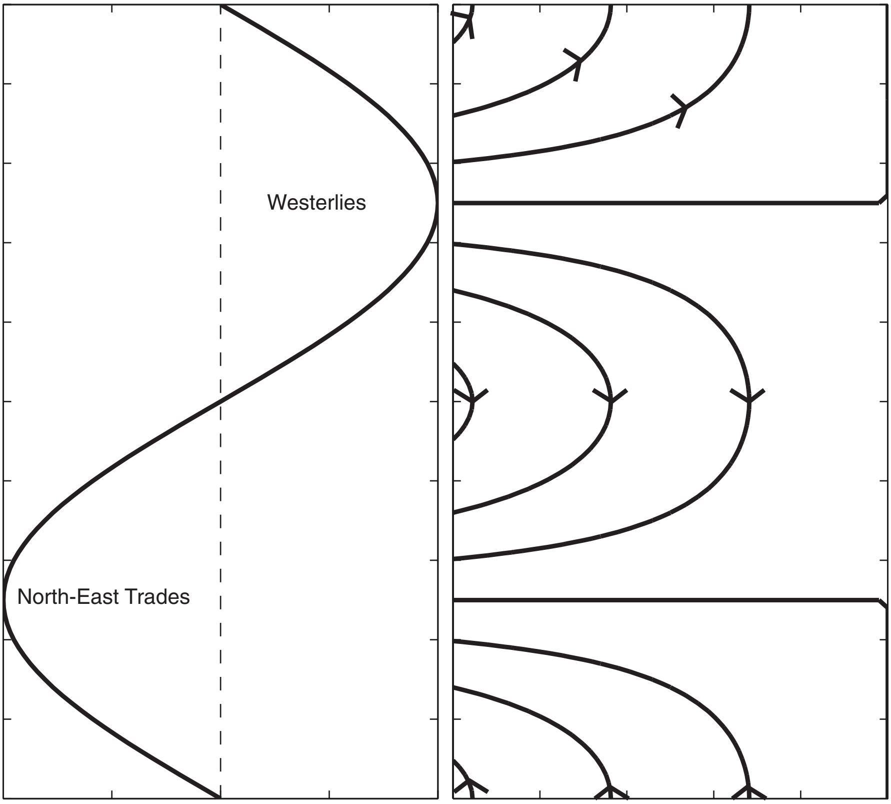


Fig. 1.14 *Left*: Idealized wind field of the Subtropical Gyre, where the positive bulge represents the Westerlies and the negative bulge the Northeasterly Trades. *Right*: Calculated streamfunction of the Sverdrup transports for the idealized wind field in the *left panel*

does not apply here, neither does the *Ekman balance* directly at the equator. The east-west component of the wind at the equator is directed towards the western boundary and as *Ekman* does not apply, the surface waters are directly “piled” up at the western boundary. This invokes a west to east pressure gradient. As the surface current is directed towards the west the water is not able to flow directly down this pressure gradient at the surface. Within the subsurface layer though, a flow along the pressure gradient can develop. This compensating flow is balanced by frictional forces and forms the rather strong Equatorial Undercurrent (EUC), which crosses nearly the entire ocean basins. The tilted sea surface is compensated at depth with a sloping thermocline, which has a similar structure as the equatorial MLD (Fig. 1.3): deeper MLDs/thermocline in the west compared to the east. The shallow thermocline in the east is favorable for *upwelling* and plays an important part in the *El Nino* phenomenon.

However, the wind system in reality is not as idealized and simple as assumed in the examples above, e.g. the Trade winds are not symmetric about the equator, which leads to a more complex surface circulation pattern (Fig. 1.15). In addition, the wind field is attributed to variability on various time scales, which then imposes variability on the wind driven current system. For instance, the Intertropical Convergence Zone (ITCZ), which is characterized by rather light easterly winds the so-called Doldrums and divides the Northeasterly Trades from the Southeasterly Trades,

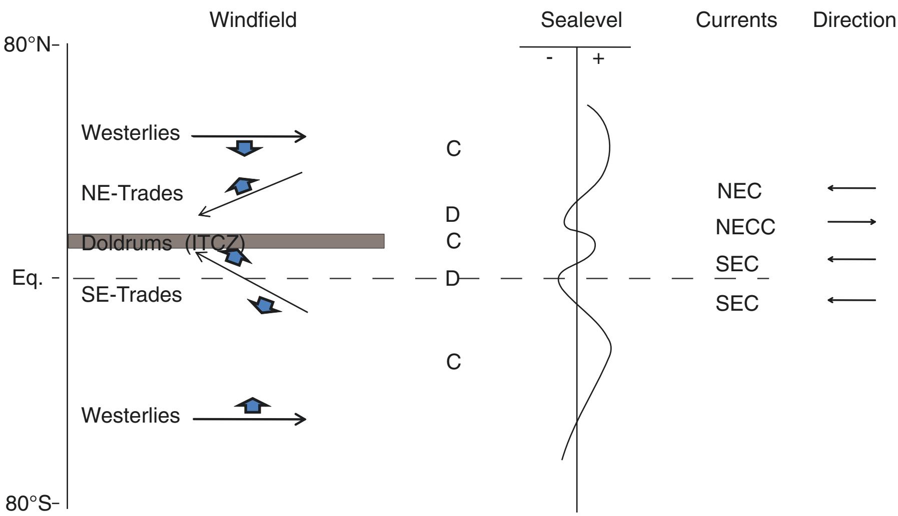


Fig. 1.15 A slightly more realistic schematic of the wind field and resulting flow patterns in the tropical Atlantic considering that the trades traverse the equator. The winds are indicated with *black arrows* on the left, the resulting Ekman transports with *blue arrows*. The Ekman transports are convergent (C) or divergent (D) and result in positive and negative displacements of sea level indicated with the *black curve* in the middle of the panel. This causes pressure gradients, which result, when in balance with the Coriolis force, in geostrophic currents indicated with *black arrows* on the right, which are namely the North Equatorial Current (NEC), the North Equatorial Counter Current (NECC) and the two branches of the South Equatorial Current (SEC)

shifts seasonally within the year. This seasonal migration is also imprinted on the wind driven current system and explains at least some of its seasonal variability.

The global surface currents of the oceans, which are mainly induced by the wind input at the surface, are summarized in Fig. 1.16. As an example the mechanisms driving the Subtropical Gyre regime in the North Atlantic were described above, which explains the existence and positions of the North Atlantic Current, the Canary Current, the North Equatorial Current and the Gulf Stream. It gets obvious that these Subtropical Gyres can be found in all other ocean basins (Fig. 1.16) and that the same mechanisms also explain the Subpolar Gyres in the Northern Hemisphere, which due to the differing wind pattern rotate counter-clockwise.

Sverdrup theory requires a boundary condition, which is mostly set at the eastern boundary of the ocean basins, where the landmass borders the ocean. It gets obvious that the region exposed to the Westerlies of the Southern Hemisphere completely lacks boundaries and therefore Sverdrup theory cannot be applied there. Instead the region bordered by the Subtropical Gyre and the South pole is dominated by the largest current in the world ocean: the Antarctic Circumpolar Current (ACC). This strong current surrounding Antarctica prevents warm waters from the Subtropics from invading the Southern Ocean. Therefore, strong temperature differences are established between Subtropical and Antarctic Water masses forming strong fronts. With the continuous wind input from the Westerlies at the surface and the absence of bordering landmasses against which water could be piled up, the ACC would continuously accelerate. Mesoscale eddies however as well as internal pressure gradients associated with topography balance the wind input at the surface and prevent further acceleration of the system (Rintoul et al. 2001).

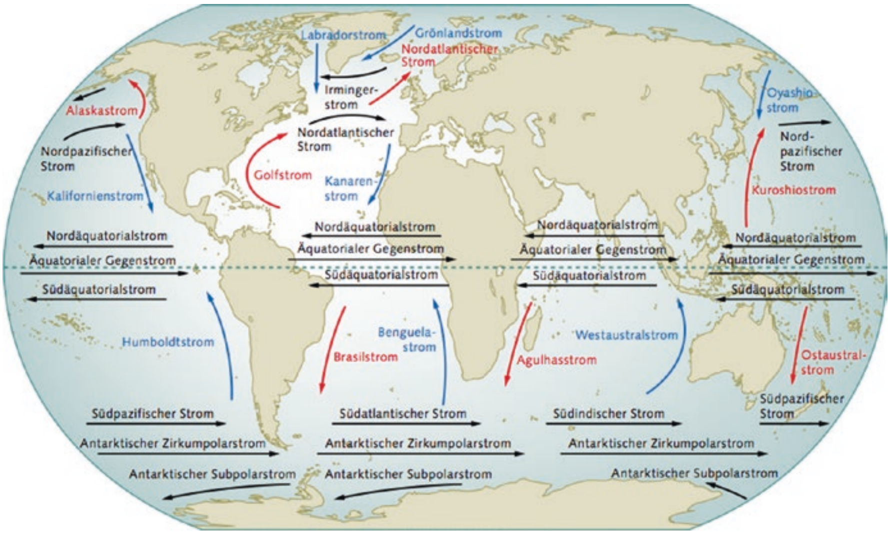


Fig. 1.16 Schematic of global surface currents (© Walther-Maria Scheid, Berlin, for maribus gGmbH, World Ocean Review)

Another important phenomenon associated with the wind forcing is *upwelling* (and of course also downwelling). As mentioned above *Ekman transports* pile up a bulk of water within the Subtropical gyre due to their convergent flow. Within this bulk, water is "pumped" into the ocean, which is referred to as *Ekman pumping*. As mentioned earlier in the description of water mass formation, this pumping of water into the ocean contributes to the *subduction* of water masses. On the other hand the wind field can also result in diverging Ekman flow, where water from below is then forced upwards (Ekman suction) for compensation. This *upwelling* of water from below, which is usually richer in nutrients than the nutrient-depleted surface water in combination with the availability of light close to the surface is usually associated with high biological activity. In a first step, plankton blooms can be observed, followed by a bloom of all different kind of species and finally a growth in the fish stock. The most productive *upwelling* regions are found in coastal areas, where the wind blows parallel to the coast and has to be oriented in the right way to induce an offshore *Ekman transport*. For example in front of Peru, which is in the Southern hemisphere and hence *Ekman transports* are directed at 90° to the left of the wind, the wind has to blow parallel to the coast towards the north. As replacement for the water pushed offshore, cold and nutrient-rich water from below is forced upwards. The four major eastern boundary upwelling systems are the Peru-Chile, California, Canary and Benguela upwelling systems, which together cover only 1% of the world ocean, but support large industrial fisheries, which are responsible for around 20% of the global fish catch (Fréon et al. 2009; Pauly and Christensen 1995). This comes along with a large sensitivity of the economy to changing oceanic conditions. For example, the Peruvian fishery is heavily challenged during *El Nino* events, when *upwelling* is inhibited and the fish stock strongly reduces.

1.7 Measurement Techniques for Direct Current Observations

In the paragraphs above some of the concepts and theories were presented about how the wind or thermohaline forcing mechanisms can move the ocean. But how can currents and their variability be monitored directly?

It was already mentioned that sound waves are important for some measurement techniques such as the Acoustic Doppler Current Profiler (ADCP). The name already points out that this instrument uses acoustics to measure the current field. In fact, it also already indicates the used principle: the Doppler Shift. The Doppler Shift describes that if a sound source and receiver move relative to each other during the emission of the sound waves, the frequency the receiver "hears" will be shifted to higher/lower frequency depending on the direction of the relative movement. An example from everyday life for the Doppler shift is the passing by of an ambulance with its alarm horn on. The sound of the alarm appears higher than normal when the ambulance is approaching, slides down as it passes and continues lower as it recedes from the observer. This principle is used in the ADCP to deduce the speed of currents. Sound pulses are sent from the instrument and then the instrument listens to the reflected signal. The objects reflecting the sound signal are small organisms, which passively drift with the currents like e.g. zooplankton. Then the frequency shift between the emitted and reflected signal is evaluated in order to deduce the speed of the currents. As ADCPs listen to various reflected signals in different time intervals, it is possible to obtain a vertical profile of velocity from their data.

ADCPs are used in different ways either mounted within the ships hull, where they measure the upper about 500–1200 m of the water column, lowered with the CTD to measure full depth ocean profiles of the flow field, permanently installed on so called moorings (Fig. 1.17) or mounted on top of gliders.

Moorings usually consist of different instruments of which often one is an ADCP (Fig. 1.17). The instruments are fixed to a strong wire and a huge anchor is attached, which pulls the lower end of the mooring to the seafloor. At irregular distances floating buoys are attached to the wire, which on the one hand straighten up the mooring, while it is in the water and on the other hand will bring it to the surface, when the anchor is detached for the recovery of instruments and data. Other instruments measuring the currents within a mooring are fixed current meters, which observe the currents at one particular depth and not in form of a vertical profile as an ADCP.

Other principles of measuring ocean surface currents are the use of so-called drifters, which basically are buoys drifting with the surface currents. The position of these floating devices can be tracked with satellite and gives a measure for the cur-

Fig. 1.17 *Left*: Sketch of a mooring by Mario Müller. An ADCP is mounted into the top buoy of the mooring, a temperature and salinity recorder, yellow floating buoys, a current meter with a large red fin and a pair of grey releasers are attached to the wire between the top buoy and the anchor at the seafloor. *Right*: Picture of an ADCP mounted within a top buoy after recovery. The four transducers send and receive the sound pulses (photo: Tim Fischer)

rents drift they were exposed to. Another method to obtain the surface currents is to use the observations of sea surface height from satellites and to derive the associated *geostrophic* surface velocities.

1.8 Small Scale Processes

The concepts above mainly describe large-scale motions, although naturally the terms large or small are relative. The phenomena described above are at least to some extent large enough to be observed with standard measurement techniques and the main features mentioned are also included in most state of the art numerical simulations of the oceans. However, there are features and phenomena on smaller scales, which are harder to observe with the instruments mentioned above and not resolved in numerical simulations. In the context of numerical simulations these processes are called sub-grid processes, which only describes that they are too small to be resolved with the grid used in a specific simulation. For example, not all of the available numerical simulations are able to resolve mesoscale eddies, which roughly correspond to scales of 10–500 km in space and 10–100 days in time. Eddies are rotating water bodies in the ocean analogue to high and low pressure systems in the atmosphere, which are formed by instability processes, e.g. the meandering of a flow like the Gulf Stream. Hence, in comparison to large circulation features as the Subtropical Gyre they can be considered "small", however they can provide important contributions to the transport of heat and/or freshwater as well as other water mass characteristics. Compared to the large-scale ocean features mesoscale eddies are not only "small", but also rather short-lived. Nevertheless, they provide an important contribution to oceanic mixing processes when they disintegrate. Therefore, although they might not be actually resolved in some of the numerical simulations, their effect of mixing ocean properties needs to be considered using so-called parametrizations. The same reasoning applies for all processes, which act on even smaller scales in space and time than the mesoscale features.

The smallest scales in the ocean are associated with turbulence. Turbulent motions can contribute to mix water mass properties across isopycnals against the stratification, which at depth has been pointed out to be an important part for the global scale overturning circulation (Munk 1966). Hence, large scales and small scales can be tightly related, which means that a correct representation of large-scale phenomena can depend on the correct representation of smaller scale effects.

The energy required to work against gravity/stratification is fed into the ocean at large scales as described above and then cascades down through meanders, eddies and waves, which finally break and transfer energy to small scale turbulent motions. Turbulence is likely to occur in regions of strong vertical shear of horizontal velocities. This means in regions, where the difference of velocities with depth is very large. An example for this are the upper layers of the equatorial Atlantic and Pacific ocean. Within these regions the strong subsurface Equatorial Undercurrent flows eastwards, whereas the surface current is directed westwards. Hence, the currents at the surface and in the subsurface are flowing in opposite directions, which can lead to instabilities and turbulence. These turbulent motions can be very effective in the redistribution of heat for example within the Atlantic Cold Tongue region, the eastern part of the equatorial Atlantic. The Atlantic Cold Tongue is a seasonally developing feature in the eastern equatorial Atlantic. Although the heating from the atmosphere is rather constant throughout the year, SSTs drop from around April to August by about 6 °C (Fig. 1.18). As numerical simulations generally predict sea surface temperatures, which are too warm within this region (Richter and Xie 2008), it is important to understand all the processes contributing to the seasonal cooling of SSTs and quantify their contribution.

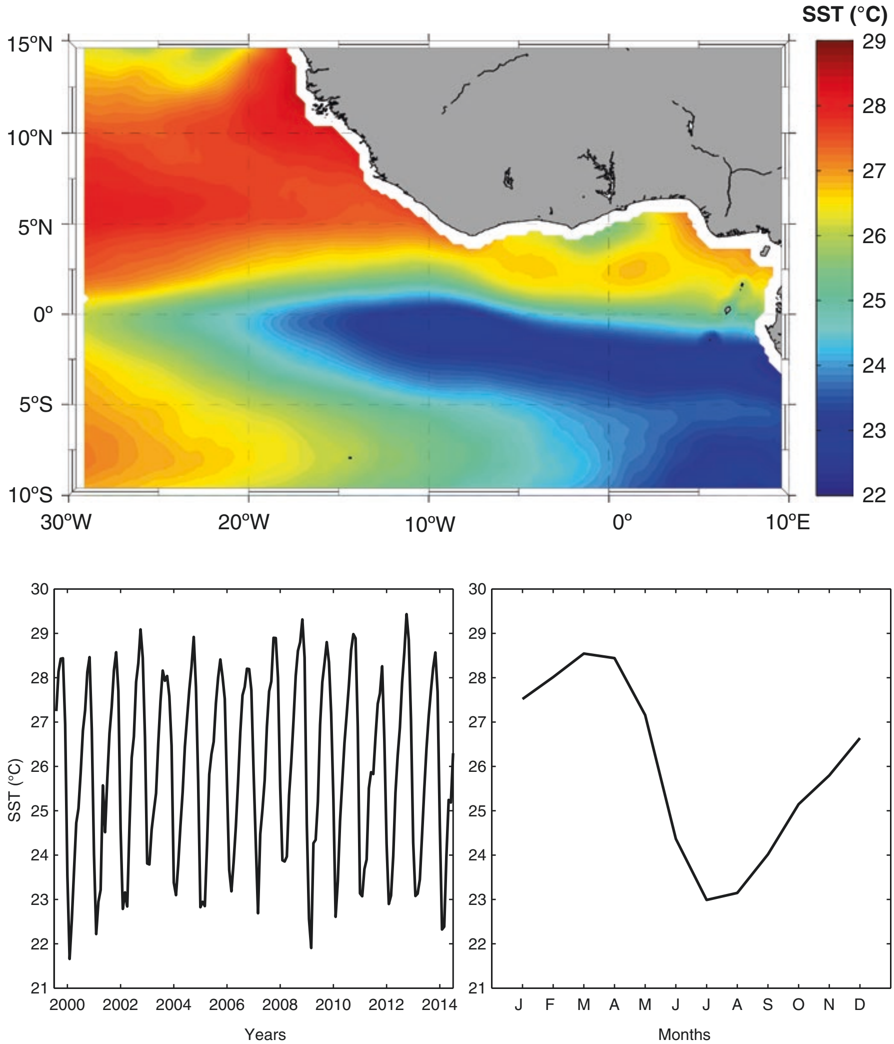


Fig. 1.18 *Top*: Average (2000–2014) SSTs in July in the eastern tropical Atlantic from daily optimally interpolated fields. *Bottom left*: Time series of monthly SSTs at 0°N, 10°W in the center of the Atlantic Cold Tongue; *bottom right*: Average seasonal cycle from the time series on the left. After Hummels et al. (2013). Sea surface temperature data available at www.remss.com/measurements/sea-surface-temperature

Estimates and comparison of all contributions to the heat budget of the mixed layer showed that the across-isopycnal turbulent heat flux, which can reach up to 60 W/m^2 at 0°N, 23°W and even 100 W/m^2 in the center of the Atlantic Cold Tongue at 0°N, 10°W, provides an important (the largest) contribution to the cooling and development of the Atlantic Cold Tongue within the Western Cold Tongue region at 23°W (10°W) (see Hummels et al. 2013, 2014). Hence, potentially a correct representation of the effects of these small scale turbulent motions in numerical simulations could at least contribute to improve the numerical simulations, which as mentioned above currently all show too warm SSTs within this region.

1.9 Waves and Tides

Picturing ocean waves most people have directly breakwaters on a beach in their minds. Most people are also familiar with the bi-daily cycle of ebb and flood. However, the ocean interior is full of a variety of ocean waves and tides, which have important effects for the ocean interior and not only within coastal regions.

Waves are oscillations accompanied with a transfer of energy that travels from one point of the ocean to another. These oscillations displace particles, but with only little or no mass transport. Instead waves displace particles only around fixed locations. The different wave types within the ocean can be classified according to their restoring forces. For sound waves, the restoring mechanism is the compressibility of seawater. Sound waves are able to travel long distances within the ocean. They are not important for the dynamics of the ocean, but are the premise for several observational techniques and navigational purposes, not only by humans, but also e.g. whales. A second class of waves in the oceans are gravity waves. The restoring force for these waves is the gravitational force and gravity waves are important for the adjustment towards a *geostrophic* balance. Whereas in the ocean interior gravity waves contribute to mixing via wave breaking, they are at the surface responsible for the swell and important for air-sea interactions. Another class of waves are the planetary waves or *Rossby waves*, where the restoring mechanism is the conservation of potential vorticity. *Rossby waves* are important for the signal propagation within the ocean, communicating a temporal change in the forcing to e.g. a *geostrophically* balanced flow, which leads to an adjustment of the balance and hence the flow. *Kelvin waves* also play an important role for the adjustment of the circulation towards changes in the forcing. *Kelvin waves* are a special kind of waves, which are trapped e.g. at the coast or the equator and can only propagate in the vicinity of this border or so-called waveguide. Equatorial waves are specific, because they are all trapped close to the equator, which means that they decay rapidly in north-south direction, but can propagate within the so-called equatorial waveguide in longitudinal and vertical directions. Equatorial waves play an important role by communicating signals across the ocean basins and are crucial for the development and evolution of climate phenomena such as e.g. *El Nino* in the Pacific.

All these different types of waves have different characteristics in terms of frequencies, wave lengths, amplitudes, phase speeds and group speeds. They are often described with a so-called dispersion relation, which relates their frequency to the wave number/length. If waves are dispersive the phase velocity and the group velocity are not the same, which means that a wave packet will spread out in space. *Kelvin waves* for example are non-dispersive, which means that the phase speed equals the group speed and that they retain their shape as they move in the alongshore direction. The analysis of these wave properties helps to understand which kind of waves contribute to a certain phenomenon and where they might originate from.

Tides are the regular rise and fall of the sea level. They are caused by the combination of the gravitational forces of the moon and sun and the rotation of the earth with the associated centrifugal force. Despite the global excitement of the tides due to the astronomic setting, there are huge local differences in the timing of ebb and flood as well as the tidal range, e.g. the tidal range in marginal seas can be rather large as in the North Sea or rather small as in the Baltic Sea. The reason for this is that due to its inertia the water cannot immediately follow the variation in the forcing of the tides, instead the forcing induces oscillatory motions of the water body. If the topographic setting of the basin is such that its natural resonance frequency is close to the frequency of the tidal forcing, the tidal range will be enlarged. Additional factors are how large the opening between the marginal sea and the open ocean is and how large the tidal range is at the opening. However, even if the actual process is complicated, the prognosis of the timing and height of the tides at numerous locations around the globe is rather precise, which is due to the deterministic nature of the tides. On the one hand the forcing of the tides is well understood from an astronomic point of view and on the other hand the deterministic behavior of the tides enables the statistical analysis and hence prediction of the tides from long-term records of tide gauges. For one of these statistical methods the so-called harmonic approach, the "net tide" at a certain location is broken down into its partial tides, where the individual partial tides have the period of the tide-inducing force, e.g. the bi-daily moon or sun tide M_2 or S_2. If an existing tide-gauge record has been analyzed and the phase and amplitude of the contributing partial tides is known, a simple combination of these partial tides will predict the tides at any requested time. In most places the semi-diurnal lunar tide (M_2) is the largest constituent. It has a period of 12 h and 25.2 min, which is exactly half a tidal lunar day and is the time required for the earth to rotate once relative to the moon. As the moon orbits in the same direction as the earth spins, the lunar day is longer than the earth day. This is the reason for the "temporal shift" of the tides from day to day.

As the tides affect the entire water column they cause a lot of friction and turbulence at the ocean floor. Together with the wind input the tides are the most important source of mechanical energy input into the ocean, which is necessary to maintain the oceanic general circulation.

Having touched on several different aspects of physical oceanography, some of these aspects will now be put together in an example of a well-known climate phenomenon:

1.10 An Example of Ocean-Atmosphere Interactions: El Nino

El Nino is the warm phase of an oscillating climate phenomenon, whereas the cold phase of this phenomenon is called La Nina. During *El Nino* winter SSTs in the eastern tropical Pacific are anomalously warm compared to the average state. This phenomenon occurs at irregular intervals (2–7 years) lasting for 9 months to 2 years and was named by Peruvian fisherman due to its development time during the year (around Christmas, *El Nino* meaning “the Boy”).

As the *El Nino* phenomenon is a process of ocean-atmosphere interaction it has an atmospheric part influencing the ocean mainly due to changes in surface winds and an oceanic part influencing the atmosphere due to changes in the SST (or more precisely the SST gradient).

In a “normal” state during Christmas time, the trade winds are blowing within the equatorial region and favor *upwelling* due to the tilted thermocline along the equator. Due to the tilted thermocline colder waters are closer to the surface in the eastern equatorial Pacific and coastal *upwelling* due to off-shore *Ekman transport* is invoked. In addition, the Humboldt current (Fig. 1.16) is strong, supplying cold and nutrient-rich water to the upwelling region.

Due to a trigger mechanism SSTs during the development of an *El Nino* are anomalously warm in the eastern tropical Atlantic, which weakens the SST gradient along the equator. The weaker SST gradient leads to a weakening of the trade winds. In fact, at a certain stage the surface winds even reverse blowing from west to east. Weaker winds lead to a relaxation of the east-west elevation in sea surface and hence a relaxation in the slope of the thermocline. In combination with the weaker winds itself this leads to less favorable conditions for *upwelling* and also to a weakening of the Humboldt current, which in turn leads to even warmer SSTs. A positive feedback sets in and a strong *El Nino* can develop, where SSTs in the eastern equatorial Pacific can be up to 5 °C higher than normal in December (Fig. 1.19).

The changes in the wind forcing excites *Kelvin waves* in the western equatorial Pacific, in this case carrying an *upwelling* signal, which travels along the equator in about 3–4 months and then triggers the end of the *El Nino* and reestablishes the *upwelling* favorable conditions. *Kelvin wave* signals can be reflected at the eastern boundary as *Rossby waves* and travel back to the west. *Rossby waves* are however considerably slower then *Kelvin waves*, which at least partly explains the larger time lag between the different states. However, *Kelvin and Rossby waves* are believed to play an important role for the signal propagation in the *El Nino*/La Nina cycle.

El Nino does not have an external trigger mechanism, but is a natural climate phenomenon, which gets exited through internal ocean atmosphere feedbacks. However, this climate phenomenon has large-scale consequences. For Peru, the warm SSTs leads to a die-off of plankton, which leads to a breakdown of the food chain with associated dramatic effects for the fish industry. In addition, the *El Nino*/La Nina

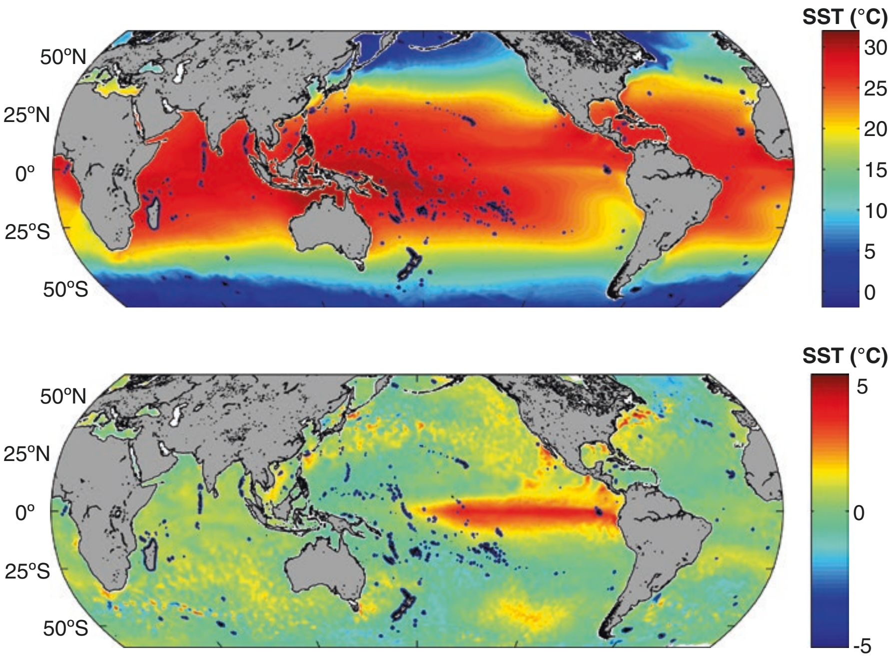


Fig. 1.19 *Top*: Average (2000–2015) global December SST. *Bottom*: SST anomaly for December 2015, when a strong El Nino is developing. Sea surface temperature data available at www.remss.com/measurements/sea-surface-temperature

cycle impacts the rainfall variability globally and was related to severe floodings and draughts all over the globe. Although the cycle of *El Nino*/La Nina is considered a natural climate phenomenon it is an ongoing research topic whether and how external forcing mechanisms such as global warming might affect the nature and frequency of this climate phenomenon (Cai et al. 2015).

1.11 Conclusions

During the last decades our knowledge about the ocean circulation and the interactions between the ocean and atmosphere impacting climate variability has greatly improved. Furthermore, the measurement techniques as well as numerical simulations of the oceans and the climate system as a whole are constantly developing. However, there are still aspects of the ocean and climate system which are not well understood and therefore hamper reliable predictions of future climate changes especially in light of the global warming issue (Hillebrand and Thor, Chap. 18, 19).

The large heat uptake and the delayed release as well as the inertia of the oceans towards variability within the atmosphere makes the oceans an important factor when evaluating aspects of the global warming issue. Furthermore, the oceans do not only take up large amounts of heat, but also large amounts of climate-relevant trace gases of anthropogenic origin such as e.g. methane, nitrous oxide and carbon dioxide (CO_2). The release or uptake of these climate-relevant trace gases by the ocean leads to changes in the earths radiation balance and thereby to global climate changes. For example the massive release of CO_2 to the atmosphere due to burning of fossil fuels plays a crucial role in the global warming issue. As CO_2 is well dissolved in seawater half of the anthropogenic CO_2, which has been released since the beginning of the industrialization, was taken up by the oceans. The ability of the ocean to store CO_2 and hence to reduce the CO_2 content in the atmosphere is a current issue of climate engineering, where man-made actions are sought in order to counteract the anthropogenic induced climate change. However, the human engagement in the climate system without fully understanding all participating processes and feedbacks raises a broad range of technical and ethical questions. An additional problem with the massive CO_2 uptake by the oceans is the question where and when some of this excessive CO_2 will be released back to the atmosphere and then further affects global warming. Finding an answer to these questions critically depends on a complete understanding of the circulation of the oceans considering all the different scales and interacting processes, which still requires a lot of oceanographic research.

Acknowledgement I would like to thank Prof. em. Dr. Jens Meincke for his advice, ideas and comments on the text, which helped to write this chapter. I also want to thank Dr. Florian Schütte for his comments, ideas, proofreading and help with finding good illustrations.

Glossary

Upwelling Describes the wind-driven upward motion of cool and usually nutrient-rich water towards the surface, where it replaces warmer and usually nutrient-depleted surface water

Convection Is a density driven water mass formation process. At high latitudes ice formation within the ocean as well as strong heat loss from the ocean to the atmosphere can increase the density of surface waters until they start to sink (convect) and get disconnected from the surface forming a new water mass

Subduction Is a wind driven water mass formation process. If the wind field e.g. produces a convergent flow in the surface layer, waters tend to pile up and get "pumped" towards the ocean interior. Hence, when this surface waters are pumped into the interior and disconnected from the surface oceanographers refer to these waters as subducted waters

El Nino Is a climate phenomenon of ocean-atmosphere interactions. The term "El Nino" refers to the warm phase of this phenomenon, when sea surface temperatures in the tropical eastern Pacific are unusually warm compared to the average state. This does not only have local impacts on climate and the economy, but is related to climate variability all over the globe

The Coriolis Force (Coriolis Effect) Is a fictitious force, which acts on objects, which are in motion relative to an already rotating reference frame, e.g. air or water moving on the rotating earth or a ball rolling on a rotating plate. The effect (Coriolis effect) of this force on air or water parcels moving on the earth is that they get deflected at a right angle to the right (left) in the Northern (Southern) Hemisphere

Geostrophy Describes a balance of forces from the simplified equations of motion, in this case the balance of the pressure gradient force and the Coriolis force. The invoked geostrophic flow is directed along isobars and has the high pressure to its right (left) in the Northern (Southern) Hemisphere

Potential temperature/density Is the temperature/density corrected for the pressure effect. A water parcel with a certain temperature/density will have a higher temperature/density if it is exposed to a higher pressure. The pressure within the ocean increases with increasing depth due to the overlying water body. Hence, when temperatures/densities of different depth layers are compared to each other, one wants to get rid of this pressure effect and defines the potential temperature (θ) and the potential density (σ_θ) as the temperature/density a water parcel would have, if it would be adiabatically brought to a standard reference pressure e.g. at the surface. Adiabatically means without a transfer of heat or matter with the surroundings

Kelvin waves Are a special kind of waves, which cannot freely propagate at the oceans surface, but instead can only propagate within a so-called wave guide, which means along topographic boundaries or the equator. Kelvin waves are *geostrophically* balanced waves and can be excited by any kind of pressure gradients, which then get balanced by the *Coriolis force*, e.g. in the Northern Hemisphere they are aligned with the coast to the right in the alongshore propagation direction. Kelvin waves play an important role for the adjustment of the circulation towards changes in the forcing. Note that also the tides propagate in form of coastal Kelvin waves

Rossby Waves/planetary waves Are waves, where the restoring mechanism is the conservation of potential vorticity. Without going into too much detail about the concept of potential vorticity, the principle is that motions with changing latitude create a gradient in the potential vorticity as the *Coriolis* parameter is dependent on latitude. This then leads to a restoring mechanism towards the original potential vorticity and hence, a disturbance with latitude can start to oscillate and travel in form of a planetary wave. These planetary waves are important for the signal propagation within the ocean, communicating a temporal change in the forcing to e.g. a *geostrophically* balanced flow, leading to an adjustment of the balance

The Ekman balance (Ekman transport/pumping) Describes a balance of forces in this case between frictional forces (at the surface or bottom of the ocean) and the *Coriolis force*. If the balance is vertically integrated over the extent of the surface Ekman layer, the net Ekman transport within this layer is directed at an 90° angle to the right/left of the wind in the Northern/Southern hemisphere. This Ekman transports can lead to divergent/convergent flows in the surface layer, which then can cause water to be lifted up (Ekman suction) or pushed into the ocean interior (Ekman pumping)

References

Bower A, Lozier S, Gary S (2011) Export of Labrador Sea Water from the subpolar North Atlantic: a Lagrangian perspective. Deep Sea Res Part II Top Stud Oceanogr 58:1798–1818

de Boyer Montegut C, Madec G, Fischer AS, Lazar A, Iudicone D (2004) Mixed layer depth over the global ocean: an examination of profile data and a profile-based climatology. J Geophys Res Oceans 109:C12

Cai W, Santoso A, Wang G, Yeh S-W, An S-I, Cobb K-M, Collins M, Guilyardi E, Jin F-F, Kug J-S, Lengaigne M, McPhaden MJ, Takahashi K, Timmermann A, Vecchi G, Watanabe M, Wue L (2015) ENSO and greenhouse warming. Nat Clim Chang 5:849–859

Ekman VW (1905) On the influence of the earth's rotation on ocean currents. Ark Mat Astr Fys 2:1–52

Fréon P, Barange M, Arístegui J (2009) Eastern boundary upwelling ecosystems: integrative and comparative approaches. Prog Oceanogr 83:1–14

Getzlaff K, Boning CW, Dengg J (2006) Lagrangian perspectives of deep water export from the subpolar North Atlantic. Geophys Res Lett 33:L21S08. doi:10.1029/2006GL026470

Hummels R, Dengler M, Bourles B (2013) Seasonal and regional variability of upper ocean diapycnal heat flux in the Atlantic cold tongue. Prog Oceanogr 111:52–74

Hummels R, Dengler M, Brandt P, Schlundt M (2014) Diapycnal heat flux and mixed layer heat budget within the Atlantic Cold Tongue. Clim Dyn 43:3179–3199

Kieke D, Yashayaev I (2015) Studies of Labrador Sea Water formation and variability in the subpolar North Atlantic in the light of international partnership and collaboration. Prog Oceanogr 132:220–232

Kuhlbrodt T, Griesel A, Montoya M, Levermann A, Hofmann M, Rahmstorf S (2007) On the driving processes of the Atlantic meridional overturning circulation. Rev Geophys 45, RG2001, doi :10.1029/2004RG000166

Marshall J, Schott F (1999) Open-ocean convection: observations, theory, and models. Rev Geophys 37:1–64

Munk W (1950) On the wind-driven ocean circulation. J Atmos Sci 7:80–93

Munk WH (1966) Abyssal recipes. Deep Sea Res Oceanogr Abstr 13:707–730

Pauly D, Christensen V (1995) Primary production required to sustain global fisheries. Nature 374:255–257

Rhein M, Kieke D, Steinfeldt R (2015) Advection of North Atlantic Deep Water from the Labrador Sea to the southern hemisphere. J Geophys Res Oceans 120:2471–2487

Richter I, Xie S-P (2008) On the origin of equatorial Atlantic biases in coupled general circulation models. Clim Dyn 31:587–598

Rintoul SR, Hughes C, Olbers D (2001) The Antarctic Circumpolar Current. In: Siedler GaJCaJG (ed) Ocean circulation and climate. Academic Press, New York

Schmidtko S, Johnson GC, Lyman JM (2013) MIMOC: a global monthly isopycnal upper-ocean climatology with mixed layers. J Geophys Res Oceans 118:1658–1672

Smith WHF, Sandwell DT (1997) Global sea floor topography from satellite altimetry and ship depth soundings. Science 277:1956–1962

Stommel H (1948) The westward intensification of wind-driven ocean currents. Trans Am Geophys Union 29:202–206

Sverdrup HU (1947) Wind-driven currents in a Baroclinic Ocean; with application to the equatorial current of the Eastern Pacific. Proc Natl Acad Sci 33:318–326

Toggweiler JR, Samuels B (1998) On the Ocean's large-scale circulation near the limit of no vertical mixing. J Phys Oceanogr 28:1832–1852

Chapter 2
Ecological Organization of the Sea

Birte Matthiessen, Franziska Julie Werner, and Matthias Paulsen

Abstract Two thirds of the Earth's surface area are covered by the oceans and shelf seas and at first sight this vast marine living space appears ecologically homogenous compared to land. A closer look, however, reveals that the global ocean accommodates very different structurally and functionally complex communities that are formed by a great diversity of plant and animal species. All communities or ecosystems (the term is interchangeably used in the following chapter) are interconnected and depend upon each other. All of them have been providing a wealth of ecosystem goods and services that humans have been depending on and economically benefiting from. The following chapter aims at giving a general overview of the ecological organization of the global ocean, which is needed to understand and evaluate past and current impacts of human activities on marine communities. On the most general level, this chapter divides the marine living space and its inhabitants into the pelagic and the benthic zone. It introduces functionally important and widely distributed communities in both zones and highlights the dynamic biological, physical, and chemical processes or mechanisms that play an important role in the maintenance and functioning of these communities.

Keywords Oceanic zone • Neritic zone • Pelagic zone • Benthic zone • Marine communities • Biomass production • Phytoplankton • Zooplankton • Nekton • Mixed layer depth • Size-structured food-web • Biological carbon pump • Migration • Light • Euphotic • Aphotic • Foundation species • Tide pool • Seaweed • Seagrass • Estuary • Mudflat • Salt marsh • Mangrove • Coral reef • Deep sea vent and seep • Competition • Consumption • Facilitation

B. Matthiessen (✉) • F.J. Werner • M. Paulsen
GEOMAR Helmholtz Zentrum für Ozeanforschung Kiel, Kiel, Germany
e-mail: bmatthiessen@geomar.de; fwerner@geomar.de; mpaulsen@geomar.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_2

2.1 Pelagic Zone

The pelagic zone is the largest habitat on earth and encompasses 99.5% of earth's inhabitable space (Herring 2002). It comprises the entire water column, extending from the sea surface to the deep sea just above the sea floor, from the tropics to the polar regions. It is a three dimensional habitat in which the inhabiting organisms, depending on their physiological tolerances and their ecological niches, can freely move. Although seemingly uniform, heterogeneous physical structure in the pelagic zone exists at different spatial and temporal scales and leads to patchy distribution of pelagic organisms. This heterogeneity is driven by ocean currents and interactions with the atmosphere through heating, cooling, seasonality, transport of water masses, water chemistry and nutrients, which differ according to depth and latitude and spatial scale (Hummels, Chap. 1). As a consequence a mosaic of significantly different productive pelagic habitats occur with the most productive areas at sites where replete nutrient concentrations from deeper water meet sufficient light penetration within upwelling (see Hummels, Chap. 1) and continental shelf regions. Major upwelling regions are typically located at the west coasts of continents (e.g., west coasts of North America (California Current), Latin America (Humboldt Current), North Africa (Canary Current) and South Africa (Benguela Current)) and off-shore sea mounts. Depending on distance from shore and water depth the pelagic environment can be subdivided into the neritic and the oceanic zone.

The neritic zone contributes 8% to total sea area and extends over the continental shelfs which today hardly exceed a water depth of 200 m (Fig. 2.5). Hence some marginal seas, such as the North Sea or the Baltic Sea, belong in their entirety to the neritic zone. Other neritic zones directly adjoin the continents and separate them from the open oceanic zone. Generally, the neritic zone is characterized by high productivity. This is caused by riverine input of mineral nutrients and sediments and by upwelling of nutrient-rich deep water on the continental slope. Combined with less stratification these conditions act favorable for photoautotrophic primary production of phytoplankton (see Sect. 2.2.1.1).

The oceanic zone encompasses the water masses off the continental shelfs that cover the great oceanic basins and makes up the vast majority (i.e., 92%) of total sea area. Conventionally, the oceanic realm is subdivided into the epipelagic (0–200 m), the mesopelagic (200–1000 m), the bathypelagic (1000–4000 m), and the abyssopelagic (>4000 m) (Fig. 2.5). A much more biologically relevant classification is the subdivision according to the light profile and thermal stratification. The first distinguishes between the euphotic zone, with sufficient light intensity for photosynthesis, and the aphotic zone (Fig. 2.5). The second is important in terms of the depth to which surface water-column mixing occurs (i.e., the mixed layer depth (MLD)) when warm surface water stratifies over the cold deep water body (see Hummels, Chap. 1). The MLD is essential for pelagic primary production because it regulates the nutrient flux and the sinking depth of phytoplankton (see Sect. 2.2.1.1). In warmer strongly stratified areas and seasons, such as in the tropics or temperate summers, the MLD is generally shallower leading to reduced nutrient flux from deeper waters compared to colder and less stratified areas, such as coastal and temperate regions, with seasonal mixing or upwelling (Longhurst 1998; de Boyer Montégut et al. 2004).

The euphotic zone of the epipelagic (Fig. 2.5) is the only pelagic area where sufficient light penetration allows for photosynthetic primary production of phytoplankton (Sect. 2.2.1.1). The phytoplankton provides approximately 50% of global primary productivity (Field et al. 1998) that supports diverse production at higher trophic levels in all the pelagic zones, i.e., from grazers of phytoplankton, such as zooplankton, over planktivorous fish, up to large predatory fish and whales (see Sects. 2.2.1.2 and 2.2.2). Moreover, the epipelagic lies at the ocean-atmosphere interface where physical processes such as thermal energy and gas (e.g., O_2, CO_2) exchanges between atmosphere and ocean take place. These processes are biologically relevant and important for the global climate as they drive the oceanic uptake of CO_2 (see Hummels, Chap. 1, Hillebrand et al., Chap. 18; Thor and Dupont, Chap. 19). Specifically, the epipelagic phytoplankton function as the onset of the so-called biological carbon pump (Volk and Hoffert 1985; Sanders et al. 2014) by photosynthetically fixing atmospheric CO_2 that has dissolved in the surface water. Owing to its close interactions with the atmosphere, increasing atmospheric CO_2 concentrations and subsequent global warming make the highly productive epipelagic zone one of the most strongly anthropogenically affected oceanic areas.

The meso-, bathy- and abyssopelagic zones strikingly differ from the epipelagic because light penetration decreases with depth (Fig. 2.5), which makes photoautotrophic primary production impossible. Thus, all inhabitants of deeper zones, with the exception of chemo-autotrophic organisms (see Sect. 2.4.6), depend on the primary production conducted at the surface. The photosynthetically generated organic matter (i.e., phytoplankton) either sinks passively (marine snow) or is transported actively downwards by vertically migrating zooplankton and fish (see Diurnal Vertical Migration (DVM) in Sect. 2.2.1.2) that excrete, or are consumed, at deeper waters than at which they feed (Kaiser et al. 2011). Along this ever deeper food web, the amount of biomass, and hence food availability, declines (Yamaguchi et al. 2002). Energy efficiency is thus a major selective force in the deep pelagic zones which has led to stealthy and sedentary animal life-styles and to smart ambush prey mechanisms in the dark (Kaiser et al. 2011). A minor portion of the photosynthetically fixed carbon from the surface in fact reaches the bottom of the deep sea where it either can support benthic life on the seafloor (see Sect. 2.4.6) or is sequestered in sediments (Broecker and Peng 1982; Ducklow et al. 2001). The latter is the endpoint of the biological carbon-pump (Volk and Hoffert 1985).

Apart from food limitation the deep oceanic zone is characterized by high pressure, low temperatures and darkness. In fact, for every 10 m increase in depth pressure increases by 1 atmosphere, which equals the mass of a bag of sugar on one's fingertip (Kaiser et al. 2011). One consequence of pressure is that gases get compressed. Thus, deep sea animals have adapted such they have lost interstitial tissues or excess cavities, such as the swim bladders of fishes. Generally they are rather small, gelatinous and minimal in their skeletal structure. Temperatures below 2000 m are constantly between 1 and 4 °C leading to a generally slow life in terms of metabolism and growth. Reduced illumination has led to special adaptations of animals to generate light, such as incorporating light-emitting bacteria in special cells (bioluminescence) in order to avoiding predation in the mesopelagic twilight zone, or detecting mating partners and finding food in the completely dark bathy- or abyssopelagial (Kaiser et al. 2011).

2.2 Pelagic Communities

Pelagic communities and food-webs are size-structured with larger organisms generally preying upon and ingesting the whole bodies of smaller sized ones (Hildrew et al. 2007; Fisher and Frank 2014). Based on their locomotory capability pelagic organisms can be categorized in two major groups, the plankton and the nekton. Whereas planktonic organisms are unable to counteract horizontal currents and thus passively drift in the horizontal layer, nektonic organisms are active swimmers and able to countervail ocean currents. Overall planktonic organisms are smaller (0.2 μm to approximately 2 cm) than those of the nekton (approximately 2 cm to 30 m) (see Fig. 2.1). Though seawater is the thinnest of all fluids it is more viscous compared

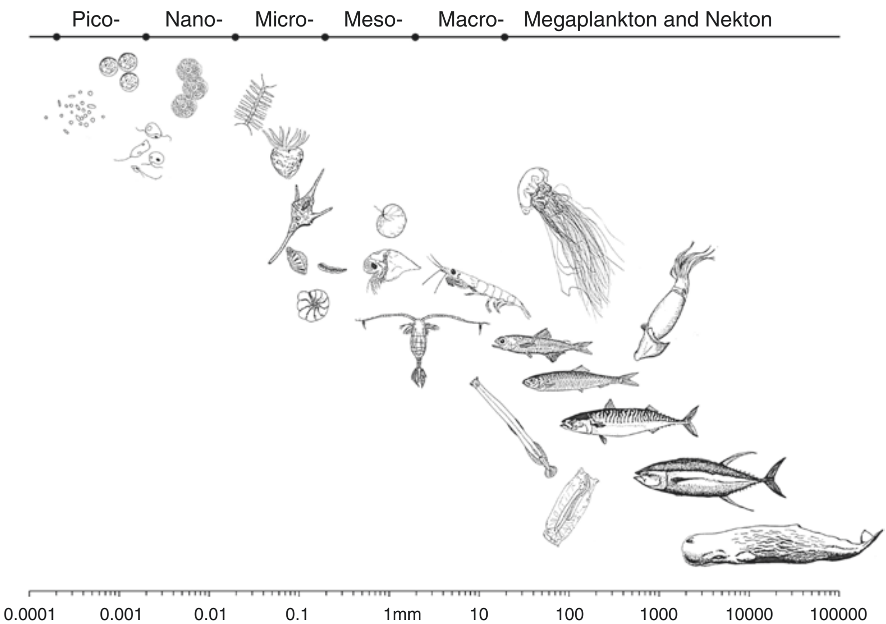


Fig. 2.1 Examples of pelagic organisms that, depending on their size and locomotory capabilities, belong either to the plankton or the nekton. Plankton alone covers five orders of magnitude in size and is generally categorized into pico- (0.2–2 μm), nano- (2–20 μm), micro- (20–200 μm), meso- (200–2000 μm), macro- (2 mm–2 cm) and megaplankton (>2 cm) (see Sect. 2.2.1). From the upper left to the lower right corner the following organism groups are pictured in an exemplary way: Bacterioplankton, picophytoplankton (*Synechococcus* sp.), heterotrophic nanoflagellates (HNFs), nanophytoplankton (*Emiliania huxleyi*, coccolithophore), microphytoplankton (*Chaetoceros* sp., diatom), microzooplankton (*Strombidium* sp., ciliate), microplankton (*Ceratium furca*, dinoflagellate), microzooplankton (foraminifera, rhizopod), mesoplankton (*Noctiluca fluorescence*, dinoflagellate), mesozooplankton (*Evadne* sp., cladoceran and *Calanus* sp., copepod), macrozooplankton (*Euphausia superba*, krill and cheaetognath, arrow worm), megazooplankton (jellyfish and salp), mesopredatory (planktivorous) fish (lantern fish (myctophidae) and herring (clupeidae)), predatory fish and squid (makerel, tuna and humbold squid), sperm whale. Illustration © 2016 Jonas Mölle and Birte Matthiessen, all rights reserved

to air. This has profound consequences for the seawater inhabiting organisms. In particular for very small ones such as plankton it is a sticky medium with a high viscosity that significantly slows down all movements (Purcell 1977).

2.2.1 Plankton

The plankton comprise organisms from all biological kingdoms that are functionally categorized into phytoplankton (eukaryotic plants and prokaryotic cyanobacteria), zooplankton (animals), bacterioplankton (bacteria) and mykoplankton (fungi). The following gives a general overview of the major phyto- and zooplankton groups and focuses on the patterns and processes that influence their distribution and abundance. The plankton groups' respective functional roles in the food web, the global ocean and for mankind are highlighted.

2.2.1.1 Phytoplankton

Phytoplankton are a highly diverse group of microscopically small (0.2–1000 μm diameter) photosynthetic protists (eukariots) and cyanobacteria (prokariots). They are the major primary producers in the ocean, globally distributed in the euphotic zone of the epipelagic, and contribute approximately 50% to global photosynthetic carbon fixation (Field et al. 1998). By taking up CO_2 they reduce the concentration of this major greenhouse gas in the atmosphere and hence affect the global climate. However, only ~1% of the photosynthetically fixed CO_2 is estimated to be permanently sequestered in the ocean by sinking cells and food web processes to the deep sea (Ducklow et al. 2001). Phytoplankton represent the basis of the pelagic food webs and hence play an important role for fisheries productivity (Ryther 1969; Ware and Thomson 2005; Chassot et al. 2010). They are the major food source for herbivorous zooplankton and hence are indirectly the nutritional basis of zooplanktivorous fish and fish larvae. Because phytoplankton consume inorganic macronutrients such as phosphate, nitrate and silicate, they play a significant role for the nitrogen, phosphorous and silicon biogeochemical cycles (Redfield 1958; Falkowski et al. 1998; Sarmiento and Gruber 2006).

Generally phytoplankton occurs in vast numbers with up to ~10^5 cells/mL during bloom events. Their actual density, however, significantly differs among regions and seasons and is driven by physical and biological processes. Their growth depends on the availability of light and nutrients, and thus physically on surface water stratification and the MLD (see Sect. 2.1 and Hummels, Chap. 1). The surface water MLD regulates the depths to which phytoplankton sink or are carried down. If the mixed layer is deep it is possible that phytoplankton sink or are transported below the euphotic zone, preventing growth even when nutrients are replete. If the mixed layer is shallow, phytoplankton stay in the euphotic zone. Hence, the onset of phytoplankton growth and the development of the massive spring blooms in temperate seasonally mixed regions depend on the onset of upper water thermal stratification and declining MLD. The effective isolation of the surface mixed layer from nutrient rich deeper water in turn means that consumed nutrients are not replenished from deeper waters. Thus, bloom termination and the generally low phytoplankton growth during summer or in permanently stratified regions at (sub)tropical latitudes is caused by nutrient limitation. Biologically, grazing, i.e., consumption, by micro- and mesozooplankton largely affects the actual phytoplankton density.

The important ecosystem functions provided by phytoplankton are not only driven by total phytoplankton biomass production, but also by their composition of cell sizes and different functional groups that hold key functional traits (Edwards and Litchmann 2014). Though phytoplankton are tiny organisms their cell and colony sizes range over several orders of magnitude (~0.2–1000 μm, Fig. 2.1), comparable to the size differences between mice and elephants (Boyce et al. 2015). These large differences in cell sizes have profound consequences for their competitive ability regarding nutrients and light, their floatation and sinking behavior, and their nutritional role for subsequent consumers.

Generally the small pico- and nanoplankton (0.2–20 μm, Fig. 2.1) are predominantly occurring in nutrient poor areas and seasons such as in the permanently stratified and little mixed tropical and subtropical oceanic regions or in summer post-bloom situations in higher latitudes and coastal areas. Due to their small cell size pico- and nanoplankton have a higher surface-area-to-volume ratio compared to larger phytoplankton, which make them the superior competitors for nutrients (Raven 1998) and is an important characteristic to survive and reproduce in nutrient poor conditions. Also the low sinking rates of picoplankton is advantageous in highly stratified areas as it prevents them from sinking out of the MLD (Edwards and Litchmann 2014).

Among the oceanic picophytoplankton are the omnipresent cyanobacteria *Prochlorococcus* and *Synechococcus* (0.5–1.6 μm) (Fig. 2.1) which can make up 80% of oceanic primary production, particularly in the low nutrient regions (Partensky et al. 1999). Other globally important oceanic phytoplankton are the nitrogen-fixing cyanobacteria (e.g., *Trichodesmium*, *Crocosphaera*, Fig. 2.2) that are able to use atmospheric nitrogen. This makes them particularly superior in nitrogen depleted regions. Although the exact amount is under debate, nitrogen-fixers significantly contribute to the total oceanic nitrogen pool (Gruber and Sarmiento 1997) which in turn facilitates other phytoplankton growth in nutrient poor regions.

The calcifying coccolithophores in their majority belong to the nanophytoplankton and are also low-nutrients and high-light adapted (Litchman 2007). They are known for the widely distributed species *Emiliania huxleyi* (Figs. 2.1 and 2.3). The coccolithophore characteristic is their calcium carbonate scales. They provide a large part of recent oceanic carbonate production (Broecker and Clark 2009). *E. huxleyi* can form massive blooms visible from space that are well distinguishable from other blooms due to the emerald appearance (Fig. 2.3). Although it remains unknown why they calcify, it makes them sensitive to ongoing ocean acidification

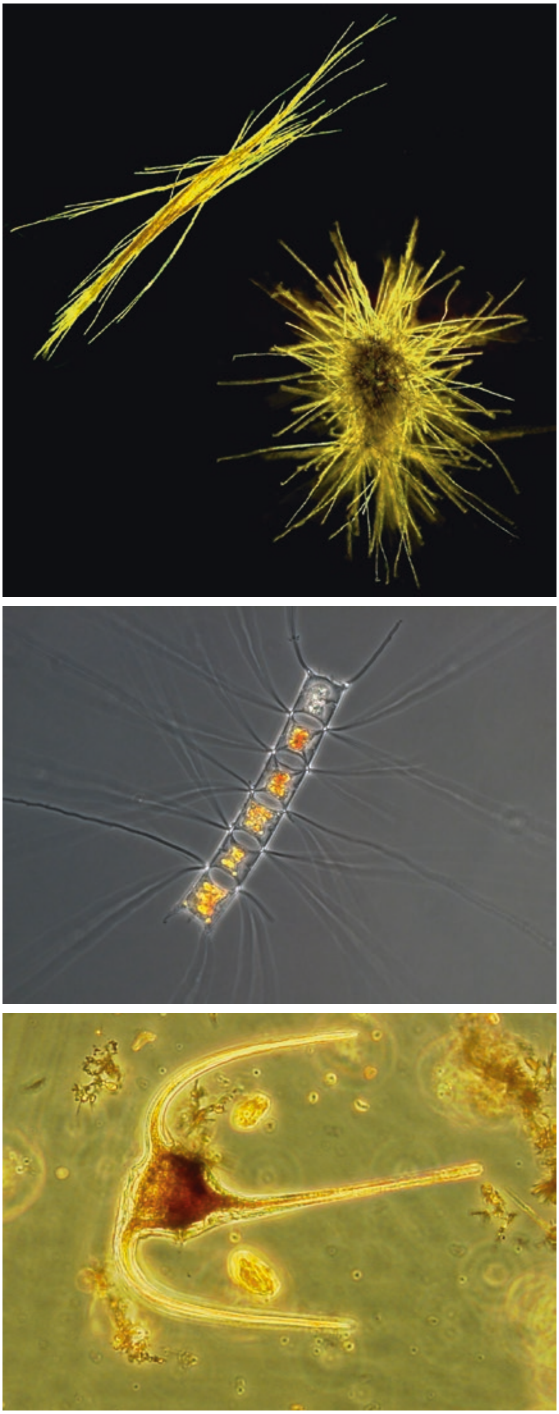


Fig.2.2 A puff colony of *Trichodesmium thiebautii* (*top*), photo used with kind permission of © Abby Heithoff, Woods Hole Oceanographic Institution, all rights reserved; the chain-forming diatom *Chaetoceros affinis* (*middle*), photo used with kind permission of © 2015 Giannina Hattich, all rights reserved; the dinoflagellate *Ceratium longipes* (*bottom*), photo used with kind permission of © 2016 Nicole Aberle-Malzahn, all rights reserved

(Thor and Dupont, Chap. 19; Beaufort et al. 2011). Chalk deposits around the world such as the White Cliffs of Dover, England (Fig. 2.3), or the Kaiserstuhl in the Baltic Sea, Germany, constitute the massive remainings of coccolithophore scales from the Jurassic.

Diatoms in contrast to the very small pico- and nanophytoplankton groups mainly belong to the microphytoplankton (>20 μm diameter, Figs. 2.1 and 2.2) and predominantly occur in periodically nutrient replete areas (e.g., coastal upwelling regions) and seasons (i.e., during spring blooms). Diatoms are extremely successful in all seas and provide about 40% of global marine primary production (Nelson et al. 1995). Their high growth rates enable them to respond rapidly to nutrient pulses by massive blooms (Litchman 2007; Edwards et al. 2012). Their characteristic feature is the silica frustule which together with their large cell-size leads to high sinking rates. Their absolute contribution is debated, but it is assumed that a relatively high proportion of the fixed carbon is exported to deeper zones and permanently sequestered at the sea floor (Smetacek 1999).

Dinoflagellates (Figs. 2.1 and 2.2) also belong in their majority to the microplankton (>20 μm). Their inferior competitive ability for nutrients is frequently compensated by mixotrophy and motility (Litchman 2007). Mixotrophy enables them to generate energy both through autotrophic photosynthesis or heterotrophic ingestion of bacteria or other phytoplankton (Stoecker 1999). Vertical motility is possible through the flagella giving them access to essential resources by migrating between nutrient rich deeper and light sufficient shallower waters (Litchman 2007). Some dinoflagellates produce toxins and are responsible for harmful algal blooms (HABs) in coastal waters. Dinoflagellate HABs show a trend to occur more often with increasing anthropogenic eutrophication of coastal waters (Beusekom, Chap. 22; Anderson et al. 2008).

An important consequence of phytoplankton cell size is that it largely affects the food web structure and efficiency. Larger cells (microphytoplankton, 20–200 μm diameter, Fig. 2.1) such as diatoms are naturally directly consumed by larger zooplankton. This leads to fewer and thus more efficient trophic transfers between phytoplankton and higher predatory trophic levels such as large pelagic fish. In contrast smaller pico- and nanophytoplankton (0.2–20 μm, Fig. 2.1) are primarily grazed by small microzooplankton which in turn are consumed by larger zooplankton, ultimately resulting in longer and more complex trophic connections in the food web (Stibor et al. 2004) and lower trophic transfer efficiency from the food-web basis to the fish (Sommer et al. 2002). Scientific research on climate change effects on plankton communities and food webs pointed out that sea surface warming increases vertical stratification (i.e., increases water column stability and declines MLD), which reduces nutrient fluxes and ocean productivity (Behrenfeld et al. 2006; Polovina et al. 2008; Hofmann et al. 2011) and likely favors picoplankton over larger cells (Polovina and Woodworth 2012). This change in phytoplankton productivity and size may ultimately have profound consequences for the oceans' food web structure and efficiency from the very basis to the upper trophic levels (Boyce and Worm 2015).

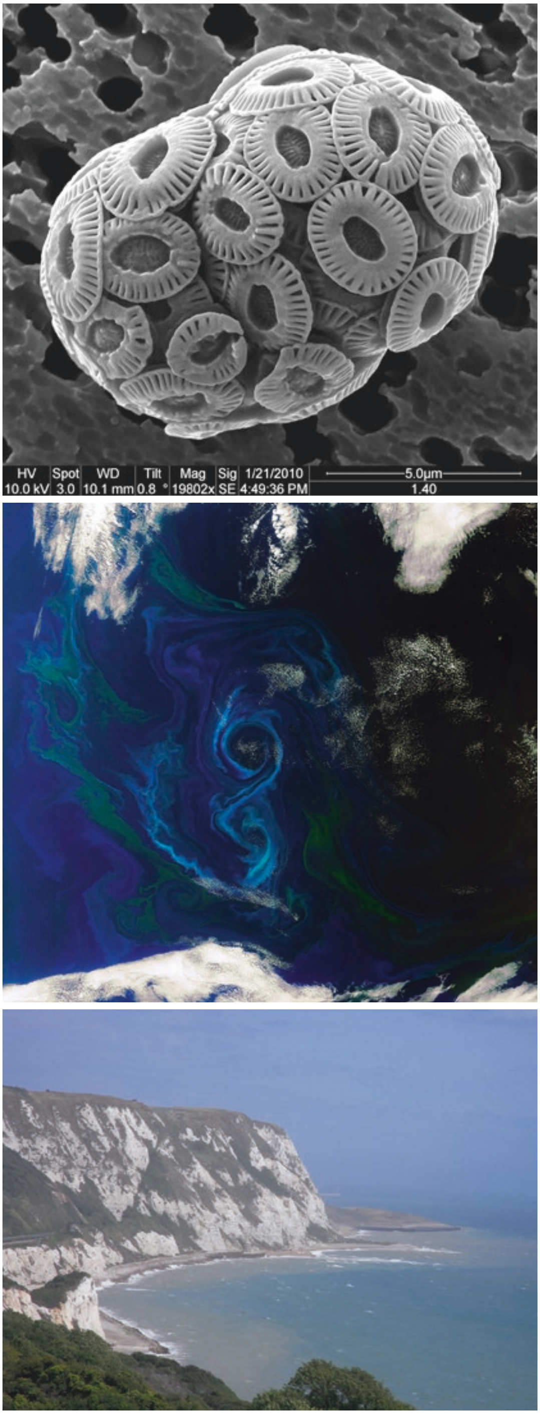


Fig. 2.3 The coccolithophore *Emiliania huxleyi* during cell division (*top*), photo © 2010 Birte Matthiessen, all rights reserved; a phytoplankton bloom South Atlantic Ocean about 600 km east of the Falkland Islands (*middle*), photo © 2012 ESA; the White Cliffs of Dover formed by coccolithophore scales in the Jurassic (*bottom*), photo © 2008 Birte Matthiessen, all rights reserved

2.2.1.2 Zooplankton

Zooplankton comprise of eukaryotic single-celled organisms (protozoa) and animals that are functionally unified by their heterotrophic life-style. Zooplankton feed upon particulate organic matter (POM) which can either be alive (other plankton) or dead (i.e., detritus). Depending on their prevalent diet zooplankton can be distinguished in herbivores (feeding on plants, i.e., phytoplankton), carnivores (feeding on animals, i.e., other zooplankton), omnivores (mixed diet), and detritivores (feeding on detritus). However, this classification is less strong pronounced in zooplankton compared to other communities, because many zooplankton organisms have a filtrating feeding mode and/or ingest their prey particles as a whole, and hence feed size selective (Sommer 1998). Thus, zooplankton diet comprises of the prevalent organisms belonging to the actually captured and ingestible particle size (compare Fig. 2.1). Functionally zooplankton can be divided in three major groups, the microzooplankton (mainly protozoa), the mesozooplankton (mainly copepods), and the macro- and megazooplankton (mainly euphausids and gelatinous forms) (Figs. 2.1 and 2.4).

The protozoic microzooplankton consists of a variety of taxonomic groups with tiny zooflagellates of only a few μm in size (heterotrophic nanoflagellates, HNFs) (Fig. 2.1), ciliates (Fig. 2.4) that belong to the nano- and the microplankton, and rhizopods that comprise among others the microplanktonic amoeba and foraminifera (Fig. 2.1). Also the rather large-sized (>1 mm) dinoflagellate *Noctiluca* that is responsible for the marine phosphorescence belongs to the protozooplankton (Fig. 2.1). Generally protozooplankton are more abundant than the 'classical' mesoplanktonic crustaceans (see below) and characterized by high metabolic rates (Sommer 1998). The fundamental role of the protozoic microzooplankon in the pelagic food web was largely underestimated until recently. With the discovery of the microbial loop (Pomeroy 1974; Pomeroy et al. 2007) their importance for the recycling of a large part of the dissolved organic matter (DOM) of the euphotic zone in the epipelagic was recognized. In the microbial loop bacterioplankton (picoplankton, Fig. 2.1) rapidly consume available (exudated or autolyzed) DOM and in turn are consumed by tiny HNFs. Ciliates then prey upon HNFs (and phytoplankton of the same size class) and thereby return the DOM to the classic pelagic food-web as ciliates are consumed by mesozooplankton. Today in particular in nutrient poor regions the microbial loop is regarded equally important to the 'classic' pelagic trophic relationship of phytoplankton - mesozooplankton crustaceans—fish.

The most important mesozooplankton (Fig. 2.1) are the copepods (Fig. 2.4) and cladocerans both belonging to the crustaceans. They are studied in much more detail than microzooplankton due to their role as main diet for fish larvae and planktivorous fish. Whereas cladocerans are restricted to the neritic realm (Fig. 2.5), copepods predominate the mesozooplankton in all seas including the oceanic regions. Cladocerans have a simple life cycle with mainly asexual reproduction and without larval stages, which under favorable conditions allows for rapid population growth with multiple generations per year. Copepod populations in contrast grow significantly slower with only one or two generations per year. The reproduction is sexual.

Fig. 2.4 The ciliate *Strombidium* sp. (*upper left*), photo used with kind permission of © Celeste López Abate, all rights reserved; the copepod *Calanus finmarchicus* (*upper right*), photo used with kind permission of © Michael Bok, all rights reserved; Antarctic krill *Euphausia superba* (*bottom left*), photo used with kind permission of © Jan Andries van Franeker, all rights reserved; the compass jellyfish *Chrysaora hysoscella* (*bottom rigt*), photo used with kind permission of © Ralph Kuhlenkamp, all rights reserved

The newly hatched nauplii larvae develop to copepodites which in their five subsequent stages increasingly resemble the adult copepods. Ecologically important is that the diet constantly shifts towards larger particle sizes during this larval and juvenile development. The difference between 'herbivorous' and 'carnivorous' copepods essentially lies in the size of the selected particles. The particular species rich calanoid copepods are the most important grazers of the larger nano- and micro(phyto)plankton and at the same time the predominant prey of planktivorous fish (Fig. 2.1). As such they represent the critical link between primary production and fish in classical food-webs. In fact, regions with strong coastal upwelling of nutrient rich waters are generally associated with large-sized, diatom-based food-webs (see Sect. 2.2.1.1). In these food-webs calanoid copepods link the food in fewer and more efficient steps towards mesopredatory and larger predatory fish (see Sect. 2.2.2) compared to food webs that are smaller-sized picoplankton-based and thus include more steps (Ryther 1969).

Whereas plankton is generally incapable to actively move horizontally against currents, many mesozooplankton species are able to adjust their depth and diurnal vertically migrate across several tens or hundreds of meters at dusk and dawn. In order to avoid visual predation they occupy deeper and sparsely illuminated waters during the day and migrate towards the food-rich surface waters at night where they feed on phytoplankton. Diurnal vertical migrations (DVM) are an ubiquitous characteristic of pelagic ecosystems (Hays 2003; Pearre 2003) explaining one part of the patchy distribution of zooplankton in the global ocean. In fact DVM by zooplankton (and following planktivorous mesopelagic fish, see Sect. 2.2.2) in the pelagic zone of the oceans is the largest behaviorally driven coordinated biomass movement on earth (Kaiser et al. 2011). Thereby, a large part of the photosynthetically generated organic matter (i.e., phytoplankton) from the surface is transported downwards. Vertically migrating zooplankton overlap through a series of yet ever-deeper depths and collectively form a ‘ladder’ of migration from the surface to the deep ocean (Kaiser et al. 2011). By feeding upon each other they transfer the photosynthetically fixed carbon. With every step down in this food ‘ladder’ the portion and thus efficiency of organic matter transferred declines which means that the food-availability declines with distance from the surface and leads to the general pattern of declining animal biomass per unit volume seawater with depth (Yamaguchi et al. 2002). Ultimately a minor portion of photosynthetically fixed carbon from the surface reaches the bottom of the deep sea where it either supports benthic life on the seafloor (see Sect. 2.4.6) or is sequestered in sediments (Broecker and Peng 1982; Ducklow et al. 2001), forming the endpoint of the biological carbon-pump (Volk and Hoffert 1985).

The ocean is rich in macro-and megaplankton (Fig. 2.1) that are mainly carnivorous and feed on zooplankton. The macro- and megaplankton comprise of a strikingly high proportion of gelatinous forms such as jellyfish (Scyphozoa, Siphonophora) (Fig. 2.4), comb jellyfish (ctenophores), arrow worms (chaetognaths), appendicularians and salps (Fig. 2.1). Jellyfish are preyed upon by some fish species such as the ocean sun fish, some tuna, shark, swordfish, some salmon species and sea turtles. However, due to their high content of water they play a minor nutritional role in the pelagic food web compared to mesozooplankton (primarily copepods) and zooplanktivorous fish. Some jellyfish species can have tentacles of several meters lengths and in case of contact with a prey or predator (or human skin) it can trigger millions of stinging cells (nematocysts) to penetrate the skin and inject venom. Yet, only some species’ venom cause truly harmful or lethal reactions in humans. Jellyfish often occur in large aggregates often named swarms or ‘blooms’ of which the formation mainly depends on currents, but also nutrients, light and temperature (i.e., season), prey availability, reduced predation and oxygen concentrations are thought to play a role. It has been observed that jellyfish abundances increased in heavily fished areas such as the Bering, Black and Caspian Seas, in the Sea of Japan and the Gulf of Mexico (Richardson et al. 2009). Current research addresses the hypothesis whether jellyfish might fill the ecological niche of overfished predatory fish in the future.

An important non-gelatinous group of the macrozooplankton is the krill (Euphausiacea, Figs. 2.1 and 2.4). Particularly in the Antarctic food-web they play a critical role as they directly link the autotrophically fixed carbon to higher trophic levels. They are filter feeders of nano- and microplankton and the major prey of Antarctic nekton (Sect. 2.2.2) such as wales, pinnipeds, penguins, fish and cuttlefish.

2.2.2 Nekton

In contrast to plankton, nekton are active swimmers and able to countervail ocean currents. They exclusively consist of animals and encompass fish (bony fishes, elasmobranchs), pelagic cephalopods, sea birds (penguins), reptiles (sea turtles) and marine mammals (whales, seals). The size range of nekton covers several orders of magnitude, from about 2 cm (small fish) up to 30 m (whales) (Fig. 2.1). Many species of the nekton are not associated to one particular marine community or habitat, but show an extensive (horizontal and vertical) migratory behavior between feeding or reproduction grounds. Long-distance horizontal migration was documented particularly for large predatory fish (e.g., sharks, tuna), marine mammals (e.g., whales) and reptiles (turtles) (Block et al. 2011), and it is also performed by large marine fish stocks such as cod (*Gadus morhua*) or Atlantic herring (*Clupea harengus*) (Muus and Nielsen 1999). Vertical migration is known to occur in mesopelagic fish in oceanic regions (see below). Distances tackled by migratory nekton range from several tens to hundreds of meters (vertical migration) to thousands of kilometers (horizontal migration). Owing to their movement between habitats, nekton interconnect different pelagic and benthic zones and food webs of the global ocean (bentho-pelagic coupling, see below).

Fish contribute the largest share to total nekton biomass and its biological production is primarily based on plankton production. Within the group of fish, small mesopredatory species play a key role for the entire marine food web as they form the trophic link between first order consumers (zooplankton or small benthic herbivorous species) and higher trophic levels (piscivorous fish, seabirds and sea mammals). Moreover, some fish species contribute to the bentho-pelagic coupling of the ocean as some of their life stages feature migratory behavior and/or are associated to particular marine zones. For instance, in some fish species spawning can be bottom-associated, whereas, once hatched, all other life stages are associated to the pelagial (e.g., herring). Other fish species feed on benthic organisms in general (e.g., cod) or frequent benthic habitats for feeding during mass spawning events of benthic organisms such as polychaetes or corals (e.g., reef fish).

In the large oceanic zone (Fig. 2.5), the mesopredatory fish species (e.g., lanternfishes of the family Myctophidae, Fig. 2.1) make up the main portion of mesopelagic fish biomass. They inhabit the oceanic twilight zone and are characterized by extensive diurnal migrations of up to several hundred meters per day (Salvanes and Kristoffersen 2001). During day time they remain in the deep mesopelagic or bathypelagic zone to avoid visual predation. At dusk they follow their prey, the diel vertically migrating mesozooplankton (see Sect. 2.2.1.2), into the euphotic zone of the epipelagic. By migrating downwards at dawn these fishes provide trophic connectivity to larger deep-sea predatory fish and transport a vast amount of particulate organic matter downwards that is excreted and respired at depth during day (Irigoien et al. 2014). They thereby contribute to biogeochemical cycling in the ocean and function as an important component of the biological carbon pump (Irigoien et al. 2014).

In the neritic zone (Fig. 2.5) or upwelling regions the most important mesopredatory fish are clupeoids (i.e., herring-like fish, Fig. 2.1). They are of commercial importance globally. Specifically, anchovy, herring and sardine build up very high biomass and contribute 20–25% to the global marine fisheries catches (Hunter and Alheit 1995). This high fish biomass can be found at sites of high primary (phytoplankton) and secondary production (zooplankton) where replete nutrient concentrations from deeper water meet sufficient light penetration within upwelling and continental shelf regions. Atlantic herring (*Clupea harengus*) and Pacific herring (*Clupea pallasii*) thrive in shelf-seas of the North Atlantic and North Pacific, whereas sardines (primarily *Sardinops* spp. and *Sardinella* spp.) and anchovies (*Engraulis* spp.) are most abundant in coastal upwelling regions and tidal fronts.

Originally marine food webs were described as top-heavy pyramids that were characterized by a high abundance of predators and a lower abundance of their prey (the mesopredatory or so-called forage fish) (e.g., Jackson et al. 2001; Sandin et al. 2008). The high turnover rates of the prey organisms sustained high predator biomass. Due to excessive whaling and strong fishing pressure on commercially important large predatory fish such as tuna (Fig. 2.1) (Krauss et al., Chap. 4), marine food webs have substantially changed. Nowadays, high proportions of forage fish compared to predatory fish and whales are characteristic of many marine ecosystems. This change in composition has unobvious and even paradox ecological consequences to the interconnected global marine food web. For example, the dead bodies of whales sinking to the ocean floor (so-called whale falls) have been providing an important food source in the deep sea environment where food is naturally scarce (see Sect. 2.1; Roman et al. 2014 and references therein). Hence, the intense removal of whale biomass in the epipelagial of the ocean has also been affecting communities well beyond the pelagic zone from which the whales were removed. Furthermore, the biomass of Antarctic krill (*Euphausia superba,* Fig. 2.4) paradoxically remained unchanged or even decreased when the abundance of their main predators, baleen whales, decreased. It turned out that the whales themselves were the most important driver of sufficient prey availability: Their nutrient-rich excretions fueled phytoplankton production, which in turn formed the nutritious basis for krill production. In other words, a positive feed-back mechanism between predator and prey self-sustained a highly productive environment in the past. The human-driven reduction of baleen whale abundance led to reduced nutrient concentrations, which resulted in reduced primary production and ultimately to low krill biomass (Roman et al. 2014 and references therein). This example nicely illustrates the importance of the (predatory) megafauna to ecosystem productivity.

2.3 Benthic Zone

The benthic zone describes the ecological region on the bottom of the ocean, extending from the shore line along the continental shelf and downward the continental slope to the deep sea floor and deep sea trenches (Fig. 2.5). This expansive marine living space can be subdivided into numerous subzones of which the most general distinguishing feature is the availability of light: the phytal (Lüning 1985), including the supralittoral, the mesolittoral, and the sublittoral (see below and Fig. 2.5), describes the benthic zone from the shore along the continental shelf. The euphotic conditions of the phytal allow bottom-living marine plants, algae and corals to thrive. Beyond the sunlit zone and downward the continental slope follow the aphotic oceanic benthic zones termed the bathyal, the abyssal and the haddal (see below and Fig. 2.5). Generally, the benthic realm exhibits high structural heterogeneity and, compared to the pelagial, comprises many different (micro-) habitats that are inhabited by complex and biodiverse communities. Among all marine plants or animals there is hardly any taxon that is not represented in the benthic zone.

Organisms living in the benthic zone are called phyto-, zoo- or bacteriobenthos, depending on their auto- or heterotrophic feeding modes. Members of the benthos include marine flowering plants, macroalgae, and single-celled microalgae, most marine invertebrates (e.g., sponges, corals and other cnidarians, worms, mollusks, echinoderms, crustaceans, and bryozoans) as well as ground fish and bacteria. Their joint feature is a close relation to the ground substrate and an often limited mobility (excluding benthic fish). In fact, contrasting plankton, many benthic organisms show a sessile or partially sessile life style with, however, planktonic larval stages that promote their dispersal and genetic exchange.

The ground substrate of the benthic zone is divisible into soft sediment and hard bottom substrate and, depending on the organism's life on or buried in the ground substrate, the organism is categorized as epifauna or infauna. A special and typical case of benthic life is termed epibiosis, where benthic organisms colonize other organisms. The highly diverse benthos can be further classified according to size into macrobenthos (>2 mm), meiobenthos (0.2–2 mm), microbenthos (<0.2 mm). Depending on the scientific question, the biota may be classified into the ecologically more relevant functioning, such as habitat engineer or foundation species, primary producer, first order consumer (herbivore), predator, filter- or deposit feeder, burrower or substrate-boring organism.

Apart from light availability and substrate properties, other abiotic factors such as temperature, salinity, pressure and oxygen availability as well as biotic structuring processes such as facilitation, competition and consumption determine marine life along the depth gradient of the benthic zone. Just like in the terrestrial biosphere, the biogeography on the bottom of the ocean therefore reflects the different physiological and ecological tolerances of the inhabiting species (i.e., their ecological niches) (Fig. 2.5).

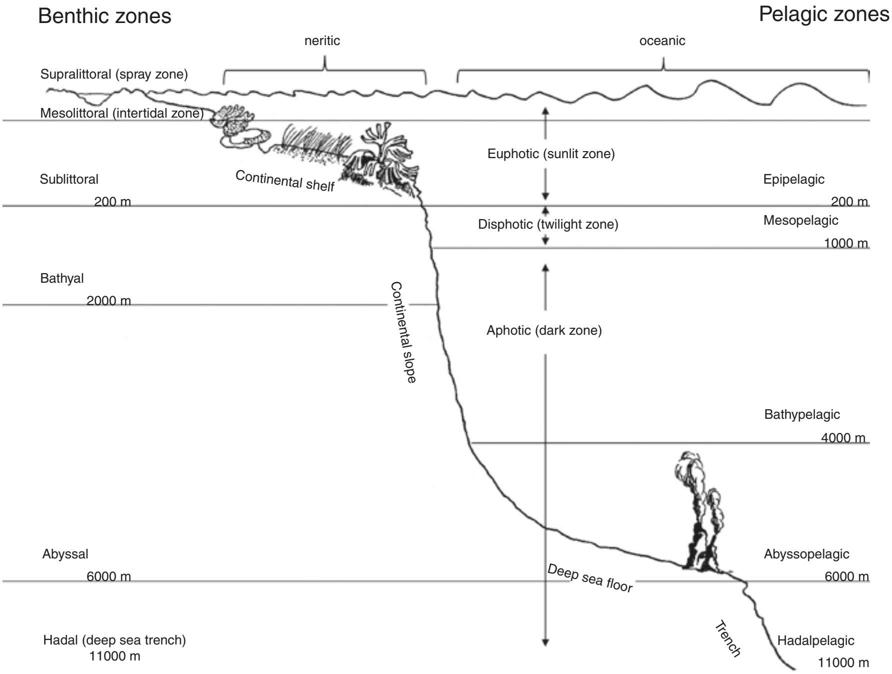


Fig. 2.5 Classification of the marine environment according to depth and light availability. The benthic zone comprises the living space on the bottom of the ocean from the shoreline, along the sunlit littoral, to the dark deep sea floor and trenches. The pelagic zone comprises the living space in the water column above the continental shelf (neritic region) and the deep sea (oceanic region). Illustration © 2016 Jonas Mölle and Franziska Julie Werner, all rights reserved

2.3.1 Euphotic Coastal Benthic Zone (Phytal)

Accounting for only about 8% of the total sea surface area, the marine habitat on the continental shelves ranks among the most productive regions of the global ocean (e.g., UNEP 2006). This high productivity is driven by the high light and nutrient availability in this zone, which comes along with the shallow water body, upwelling of nutrient-replete water masses from the deep (see Hummels, Chap. 1), but also with riverine influxes of minerals and organic material. These favorable conditions fuel autotrophic primary production which sustains high secondary production in both, the coastal benthic and the pelagic food web (see Sect. 2.2).

The supralittoral (spray zone) describes the euphotic benthic zone that is regularly splashed, but not submerged by seawater (Fig. 2.5). It represents one of the most inhospitable benthic living spaces as it requires its inhabitants to cope with high fluctuations in temperature, salinity, air pressure, strong mechanical forcing of the surge as well as with predation pressure from terrestrial and marine consumers. Self-evidently, species diversity of the supralittoral is low compared to other benthic zones of the Phytal as only few organisms manage to withstand the high variability in environmental conditions. A typical example for a marine community of the supralittoral is the tide pool community on rocky shores (see Sect. 2.4.1).

The mesolittoral (intertidal zone) differs from the supralittoral in that the phases of dryness and submergence by seawater are bound to the tidal rhythm (Fig. 2.5). In other words, the mesolittoral zone reflects the tidal range and, depending on the coastal profile, it may spatially represent a narrow zone on steep rocky shores or may show a wide expansion on very shallow coasts. Generally, species diversity in the mesolittoral is higher compared to the supralittoral, with species sensitive to strong environmental gradients being more frequently found in deeper levels that are least affected by the tidal oscillation. An example of a very extensive mesolittoral zone on soft bottom is the Wadden Sea.

The sublittoral zone ranges from the shallow euphotic benthic zone that is continuously submerged by seawater to the maximum depth of light penetration (up to 200 m depth) (Fig. 2.5). At its deeper end the disphotic ('poorly lit') or twilight zone begins, which also forms the distribution boundary depth for photosynthetic marine plants, algae and corals. In contrast to the other littoral zones, the sublittoral features relatively stable environmental conditions in terms of its submergence and its fully marine setting, both of which promote the establishment of highly diverse communities such as kelp forests, seagrass meadows or coral reefs (see Sect. 2.4.2 ff.).

2.3.2 Aphotic (Dark) Oceanic Benthic Zone

The deep aphotic zone accounts for the largest portion (90%) of the marine benthic environment. Owing to the lack of solar energy, vegetation and photosynthetic primary production are largely nonexistent and food webs are mainly driven by heterotrophy. Hence, members of the deep benthos, just like members of the deep pelagic food web (Sect. 2.1), rely on the downward flux of organic material (e.g., dead or living animals, or marine snow) sinking or migrating from the sea surface to the ocean floor. Given that 80–90% of the organic matter is consumed within the upper 1000 m of the ocean, food availability in the deep benthic realm is generally low. A special mode of nutrition in the aphotic benthic zone is chemoautotrophy. Here, chemoautotrophic bacteria and archaea replace photosynthetic primary production by using geothermally produced inorganic energy as a food source near deep sea vents and cold seeps. Generally, however, the hostile living conditions of complete darkness, high seawater pressure, low temperature and low food supply in the deep benthic zone are assumed to sustain communities of lower biodiversity compared to the productive euphotic benthic zone.

The bathyal encompasses the deep benthic habitat along the continental slope from about 200 m to 2000 m depth (Fig. 2.5). It accounts for nearly one third of the aphotic marine benthic zone. At bathyal depths the variability of environmental parameters is relatively low with temperature comprising on average 4 °C and salinity containing on average 35 psu. Low water exchange driven by weak currents may induce temporary low oxygen concentrations. The ground substrate of the bathyal mainly comprises sediments and minerals of terrestrial, pelagic and authigenic (i.e., formed in situ) origin. Bathybenthic communities mainly encompass near-bottom swimming fish, porifera, holothurians, cnidarians, crustaceans, echinoderms, mollusks, brachiopods, worms, and foraminiferans.

The abyssal plain (deep-sea floor) is the most extensive benthic zone, covering about 75% of the oceans area and >50% of the global surface area. It is located on the deep sea floor between 2000 m and 6000 m depth (Fig. 2.5). Similar to the bathybenthic realm, environmental conditions in the abyssal are relatively uniform with temperatures ranging between 0 and 4 °C and salinity comprising on average 35 psu. The ground substrate can be soft sediment and organic ooze, or hard substrate such as sea mounts or manganese nodules. In the cold, dark and barren environment life is assumed to be generally scarce and slow, but large-scale patterns of biodiversity in the abyssal are poorly understood so far. It has been suggested that species diversity in the abyss may be higher in habitats underlying productive upwelling regions compared to habitats underlying oligotrophic ocean gyres (Smith et al. 2006). An exception forms in areas of volcanic and tectonic activity where hydrothermal vents and seeps form densely populated, high-energy habitats, hosting diverse deep sea communities of crustaceans, mollusks, polychaete worms and fish (see Sect. 2.4.6).

The hadal zone comprises the deep ocean trenches (>6000 m) that formed by tectonic plate subduction (Fig. 2.5). It accounts for less than 1% of the seafloor. The deepest currently known trench zone extends to nearly 11,000 m (Challenger Deep, Mariana Trench). Even under these most extreme conditions in terms of pressure (600–1100 atm) and temperature (0–4 °C), life evolved; its ecology, however, is hardly known so far. Organisms observed in the hadal benthic zone include polychaete worms, mollusks, crustaceans, holothurians, and foraminiferans.

2.4 Benthic Communities

In the most general sense one can distinguish six fundamental types of benthic communities in the marine realm, which will be introduced in the following section. They include tide pool and seaweed communities on rocky shores, seagrass meadows on sandy shores, coral reefs, estuarine communities (including mud flats, salt marshes, and mangroves), and deep sea communities. Most of these fundamental types can be found in all oceans of the world, showing a distribution pattern in dependence on latitude, substrate properties, and depth gradients. Most of them are interlinked through migration and trophic transfer, and all of them deliver ecosystem goods and services, such as food, raw materials, chemical resources, and carbon fixation and export, upon which humans have been depending and from which they have greatly been economically and culturally benefiting (e.g., Costanza et al. 1997; UNEP 2006).

All benthic communities are structured and maintained by dynamic (abiotic) interactions with the physical and chemical environment and by (biotic) interactions between the organisms. The three most fundamental self-regulatory mechanisms are facilitation, competition (bottom-up regulation) and consumption (top-down regulation). For instance, foundation species, such as corals or seaweeds, give structure to the environment and provide substrate, food, and shelter to other organisms. They modify the physical and chemical conditions and thereby exert facilitative or restrictive influence on the abundance, diversity, and dynamics of other members of the community (Bruno and Bertness 2001). In the benthic realm, communities or ecosystems are often named after such habitat engineers (e.g., coral reef, kelp forest). Bottom-up regulation of a community derives from the availability of resources. Precisely, primary producer abundance and composition is driven by the competition for inorganic resources such as nutrients and light. Consumer abundance and composition is driven by the availability of primary biomass and/ or by the availability of prey organisms. Top-down regulation in turn antagonizes the effect of bottom-up forces, i.e., the strength of consumption (grazing or predation) regulates the abundance and diversity of prey species. A community is said to be predominantly driven by bottom-up forces when a rapid increase of benthic or planktonic algal biomass occurs in response to high nutrient and light availability (blooming event), that is not countervailed by consumption. All regulating mechanisms are tightly interrelated and their relative strengths vary in space and time. Scientific research has shown that human-induced alteration of the physical environment (e.g., eutrophication or climate change) or of the community composition (e.g., over-exploitation of predators) can trigger imbalance in the maintaining mechanisms by, for instance, promoting production at the bottom of the food web or by weakening top-down regulation (e.g., Eriksson et al. 2009; Werner et al. 2016). These changes in the self-regulatory mechanisms can drive communities or ecosystems toward an alternative stable system with uncertain implications on their ecosystem goods and services and hence on human welfare (Salomon and Dahms, Chap. 3).

2.4.1 Tide Pool Communities

Tide pool communities can be found in the supralittoral of all rocky shorelines around the world. They form in shallow depressions of coastal rocks and cliffs that are temporarily filled with water from tidal waves, surf, and rainfall (Fig. 2.6a). Tide pool habitats are characterized by a high fluctuation in physical conditions which makes survival a challenge (Metaxas and Scheibling 1993). Associated communities therefore show durational instability and highly dynamic patterns of migration and extinction. Many members of tide pool communities are hard-shelled or developed adaptations such as dormant stages in order to avoid desiccation. Microalgae, intertidal macroalgae, and lichens grow well in the sunlit rock pool habitat and support food webs composed of gastropods, crustaceans, mussels, echinoderms, and sea anemones, shorebirds and mammals (e.g., sea otter, raccoon). Species number and diversity may vary with the size of the rock pool and its tidal zonation (Martins et al. 2007). Generally, however, diversity is low and food chain length is short compared to other benthic communities.

Fig. 2.6 Depictions of some of the fundamental types of benthic communities found in the world's oceans: (**a**) Tide pools on a rocky shore of the Swedish northwest coast (Skagerrak), photo © 2004 Birte Matthiessen, all rights reserved; (**b**) A dense vegetation of the seaweed *Fucus vesiculosus* on hard-bottom substrate in the western Baltic Sea, photo © 2016 Franziska Julie Werner, all rights reserved; (**c**) A seagrass meadow of the genus *Posidonia* on sandy-bottom substrate in the Mediterranean Sea, photo used with kind permission of © 2015 Thorsten Reusch, all rights reserved; (**d**) A Mudflat with feeding seabirds in the Wadden Sea; southeastern North Sea, photo used with kind permission of © 2016 Hartmut Engel, all rights reserved; (**e**) Mangroves and their submerged root system on the shoreline of Ovalau, Fiji, Southern Pacific, photo used with kind permission of © 2016 Tom Vierus, all rights reserved; (**f**) A diverse and colorful assemblage of reef-building corals in the Beqa Lagoon, Fiji, Southern Pacific, photo used with kind permission of © 2015 Tom Vierus, all rights reserved; (**g**) a deep sea vent community on the Mid-Atlantic Ridge, Atlantic Ocean, photo © ROV KIEL 6000; GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel

2.4.2 Seaweed Communities

Seaweeds such as kelp or fucoids (Fig. 2.6b) show a wide distribution range on the rocky shores of the global ocean. They attach to hard substrate by their holdfast and provide perennial, three dimensional habitat, nursery ground, and food to a highly diverse assemblage of associated microalgae, ephemeral macroalgae, invertebrates, and fish (Colman 1940; Dayton 1985; Christie et al. 2009). High primary production in seaweed stands (Ramus 1992) promotes high secondary production in the associated community and sustains a highly productive food web that extends beyond the coastal waters in which seaweed communities thrive (Harrold et al. 1998; Mann 2000) (also see Sect. 2.2.1). Humans greatly benefit from seaweed communities, because they provide coastal protection through the buffering of wave impacts and contribute to nutrient retention and cycling in coastal waters, which indirectly promotes marine fisheries (Graham 2004; Norderhaug et al. 2005; Rönnbäck et al. 2007). Yet, increasing human population densities, coastal development, harvesting of resources, and climate change have rapidly and globally altered coastal marine habitats, and put the maintenance and functioning of rocky shore seaweed communities at risk (e.g., Airoldi and Beck 2007; Wernberg et al. 2011; Steneck et al. 2013).

2.4.3 Seagrass Meadows

In shallow sandy-bottom habitats of all continents (except Antarctica) seagrass meadows form the highly productive counterpart to rocky shore seaweed communities (Fig. 2.6c). Similar to seaweeds, seagrasses function as the foundation species in highly diverse and productive communities composed of algae, invertebrates, fish, turtles, marine birds and mammals (e.g., Heck and Wetstone 1977; Duarte and Chiscano 1999; Beck et al. 2001). In contrast to seaweeds, seagrasses are vascular flowering plants that reinvaded the marine realm and still hold attributes of their terrestrial ancestors (Les et al. 1997). Specifically, they possess root systems that bury into the soft sediment and form thick mats of rhizomes. The latter not only deliver nutrients from the subsurface and function as holdfast to the plant, but also essentially contribute to the stabilization of the otherwise mobile sandy sediment. Moreover, above ground, seagrass shoots form densely vegetated meadows that can cover large areas of seabed and dissipate wave energy and currents. Hence, seagrass meadows increase the light availability in sandy-bottom habitats by decreasing the turbidity, and they contribute to shoreline protection by reducing erosion (Fonseca and Cahalan 1992). However, established seagrass meadows are conservative with regard to their spreading or persistence in one location (Tardent 1993). This characteristic makes them a steady but vulnerable habitat. Even small-scale environmental changes (e.g., coastal construction, summer heat waves under proceeding global climate change) may put seagrass meadows at risk of local extinction (Reusch et al. 2005; Orth et al. 2006).

2.4.4 Estuaries (Including Mudflats, Salt Marshes and Mangroves)

Estuaries rank among the youngest aquatic ecosystems in geological and evolutionary terms as many of them formed only at the end of the last ice age (about 6000–10,000 years BP) when ice sheets retreated and continental shelves and river valleys were flooded (e.g., Chesapeake Bay, USA). Estuaries represent the transition zone between marine and freshwater (riverine) habitats. At the lower boundary, they feature a free connection to the sea where plumes of reduced salinity reach into the open sea; at the upper boundary, they are mainly fresh water habitats with, however, daily tidal influence. Benthic ecology in estuaries is driven by this continuum of salt and freshwater mixing, which acts as a strong selection force in favor of organisms that either are able to adjust the balance between the salt concentration of their body fluid and the surrounding water (osmoregulators) or that show exceptionally high tolerances to osmotic changes of their internal fluid concentrations (osmoconformers). Benthic communities associated to estuaries include mudflat (Fig. 2.6d) and saltmarsh communities in the temperate regions, and mangrove swamps in the tropics (Fig. 2.6e).

In mudflats, plant biomass and primary production are generally low. However, high loads of organic material, originating from the terrestrial, marine and riverine surrounding, support high secondary production (detritus-powered food web) of infaunal invertebrate species such as crustaceans, mussels, and worms (Day et al. 1989). This makes estuarine mudflats a vital nursery and feeding ground for many marine fish and (migratory) bird species (Fig. 2.6d). Temperate salt marshes are dominated by grasses, reeds or rushes, whereas tropical mangrove swamps are dominated by trees or woody shrubs. Both provide fertile habitat that supports biologically rich communities composed of aquatic and terrestrial creatures (Day et al. 1989). Their ecosystem services delivered to humankind extent beyond the provision of coastal protection, the fixation and sequestration of CO_2, and the supply of recruits to local fisheries (Robertson and Duke 1987; Able and Fahay 1998). The dense and spongy root systems of marsh grasses and mangroves function as enormous filter systems that keep riverine sediments, nutrients as well as pollutants from being washed out to the sea by tidal currents (Bertness et al. 2014). Yet, particularly mangrove forests rank among the most degraded habitat types on earth due to their clearing, pollution and sedimentation in consequence of coastal development, agriculture, and aquaculture (Valiela et al. 2001).

2.4.5 Coral Reefs

Tropical coral reefs are the largest biogenic constructs ever built on this planet. Owing to their exceptionally high biodiversity and productivity they are often described as the marine counterpart to terrestrial tropical rainforests (Fig. 2.6f). Corals can be found in all the world's ocean basins. However, massive reef structures are restricted to the geographical zone between 25° north and south latitude. They are mainly made up of the calcium carbonate skeletons of hermatypic corals (i.e., reef-building corals), which require mean annual sea surface temperatures of about 23 °C and euphotic waters of low turbidity (i.e., low productivity). It appears paradox that the most productive and diverse of all benthic communities thrives in the nutrient deserts of the tropical oceans. However, tight nutrient cycling within the coral reef system allows for its sustenance and growth in spite of the oligotrophic environment. For instance, many reef-building corals hold mutualistic symbioses with phototrophic dinoflagellates (zooxanthellae). The endosymbiotic algae receive waste products such as nitrogenous compounds from the coral polyp. In return, the polyp is supplied with up to 90% of the photosynthetic products (e.g., glucose) generated by the algae. This mechanism on the very basis of the coral reef food web is critical to the settlement, existence and productivity of reef-associated organisms across trophic levels, such as ahermatypic corals, sponges, invertebrates, fish, and mammals (Hatcher 1988).

Compared to other coastal benthic communities, coral reefs possibly are the ones most vulnerable to and most severely impacted by human activities. This is firstly because they have been heavily exploited as an important source of income with respect to fisheries, raw materials and tourism (Hoegh-Guldberg 1999; Sale 2008). Secondly, they are highly sensitive to environmental changes induced by human development, such as local seawater pollution and sedimentation, global climate warming and ocean acidification (e.g., Hoegh-Guldberg 1999; Hughes et al. 2003; Hoegh-Guldberg et al. 2007). Degradation in reef communities most clearly shows in coral bleaching events, of which the most severe in history is currently being observed at the northernmost 1000 kilometers of the Great Barrier Reef, Australia (Cressey 2016). Coral bleaching describes a stress response of the coral polyp during which it expels its zooxanthellae. As the endosymbiotic algae is giving the coloring to the coral, the latter turns white during this process. Massive bleaching events have been attributed to thermal stress and are predicted to increase under proceeding global warming and sea surface temperature anomalies (Hoegh-Guldberg et al. 2007). Depending on the magnitude and duration of the stressful event, corals can recover from bleaching, but often are subject to higher mortality, reduced growth, less recruitment, and higher susceptibility to diseases (Hughes et al. 2010).

2.4.6 Deep Sea Vent and Seep Communities

Submarine hydrothermal vent and cold seep communities form the deepest known, most remote and ecologically least explored communities on earth. Hydrothermal vent communities (Fig. 2.6g) are typically associated to deep mountain ridges (e.g., the East Pacific Rise and the Mid-Atlantic Ridge) and to areas of the ocean basin where magma wells up, new crust is being formed and seafloor tectonic plates diverge. At hydrothermal vents hot magma and cold ocean water meet through fissures in the newly formed basaltic rock, resulting in the release of hot water vapor, methane, and other dissolved chemical compounds. In contrast to this, cold seeps are commonly located along continental margins where methane, hydrogen sulfide, and oil seep out of sediments. On the basis of the food webs of hot vents and cold seeps chemosynthetic bacteria convert carbon dioxide into sugars and thereby locally sustain productive and diverse communities. Instead of solar energy (as used by photosynthetic primary producers for the production of sugars), however, chemoautotrophs use the energy of hydrogen sulfide or methane for primary production (Van Dover 2000). Hence, hydrothermal vent and cold seep communities are based on natural gases. They primarily include worms, shrimps, mussels, and limpets. Some first order consumers directly feed on microbial assemblages, some harbor chemoautotrophic symbionts as a source for energy.

Owing to their relatively recent discovery in the 1970s (Ballard 1977) and remoteness, the ecology of deep sea communities is far less understood than that of other well-accessible benthic communities. However, general ecological features of deep sea habitats, such as low temperature (except for hot vents) and low organic energy flux, can be expected to yield communities characterized by low productivity, low rates of growth and reproduction, and slow colonization (Gage and Tyler 1991; Smith and Demopoulos 2003). All of these attributes make deep sea communities susceptible to disturbance and slow in recovery. To date, human activities like bottom-fishing, oil and gas exploitation, and waste disposal are known to have deleterious effects on deep sea environment (e.g., Smith et al. 2008). Expected threats to come are climate change and deep sea mining of mineral resources, methane-hydrates, and manganese nodules (Smith et al. 2008).

2.5 Conclusion

In summary the global ocean may appear to be one homogenous living space, but in practice dynamic biological, physical, and chemical processes create spatially and temporally variable environmental conditions that influence marine life. The biogeography of the oceans reflects this variability with species and communities existing and performing in habitats that match their ecological niches. In the most general sense one can subdivide the ocean into the pelagic and the benthic zone. In both zones the availability of inorganic resources such as light and nutrients is vital to the associated communities and food webs as most of them are based on photosynthetic primary production (e.g., pelagic phytoplankton provides about 50% of global primary productivity). Within all marine communities the ecological organization and functioning is driven by abiotic and biotic interactions, such as facilitation, competition for resources, and consumption. In the pelagic zone, communities are commonly described by means of their main components phytoplankton, zooplankton, and nekton. Pelagic food webs are understood to be size-structured, meaning that organisms belonging to a larger size-class feed upon those belonging to the respective smaller one. In the benthic zone, communities are commonly described by means of foundation species that act as a habitat engineer and thereby facilitate or restrict the abundance of other species or functional groups of the community. Benthic communities are often named after their foundation species which vary according to latitude, bottom substrate, and depth gradient.

While the presented distinguishing features help to structure and understand the complexity of life in the global ocean, one has to keep in mind that the vast marine living space is ecologically interconnected by currents and active migratory behavior of its inhabitants. Anthropogenic alteration of the marine environment can therefore have ecological consequences that reach beyond the species or community that is directly affected by the activity. The latter implies that efforts to conserve and sustainably manage marine ecosystems and their goods and services provided to humankind need to envision strategies that go beyond marine communities and across exclusive economic zones.

References

Able KW, Fahay MP (1998) The first year in the life of estuarine fishes in the Middle Atlantic Bight. Rutgers University Press, New Brunswick, NJ

Airoldi L, Beck MW (2007) Loss, status and trends for coastal marine habitats of Europe. In: Gibson RN, Atkinson RJA, Gordon JDM (eds) Oceanography and marine biology, vol 45. Oceanography and marine biology, CRC Press, pp 345–405

Anderson DM, Burkholder JM, Cochlan WP, Glibert PM, Gobler CJ, Heil CA, Kudela RM, Parsons ML, Rensel JEJ, Townsend DW, Trainer VL, Vargo GA (2008) Harmful algal blooms and eutrophication: examining linkages from selected coastal regions of the United States. Harmful Algae 8(1):39–53. doi:10.1016/j.hal.2008.08.017

Ballard RD (1977) Notes on a major oceanographic findings. The discovery of hydrothermal vents. Oceanus 20

Beaufort L, Probert I, de Garidel-Thoron T, Bendif EM, Ruiz-Pino D, Metzl N, Goyet C, Buchet N, Coupel P, Grelaud M, Rost B, Rickaby REM, de Vargas C (2011) Sensitivity of coccolithophores to carbonate chemistry and ocean acidification. Nature 476(7358):80–83

Beck MW, Heck KL, Able KW, Childers DL, Eggleston DB, Gillanders BM, Halpern B, Hays CG, Hoshino K, Minello TJ, Orth RJ, Sheridan PF, Weinstein MR (2001) The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. Bioscience 51(8):633–641. doi:10.1641/0006-3568(2001)051[0633:ticamo]2.0.co;2

Behrenfeld MJ, O'Malley RT, Siegel DA, McClain CR, Sarmiento JL, Feldman GC, Milligan AJ, Falkowski PG, Letelier RM, Boss ES (2006) Climate-driven trends in contemporary ocean productivity. Nature 444(7120):752–755. http://www.nature.com/nature/journal/v444/n7120/suppinfo/nature05317_S1.html

Bertness MD, Bruno JF, Silliman BR, Stachowiz JJ (2014) Marine community ecology and conservation. Sinauer Associates, Sunderland, MA

Block BA, Jonsen ID, Jorgensen SJ, Winship AJ, Shaffer SA, Bograd SJ, Hazen EL, Foley DG, Breed GA, Harrison AL, Ganong JE, Swithenbank A, Castleton M, Dewar H, Mate BR, Shillinger GL, Schaefer KM, Benson SR, Weise MJ, Henry RW, Costa DP (2011) Tracking apex marine predator movements in a dynamic ocean. Nature 475(7354):86–90. doi:10.1038/nature10082

Boyce DG, Worm B (2015) Patterns and ecological implications of historical marine phytoplankton change. Mar Ecol Prog Ser 534:251–272. doi:10.3354/meps11411

Boyce DG, Frank KT, Leggett WC (2015) From mice to elephants: overturning the 'one size fits all' paradigm in marine plankton food chains. Ecol Lett 18(6):504–515. doi:10.1111/ele.12434

de Boyer Montégut C, Madec G, Fischer AS, Lazar A, Iudicone D (2004) Mixed layer depth over the global ocean: an examination of profile data and a profile-based climatology. J Geophys Res Oceans 109(C12). doi:10.1029/2004JC002378

Broecker WS, Clark E (2009) Ratio of coccolith $CaCO_3$ to foraminifera $CaCO_3$ in late Holocene deep sea sediments. Paleoceanography 24(3). doi:10.1029/2009PA001731

Broecker WS, Peng HT (1982) Tracers in the Sea Eldigio Press. Palisades, New York

Bruno J, Bertness MD (2001) Positive interactions, facilitations and foundation species. In: Bertness MD, Gaines SD, Hay ME (eds) Marine community ecology. Sinauer Associates, Sunderland, MA

Chassot E, Bonhommeau S, Dulvy NK, Mélin F, Watson R, Gascuel D, Le Pape O (2010) Global marine primary production constrains fisheries catches. Ecol Lett 13(4):495–505. doi:10.1111/j.1461-0248.2010.01443.x

Christie H, Norderhaug KM, Fredriksen S (2009) Macrophytes as habitat for fauna. Mar Ecol Prog Ser 396:221–233. doi:10.3354/meps08351

Colman J (1940) On the faunas inhabiting intertidal seaweeds. J Mar Biol Assoc U K 24(01):129–183. doi:10.1017/S0025315400054503

Costanza R, dArge R, deGroot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, Oneill RV, Paruelo J, Raskin RG, Sutton P, vandenBelt M (1997) The value of the world's ecosystem services and natural capital. Nature 387(6630):253–260. doi:10.1038/387253a0

Cressey D (2016) Coral crisis: great barrier reef bleaching is "the worst we've ever seen". Nat News. doi:10.1038/nature.2016.19747

Day JW, Hall CAS, Kemp WM, Yanez-Arancibia A (1989) Estuarine ecology. John Wiley & Sons, Inc., New York, Chichester, Brisbane, Toronto, Singapore

Dayton PK (1985) Ecology of kelp communities. Annu Rev Ecol Syst 16:215–245. doi:10.1146/annurev.es.16.110185.001243

Duarte CM, Chiscano CL (1999) Seagrass biomass and production: a reassessment. Aquat Bot 65(1–4):159–174. doi:10.1016/s0304-3770(99)00038-8

Ducklow HW, Steinberg DK, Buesseler KO (2001) Upper ocean carbon export and the biological pump. Oceanography 14(4):50–58

Edwards KF, Litchmann E (2014) Phytoplankton communities. In: Bertness MD, Bruno JF, Silliman BR, Stachowicz JJ (eds) Marine community ecology and conservation. Sinauer Associates, Inc., Sunderland, MA, pp 365–382

Edwards KF, Thomas MK, Klausmeier CA, Litchman E (2012) Allometric scaling and taxonomic variation in nutrient utilization traits and maximum growth rate of phytoplankton. Limnol Oceanogr 57(2):554–566. doi:10.4319/lo.2012.57.2.0554

Eriksson BK, Ljunggren L, Sandstrom A, Johansson G, Mattila J, Rubach A, Raberg S, Snickars M (2009) Declines in predatory fish promote bloom-forming macroalgae. Ecol Appl 19(8):1975–1988. doi:10.1890/08-0964.1

Falkowski PG, Barber RT, Smetacek V (1998) Biogeochemical controls and feedbacks on ocean primary production. Science 281(5374):200–206. doi:10.1126/science.281.5374.200

Field CB, Behrenfeld MJ, Randerson JT, Falkowski P (1998) Primary production of the biosphere: integrating terrestrial and oceanic components. Science 281(5374):237–240. doi:10.1126/science.281.5374.237

Fisher JAD, Frank KT (2014) Pelagic communities. In: Bertness MD, Bruno JF, Silliman BR, Stacowicz JJ (eds) Marine community ecology and conservation. Sinauer Associates, Inc., Sunderland, MA, pp 337–363

Fonseca MS, Cahalan JA (1992) A preliminary evaluation of wave attenuation by 4 species of seagrass. Estuar Coast Shelf Sci 35(6):565–576. doi:10.1016/s0272-7714(05)80039-3

Gage JD, Tyler PA (1991) Deep-sea biology: a natural history of organisms at the deep-sea floor, Cambridge University Press, Cambridge. doi:10.1017/S0025315400053339

Graham MH (2004) Effects of local deforestation on the diversity and structure of Southern California giant kelp forest food webs. Ecosystems 7(4):341–357. doi:10.1007/s10021-003-0245-6

Gruber N, Sarmiento JL (1997) Global patterns of marine nitrogen fixation and denitrification. Glob Biogeochem Cycles 11:235–266

Harrold C, Light K, Lisin S (1998) Organic enrichment of submarine-canyon and continental-shelf benthic communities by macroalgal drift imported from nearshore kelp forests. Limnol Oceanogr 43(4):669–678

Hatcher BG (1988) Coral reef primary productivity – a beggar's banquet. Trends Ecol Evol 3(5):106–111. doi:10.1016/0169-5347(88)90117-6

Hays GC (2003) A review of the adaptive significance and ecosystem consequences of zooplankton diel vertical migrations. Hydrobiologia 503(1):163–170. doi:10.1023/B:HYDR.0000008476.23617.b0

Heck KL, Wetstone GS (1977) Habitat complexity and invertebrate species richness and abundance in tropical Seagrass meadows. J Biogeogr 4(2):135–142. doi:10.2307/3038158
Herring P (2002) The Biology of the Deep Ocean. Oxford University Press, New York
Hildrew AG, Rafaelli DG, Edmonds-Brown R (2007) Body size: the structure and function of aquatic ecosystems. Cambridge University Press, Cambridge
Hoegh-Guldberg O (1999) Climate change, coral bleaching and the future of the world's coral reefs. Mar Freshw Res 50(8):839–866. doi:10.1071/mf99078
Hoegh-Guldberg O, Mumby PJ, Hooten AJ, Steneck RS, Greenfield P, Gomez E, Harvell CD, Sale PF, Edwards AJ, Caldeira K, Knowlton N, Eakin CM, Iglesias-Prieto R, Muthiga N, Bradbury RH, Dubi A, Hatziolos ME (2007) Coral reefs under rapid climate change and ocean acidification. Science 318(5857):1737–1742. doi:10.1126/science.1152509
Hofmann M, Worm B, Rahmstorf S, Schellnhuber HJ (2011) Declining ocean chlorophyll under unabated anthropogenic CO_2 emissions. Environ Res Lett 6:1–8
Hughes TP, Baird AH, Bellwood DR, Card M, Connolly SR, Folke C, Grosberg R, Hoegh-Guldberg O, Jackson JBC, Kleypas J, Lough JM, Marshall P, Nystrom M, Palumbi SR, Pandolfi JM, Rosen B, Roughgarden J (2003) Climate change, human impacts, and the resilience of coral reefs. Science 301(5635):929–933. doi:10.1126/science.1085046
Hughes TP, Graham NAJ, Jackson JBC, Mumby PJ, Steneck RS (2010) Rising to the challenge of sustaining coral reef resilience. Trends Ecol Evol 25(11):633–642. doi:10.1016/j.tree.2010.07.011
Hunter JR, Alheit J (1995) International GLOBEC small pelagic fishes and climate change program. GLOBEC report no. 8:72p
Irigoien X, Klevjer TA, Røstad A, Martinez U, Boyra G, Acuna JL, Bode A, Echevarria F, Gonzalez-Gordillo JI, Hernandez-Leon S, Agusti S, Aksnes DL, Duarte CM, Kaartvedt S (2014) Large mesopelagic fishes biomass and trophic efficiency in the open ocean. Nat Commun 5:3271
Jackson JB, Kirby MX, Berger WH, Bjorndal KA, Botsford LW, Bourque BJ, Bradbury RH, Cooke R, Erlandson J, Estes JA (2001) Historical overfishing and the recent collapse of coastal ecosystems. Science 293(5530):629–637
Kaiser MJ, Attrill MJ, Jennings S, Thomas DN, Barnes AKA, Brierley DKA, Hiddink JG, Kaartokallio H, Polunin NVC, Raffaelli DG (2011) Marine ecology: processes, systems, impacts, 2nd edn. Oxford University Press, New York
Les DH, Cleland MA, Waycott M (1997) Phylogenetic studies in alismatidae. II: Evolution of marine angiosperms (seagrasses) and hydrophily. Syst Bot 22(3):443–463. doi:10.2307/2419820
Litchman E (2007) Resource competition and the ecological success of phytoplankton. In: Falkowski PG, Knoll AH (eds) Evolution of primary producers in the sea. Elsevier, Boston, MA, pp 351–375
Longhurst A (1998) Ecological geography of the sea. Academic, San Diego, CA
Lüning K (1985) Meeresbotanik. Thieme, Stuttgart
Mann K (2000) Ecology of coastal waters with implications for management, 2nd edn. Blackwell Science, Malden, MA
Martins GM, Hawkins SJ, Thompson RC, Jenkins SR (2007) Community structure and functioning in intertidal rock pools: effects of pool size and shore height at different successional stages. Mar Ecol Prog Ser 329:43–55. doi:10.3354/meps329043
Metaxas A, Scheibling RE (1993) Community structure and organization of tidepools. Mar Ecol Prog Ser 98(1–2):187–198. doi:10.3354/meps098187
Muus BJ, Nielsen JG (1999) Die Meeresfische Europas. Kosmos Verlag, Stuttgart
Nelson DM, Treguer P, Brzezinski MA, Leynaert A, Queguiner B (1995) Production and dissolution of biogenic silica in the ocean: revised global estimates, comparison with regional data and relationship to biogenic sedimentation. Glob Biogeochem Cycles 9(3):359–372. doi:10.1029/95gb01070
Norderhaug KN, Christie H, Fossa JH, Fredriksen S (2005) Fish-macrofauna interactions in a kelp (Laminaria hyperborea) forest. J Mar Biol Assoc U K 85(5):1279–1286. doi:10.1017/s0025315405012439
Orth RJ, Carruthers TJB, Dennison WC, Duarte CM, Fourqurean JW, Heck KL Jr, Hughes AR, Kendrick GA, Kenworthy WJ, Olyarnik S, Short FT, Waycott M, Williams

SL (2006) A global crisis for seagrass ecosystems. Bioscience 56(12):987–996. doi:10.1641/0006-3568(2006)56[987:agcfse]2.0.co;2
Partensky F, Hess WR, Vaulot D (1999) *Prochlorococcus*, a marine photosynthetic procaryote of global significance. Microbiol Mol Biol Rev 63:106–127
Pearre S (2003) Eat and run? The hunger/satiation hypothesis in vertical migration: history, evidence and consequences. Biol Rev 78(1):1–79. doi:10.1017/s146479310200595x
Polovina JJ, Woodworth PA (2012) Declines in phytoplankton cell size in the subtropical oceans estimated from satellite remotely-sensed temperature and chlorophyll, 1998–2007. Deep-Sea Res Part II Top Stud Oceanogr 77–80:82–88. doi:10.1016/j.dsr2.2012.04.006
Polovina JJ, Howell EA, Abecassis M (2008) Ocean's least productive waters are expanding. Geophys Res Lett 35:L03618. doi:10.1029/2007GL031745
Pomeroy LR (1974) The oceans food-web, a changing paradigm. Bioscience 24:499–504
Pomeroy LR, PJl W, Azam F, Hobbie JE (2007) The microbial loop. Oceanography 20(2):28–33. doi:10.5670/oceanog.2007.45
Purcell EM (1977) Life at low Reynold numbers. Am J Phys 45:3–11
Ramus J (1992) Productivity of seaweeds. In: Falkowski PG, Woodhead AD, Vivirito K (eds) Primary productivity and biogeochemical cycles in the sea. Springer US, Boston, MA, pp 239–255. doi:10.1007/978-1-4899-0762-2_13
Raven JA (1998) The twelth Transley lecture. Small is beautiful: the picophytoplankton. Funct Ecol 12:503–513
Redfield AC (1958) The biological control of chemical factors in the environment. Am Sci 46(46):205–221
Reusch TBH, Ehlers A, Hammerli A, Worm B (2005) Ecosystem recovery after climatic extremes enhanced by genotypic diversity. Proc Natl Acad Sci U S A 102(8):2826–2831. doi:10.1073/pnas.0500008102
Richardson AJ, Bakun A, Hays GC, Gibbons MJ (2009) The jellyfish joyride: causes, consequences and management responses to a more gelatinous future. Trends Ecol Evol 24(6):312–322. doi:10.1016/j.tree.2009.01.010
Robertson AI, Duke NC (1987) Mangroves as nursery sites – comparisons of the abundance and species composition of fish and crustaceans in mangroves and other nearshore habitats in tropical Australia. Mar Biol 96(2):193–205. doi:10.1007/bf00427019
Roman J, Estes JA, Morissette L, Smith C, Costa D, McCarthy J, Nation JB, Nicol S, Pershing A, Smetacek V (2014) Whales as marine ecosystem engineers. Front Ecol Environ 12(7):377–385. doi:10.1890/130220
Rönnbäck P, Kautsky N, Pihl L, Troell M, Soerqvist T, Wennhage H (2007) Ecosystem goods and services from Swedish coastal habitats: identification, valuation, and implications of ecosystem shifts. Ambio 36(7):534–544. doi:10.1579/0044-7447(2007)36[534:egasfs]2.0.co;2
Ryther JH (1969) Photosynthesis and fish production in the sea. Science 166(3901):72–76. doi:10.1126/science.166.3901.72
Sale PF (2008) Management of coral reefs: where we have gone wrong and what we can do about it. Mar Pollut Bull 56(5):805–809. doi:10.1016/j.marpolbul.2008.04.009
Salvanes AGV, Kristoffersen JB (2001) Mesopelagic fishes. In: Steele J (ed) Encyclopedia of ocean sciences. Academic, Oxford, pp 1711–1717. doi:10.1006/rwos.2001.0012
Sanders R, Henson SA, Koski M, De La Rocha CL, Painter SC, Poulton AJ, Riley J, Salihoglu B, Visser A, Yool A, Bellerby R, Martin AP (2014) The biological carbon pump in the North Atlantic. Prog Oceanogr 129(part B):200–218. doi:10.1016/j.pocean.2014.05.005
Sandin SA, Smith JE, DeMartini EE, Dinsdale EA, Donner SD, Friedlander AM, Konotchick T, Malay M, Maragos JE, Obura D, Pantos O, Paulay G, Richie M, Rohwer F, Schroeder RE, Walsh S, Jackson JBC, Knowlton N, Sala E (2008) Baselines and degradation of coral reefs in the northern Line Islands. PLoS One 3(2):e1548. doi:10.1371/journal.pone.0001548
Sarmiento JL, Gruber N (2006) Ocean biogeochemical dynamics. Princeton University Press, Princeton, NJ
Smetacek V (1999) Diatoms and the ocean carbon cycle. Protist 150:25–32

Smith CR, Demopoulos AWJ (2003) Ecology of the deep Pacific Ocean floor. In: Tyler PA (ed) Ecosystems of the deep oceans. Elsevier, Amsterdam

Smith CR, Drazen J, Mincks SL (2006) Deep-sea biodiversity and biogeography: perspectives from the abyss. Paper presented at the international seabed authority seamounts workshop

Smith CR, Levin LA, Koslow JA, Tyler PA, Glover AG (2008) The near future of the deep seafloor ecosystems. In: Polunin N (ed) Aquatic ecosystems : trends and global prospects. Cambridge University Press, Cambridge, UK; New York, pp 334–349

Sommer U (1998) Biologische Meereskunde. Springer, Berlin, Heidelberg

Sommer U, Stibor H, Katechakis A, Sommer F, Hansen T (2002) Pelagic food web configurations at different levels of nutrient richness and their implications for the ratio fish production: primary production. Hydrobiologia 484(1–3):11–20. doi:10.1023/a:1021340601986

Steneck RS, Leland A, McNaught DC, Vavrinec J (2013) Ecosystem flips, locks, and feedbacks: the lasting effects of fisheries on Maine's kelp forest ecosystem. Bull Mar Sci 89(1):31–55. doi:10.5343/bms.2011.1148

Stibor H, Vadstein O, Diehl S, Gelzleichter A, Hansen T, Hantzsche F, Katechakis A, Lippert B, Løseth K, Peters C, Roederer W, Sandow M, Sundt-Hansen L, Olsen Y (2004) Copepods act as a switch between alternative trophic cascades in marine pelagic food webs. Ecol Lett 7(4):321–328. doi:10.1111/j.1461-0248.2004.00580.x

Stoecker DK (1999) Mixotrophy among dinoflagellates. J Eukaryot Microbiol 46(4):397–401. doi:10.1111/j.1550-7408.1999.tb04619.x

Tardent P (1993) Meeresbiologie – Eine Einführung. Georg Thieme Verlag, Stuttgart

UNEP – United Nations Environment Program (2006) Marine and coastal ecosystems and human well-being: a synthesis report based on the findings of the Millennium Ecosystem Assessment

Valiela I, Bowen JL, York JK (2001) Mangrove forests: one of the world's threatened major tropical environments. Bioscience 51(10):807–815. doi:10.1641/0006-3568(2001)051[0807:mfootw]2.0.co;2

Van Dover C (2000) The ecology of deep-sea hydrothermal vents. Princeton University Press, Princeton, NJ

Volk T, Hoffert MI (1985) Ocean carbon pumps: analysis of relative strengths and efficiencies in ocean-driven atmospheric CO_2 changes. In: Sundquist ET, Broecker WS (eds) The carbon cycle and atmospheric CO_2: natural variations archean to present. American Geophysical Union, Washington, DC, pp 99–110. doi:10.1029/GM032p0099

Ware DM, Thomson RE (2005) Bottom-up ecosystem trophic dynamics determine fish production in the Northeast Pacific. Science 308(5726):1280–1284. doi:10.1126/science.1109049

Wernberg T, Russell BD, Thomsen MS, Gurgel CFD, Bradshaw CJA, Poloczanska ES, Connell SD (2011) Seaweed communities in retreat from ocean warming. Curr Biol 21(21):1828–1832. doi:10.1016/j.cub.2011.09.028

Werner FJ, Graiff A, Matthiessen B (2016) Even moderate nutrient enrichment negatively adds up to global climate change effects on a habitat-forming seaweed system. Limnol Oceanogr. doi:10.1002/lno.10342

Yamaguchi A, Watanabe Y, Ishida H, Harimoto T, Furusawa K, Suzuki S, Ishizaka J, Ikeda T, Takahashi MM (2002) Community and trophic structures of pelagic copepods down to greater depths in the western subarctic Pacific (WEST-COSMIC). Deep-Sea Res I Oceanogr Res Pap 49(6):1007–1025. doi:10.1016/S0967-0637(02)00008-0

Chapter 3
Marine Ecosystem Services

Markus Salomon and Henriette Dahms

Abstract Marine ecosystems deliver a number of goods and services, such as food, recreation areas, raw materials or active substances for medicine, which are important to fulfill basic needs and to support the well-being of humans. The concept of ecosystem services is useful to get a better understanding of the benefits humans obtain from marine ecosystems and to improve their communication. There have been several attempts to refine ecosystem services categories in order to establish a common classification system which could simplify the incorporation of ecosystem services into everyday policy-decisions-making and economic accounting systems. The concept of ecosystem services plays an important role in the evaluation of costs and benefits that are associated with the protection of natural capital or ecosystems. But the valuation of natural capital has limitations and pitfalls. Besides the monetary value of marine ecosystem services there are also strong non-economic reasons to protect marine biodiversity from threats from anthropogenic pressures and to preserve it for current and future generations.

Keywords Marine ecosystem services • Millennium Ecosystem Assessment • The Economics of Ecosystem and Biodiversity (TEEB) • Carbon sequestration • Fishing resources • Maritime tourism • Offshore oil and gas exploitation

3.1 Introduction

Oceans and seas are an important part of the ecosphere. They are closely interlinked with the atmosphere and the global climate system. Oceans and seas deliver a number of different goods and services which are essential to provide basic needs and to support livelihoods and the well-being of humans (Fig. 3.1). Benefits humans obtain are for example food and recreation.

M. Salomon (✉) • H. Dahms
German Advisory Council on the Environment, Berlin, Germany
e-mail: markus.salomon@umweltrat.de; henriette.dahms@umweltrat.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_3

Fig. 3.1 Important marine ecosystem services. Based on Rogers et al. (2014), TEEB (2010) and Millennium Ecosystem Assessment Board (2005)

In the following we will illustrate different classification systems for ecosystems services (Sect. 3.2), give a short overview of important goods and services provided by marine ecosystems (Sect. 3.3) and deliver a critical appraisal of the valuation of natural capital (Sect. 3.4).

3.2 Categorization

The natural capital of oceans and seas can be divided into an abiotic and a biotic component (EEA 2015). The abiotic component comprises, among other things, raw materials, transportation ways, and energy. The biotic component directly supports livelihood of human beings. A part of the natural capital is renewable, and its availability, such as fish for food, is often critical for people.

The benefits humans obtain from ecosystems are called ecosystem services. This concept is not new, but it was popularized by the 2005 Millennium Ecosystem Assessment (MA) which was initiated by the United Nations (Millennium Ecosystem Assessment Board 2005). The MA divided ecosystem services into four different categories:

1. provisioning services: goods and services with a clear monetary value such as food and raw materials,
2. regulating services: for example regulation of climate and control of local rain fall,
3. cultural services: like recreation and leisure, aesthetic beauty or spiritual benefits,
4. supporting services: are not directly used by people but are essential for the ecosystems, like photosynthesis, sediment formation or nutrient cycling and needed to maintain other services.

Recently, there have been several attempts to refine ecosystem services categories in order to establish a common classification system (e.g. TEEB and CICES). Still the systems differ in some details (United States Environmental Protection Agency 2014).

In principle, the international initiative "The Economics of Ecosystem and Biodiversity" (TEEB) follows a similar definition and classification of ecosystem services compared to the MA approach and refined the MA definition in some details (TEEB 2010). One difference is for example that "habitats for species" and "maintenance of genetic diversity" are categorized as supporting services. TEEB's primary intention is to put the ecosystem services approach into practice by developing specific concepts and launching reports in which examples of valuation are collected and elements of a biodiversity or ecosystem valuation framework are identified. The global TEEB reports inspired a number of studies around the world which identify ways to integrate ecosystem services into national policies (UNEP TEEB Office n.d.).

The Common International Classification of Ecosystem Services (CICES) from 2013 is another approach (Maes et al. 2014). CICES defines ecosystem services as those services, which directly contribute to the well-being of human beings. Therefore only the outputs or products from ecosystems people directly use are integrated into the CICIES typology. Only biota and its interaction with abiotic constituents (such as absorption of CO_2) belongs to these benefits, not the abiotic output such as salt and gravel. And in contrast to the MA approach ecosystem services are categorized into the following three instead of four categories: provisioning services, regulation and maintenance services as well as cultural services.

The importance of ecosystem services was also emphasized by the establishment of the "Intergovernmental Platform on Biodiversity and Ecosystem Services" (IPBES) in 2012. Its task is to collect, summarize and evaluate information and knowledge generated by different institutions for scientists and policy makers (IPBES Secretariat 2016).

3.3 Important Goods and Services

The abiotic part of the natural capital of oceans and seas can play a role in supporting the livelihood of humans but is independent of the state of the marine ecosystem. One example is the importance of seas and oceans for global merchandise trade, since they provide the highways for maritime transport. The evolution of the global trade system was highly dependent on the development of maritime shipping. About 90% of today's global trade is done by sea (IMO 2012; Simcock, Chap. 6). But maritime shipping is, with some minor exceptions, not threatened by the pollution of seas and oceans.

Sediments from the seabed are also considered part of the abiotic constituent of the marine capital. They are a relevant source for inert raw materials such as sand and gravel which are needed for all kinds of construction work (Vogt et al., Chap. 10). To satisfy the growing demand for energy, gas and oil are also extracted from deposits under the seabed. Today, about 37% of oil and 28% of gas are produced offshore and this share is increasing (Bücker et al. 2014; Patin, Chap. 8). At the same time, there is a tendency that extraction activities are moving from shallow to deeper waters. In addition, the sea floor of the continental shelf and the deep sea accommodate a number of valuable metals, among them scarce metals such as germanium and antimony. These metals can for instance be found in manganese nodules, cobalt crusts and massive sulphides (Weaver et al., Chap. 11).

Another example for an abiotic natural capital is the oceans' role in climate regulation. The exchange of heat between water masses of the oceans and air is a fundamental process influencing the global climate system. The El-Nino phenomenon, an oscillation of the ocean-atmosphere system in the tropical Pacific, is a well-known example that demonstrates this interaction (Philander 1990; Hummels, Chap. 1).

A rather new use of the oceans with great potential in the future is the generation of renewable energy such as offshore wind power and ocean energy (tidal currents, wave energy etc.) (Lüdeke, Chap. 9).

Biotic marine capital is of special relevance for human well-being. It is, in contrast to the abiotic component, renewable to some degree and even beyond its direct use sensitive to anthropogenic activities. The most important function of seas and oceans in this sense is the production of algae biomass, especially in form of microscopically small species (phytoplankton), from nutrients and solar radiation (Bollmann et al. 2010). The production of phytoplankton is the base of the marine food web, an essential source of food for zooplankton, which itself is the dominant food source for small fish and numerous other organisms. Moreover, this process also plays a crucial role for carbon sequestration. Not to forget that the formation of energy sources such as oil and gas was based on this process. Furthermore, agglomerations of macroalgae such as sea grass meadows and kelp forests are vital habitats and shelter from predation for juvenile fish, also commercial species.

Fish, crustaceans and mollusks captured from the sea are the most important marine provisioning service. Fish is a highly valuable natural protein source and provides essential nutrients, vitamins and omegy-3 fatty acids. Approximately 87% of global fishery production stems from marine waters (Kraus and Diekmann, Chap. 4; Wilding et al., Chap. 5) (FAO 2014). Fisheries and mariculture are important for food security and creates millions of jobs especially in coastal areas. Fish are not only exploited for human consumption, but also for the use as feed for fish farming. Beside fish, crustacean and mollusks, algae are also directly consumed by humans. Marine macroalgae are also harvested for their ingredients. Alginate is a well-known product derived from seaweed. Worldwide, around 25,000 tonnes of alginate are extracted from kelps every year. They are used in bulking, gelling and stabilizing processes in food, pharmaceutical and textile industries (Bixler and Porse 2011; Smale et al. 2013). A rather new idea is to use marine algae as a resource for biofuels.

Biological materials from the sea such as corals or seashells are also used for ornaments and decoration. The utilization of natural products from the marine environment for cosmetics, antifoulings or pharmaceuticals is a rather young sector of maritime activities (Molinski et al. 2009). Due to the broad range of environmental conditions to which a great number of marine organisms have adapted, they are an interesting resource for bioactive substances such as drugs for medicinal products. One example for this is the marine tunicate *Ecteinascidia turinata*, which is a source of the anticancer agent trabectidin (European Marine Board 2013).

The oceans' most important regulation service is carbon sequestration. Oceans are the dominant natural sink for anthropogenic carbon dioxide (CO_2). They have absorbed approximately one third of all anthropogenic CO_2-emissions over the industrial period (Khatiwala et al. 2012; Hillebrand et al., Chap. 18; Thor and Dupont, Chap. 19). Seawater is also able to absorb other substances from the air which stem predominantly from combustion processes, one example being mercury. Marine microorganisms play a crucial role in decomposing and detoxifying hazardous substances from oil spills or wastewater from land and sea based sources (Köster, Chap. 16). In a similar way, biological processes and organisms help to treat waste which is released into the sea or entered the sea via rivers (Rogers et al. 2014; Werner and Stöfen O'Brien, Chap. 23).

Another important regulating service provided by seas and oceans is the protection of coasts from erosion via sub- and intertidal vegetation such as seagrass, corals, mussels, kelp beds and mangrove forests. As an example, seagrass meadows play an essential role for the attenuation of waves, enhanced sedimentation and, due to their ability to stabilize sediments, the prevention of erosion (Christianen et al. 2013).

A prominent example for cultural services is the esthetic beauty of the sea; this includes the seascape and the marine life. Opportunities for recreation and leisure such as swimming, scuba diving and relaxing at the beach, are a special benefit for the mental and physical health of residents and tourists. This is especially relevant for the tourism sector, which has become the predominant economic sector in many coastal areas, providing jobs and income (Simcock, Chap. 17). Cultural services can also be non-use values. One examples are whales, to which humans are attached without having the possibility to experience their habitats. Furthermore, seas and oceans contribute to education, research and learning. Marine research is quite vital to improve our understanding on ecosystem functioning, origin of life and carbon cycling in the context of climate change.

Supporting services are services which have no direct benefit for humans, which is why they are excluded from the CICES classification system, but are essential for maintaining the ecosystems themselves. One example is photosynthesis. This biochemical process is the base for nearly all life in oceans and seas (see above). In a similar way marine ecosystems are dependent on the cycling of nutrition.

3.4 Valuation of Marine Ecosystem Services

In many cases, cost-benefit analyses are requested before protection measures for marine ecosystems will be established. The biggest challenge in this context is to determine the value of the benefits of these measures, including non-monetary values.

An important intention of valuing ecosystem services is to deliver strong arguments for the conservation of natural resources and the environment. Often, humans do not take the complete value of ecosystems into account in their (economic) decision-making processes. To estimate the "real" or more realistic value of ecosystem services can help to improve the decision-making and improve the management of our natural resources. According to Costanza et al. (2014) the value of ecosystem services is the relative contribution of ecosystems to sustainable human well-being. In their opinion, all decisions that lead to trade-offs contain valuation, either implicitly or explicitly.

Valuation of environment pretty much follows the concept of total economic value (TEV) (Dziegielewska 2013; van Doorn et al. 2015). The TEV approach distinguishes between use and non-use values and also comprises indirect and nonmaterial values. Use values are differentiated in direct use values, such as fish consumed by humans, and indirect uses, such as the function of ecosystems (e.g. carbon sequestration). Non-use values are the existence value that people attach, for instance, to marine creatures like whales without experiencing their habitat and the bequest value. The latter one is the attributed value from ensuring that certain goods and services will be preserved for future generations.

There exists a number of economic methods or techniques to valuate ecosystem services (World Environment Center Europe e.V. 2014; DEFRA 2007). This is rather simple for goods and services which are exchanged on a market and accordingly have a market price. In absence of markets indirect techniques can deliver approximate values. So called revealed preference approaches take into account other information on individual choices from existing complementary markets such as travel cost, hedonic pricing and averting behavior. For non-use values, a stated preference method can be used with the help of carefully structured surveys (choice analyses). One of the shortcomings of stated preference techniques is that the respondents are not always able to understand the total impact an ecosystem service might have on their well-being (DEFRA 2007).

In recent years, an increasing number of research on the measuring and valuing of ecosystem services has been published (Seppelt et al. 2011; EEA 2011). A very early and prominent study on this issue is the one by Costanza et al. from 1997 (Costanza et al. 1997). In a follow-up, the authors estimated the global value of ecosystem services to be 145 trillion US dollars per annum (in 2007 US dollars) for the year 2011. The share of marine ecosystem services was 40% (Costanza et al. 2014).

Rogers et al. (2014) recently investigated the ecosystem services of high-seas. They identified 15 different types of ecosystem services. Due to insufficient scientific information only a few of them could be accurately valued. An evaluation was possible for fisheries and carbon storage, both important ecosystem services. The estimated value of carbon storage by high-sea ecosystems ranged between 74 and 222 billion US dollars, the value of fisheries was estimated at 16 billion US dollars. It has to be kept in mind that only a small share of fish (around 12% of total catch) is caught in the high seas, the rest in coastal waters.

Although the concept of natural capital is well established, the idea to monetarize natural goods and services is still controversial. One argument is the huge complexity of correctly valuing ecosystem services. Some ecosystem services, such as fish, have a market value. Others are public goods and do not have a market. To define a value for services without any market is a special challenge. The dependencies of different species on each other are often not known or poorly understood. A typical prey-predator relation is normally simple to understand. But what, for example, is the value of a *Gammarus* species (small crustacean) feeding on epiphytes that are growing on kelps? These epiphyts might, under special circumstances, be a threat to the algae, which themselves provide habitat and shelter for juvenile commercial fish species.

Another argument against valuation is that natural capital is vital for the survival of human beings and irreplaceable and so of infinite value (van Doorn et al. 2015).

Furthermore, from a more ecocentric point of view the main failure of the concept is that it does not take into account the intrinsic value of an organism, species or ecosystem. Intrinsic value is the value of something in and for itself, irrespective of its utility for someone else, particularly human beings (Millennium Ecosystem Assessment Board 2005).

3.5 Conclusions

Oceans and seas provide important ecosystem services. To maintain the marine ecosystems is, therefore, essential for human beings. The degradation of the marine capital has already had and will have a direct impact on our well-being, especially in the long term. There are a number of indications that we do not use the natural capital in a sustainable way (Chaps. 4 to 25 of this book). Accordingly, it is required to better introduce the value of marine ecosystems in our decision-making processes and keep its use within the ecosystem's carrying capacity (see also EEA 2015). This is of special importance for the biotic part of the seas' natural capital which is, at least in parts, renewable. These goods and services, which are essential to fulfill basic human needs, also need to be protected from anthropogenic activities which have no intention to make use of the marine resources such as landbased industries and agriculture.

The concept of ecosystem services is very helpful to make the value of ecosystems or biodiversity visible and communicate it. It is important for us to improve our understanding of the ways our daily life benefit and rely on intact ecosystems. A common classification system for ecosystem services could simplify their incorporation into everyday decision-making processes and economic accounting systems. But the valuation of natural capital has its limitations and pitfalls. One reason therefore is, that it is not possible to find a true market value for all benefits, especially indirect ones, and impossible for the ones which will be relevant in the future. Finally, it has to keep in mind that there are not only important economic but also societal, ethical and religious reasons to preserve the marine biodiversity for current and future generations.

References

Bixler HJ, Porse H (2011) A decade of change in the seaweed hydrocolloids industry. J Appl Phycol 23:321–335

Bollmann M, Bosch T, Colijn F, Ebinghaus R, Froese R, Güssow K, Khalilian S, Krastel S, Körtzinger A, Langenbuch M, Latif M, Matthiessen B, Melzner F, Oschlies A, Petersen S, Proelß A, Quaas M, Reichenbach J, Requate T, Reusch T, Rosenstiel P, Schmidt JO, Schrottke K, Sichelschmidt H, Siebert U, Soltwedel R, Sommer U, Stattegger K, Sterr H, Sturm R, Treude T, Vafeidis A, van Bernem C, van Beusekom J, Voss R, Visbeck M, Wahl M, Wallmann K, Weinberger F (2010) World Ocean Review 1: Living with the oceans. Maribus, Hamburg

Bücker C, Jenisch U, Lutter S, Matz-Lück N, Messner J, Petersen S, Rüpke LH, Schwarz-Schampera U, Wallmann K, Berndt C, Bialas J, Fuchs J (2014) World Ocean Review: Living with the oceans. 3 Marine resources – opportunities and risks. Maribus, Hamburg

Christianen MJ, van Belzen J, Herman PM, van Katwijk MM, Lamers LP, van Leent PJ, Bouma TJ (2013) Low-canopy seagrass beds still provide important coastal protection services. PLoS One 8(5):e62413. doi:10.1371/journal.pone.0062413

Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P, van den Belt M (1997) The value of the world's ecosystem services and natural capital. Nature 387(6630):253–260

Costanza R, de Groot R, Sutton P, van der Ploeg S, Anderson SJ, Kubiszewski I, Farber S, Turner RK (2014) Changes in the global value of ecosystem services. Glob Environ Change 26:152–158. doi:10.1016/j.Gloenvcha.2014.04.002

DEFRA (Department for Environment Food and Rural Affairs) (2007) An introductory guide to valuing ecosystem services. DEFRA, London

van Doorn E, Friedland R, Jenisch U, Kronfeld-Goharani U, Lutter S, Ott K, Quaas M, Rehdanz K, Rickels W, Schmidt JO, Visbeck M (2015) World ocean review – living with the oceans. 4 Sustainable use of our oceans – making ideas work. Maribus, Hamburg

Dziegielewska D (2013) Total economic value. The Encyclopedia Of Earth. http://www.eoearth.org/view/article/156666. Accessed 02 Dec 2015

EEA (European Environment Agency) (2011) Common International Classification of Ecosystem Services (CICES): 2011 update. Paper prepared for discussion at the expert meeting on ecosystem accounts organised by the UNSD, the EEA and the World Bank, London, December 2011. EEA, Copenhagen

EEA (European Environment Agency) (2015) State of Europe's seas. EEA report. EEA, Copenhagen

European Marine Board (2013) Linking oceans and human health: a strategic research priority for Europe. Position paper 19 of the European Marine Board. Ostend, Belgium

FAO (Food and Agriculture Organisation of the United Nations) (2014) The state of world fisheries and aquaculture – opportunities and challenges. FAO, Rome

IMO (International Maritime Organisation) (2012) International shipping facts and figures – information resources on trade, safety, security, and the environment. Rev. edn. IMO Maritime Knowledge Centre, London

IPBES Secretariat (2016) IPBES. http://www.ipbes.net/index.php/about-ipbes. Accessed 28 Jan 2016

Khatiwala S, Tanhua T, Fletcher SM, Gerber M, Doney SC, Graven HD, Gruber N, McKinley GA, Murata A, Rios AF, Sabine CL, Sarmiento JL (2012) Global ocean storage of anthropogenic carbon. Biogeosciences 9:8931–8988

Maes J, Teller A, Erhard M, Murphy P, Paracchini ML, Barredo JI, Grizzetti B, Cardoso A, Somma F, Petersen J-E, Meiner A, Gelabert ER, Zal N, Kristensen P, Bastrup-Birk A, Biala K, Romao C, Piroddi C, Egoh B, Fiorina C, Santos F, Naruševičius V, Verboven J, Pereira H, Bengtsson J, Kremena G, Marta-Pedroso C, Snäll T, Estreguil C, San Miguel J, Braat L, Grêt-Regamey A, Perez-Soba M, Degeorges P, Beaufaron G, Lillebø A, Abdul Malak DA, Liquete C, Condé S, Moen J, Östergård H, Czúcz B, Drakou EG, Zulian G, Lavalle C (2014) Mapping and assessment of ecosystems and their services: indicators for ecosystem assessments under action 5 of the EU Biodiversity Strategy to 2020. Technical report 2014. Publications Office of the European Union, Luxembourg

Millennium Ecosystem Assessment Board (2005) Ecosystems and human well-being: synthesis. Island Press, Washington, DC

Molinski TF, Dalisay DS, Lievens SL, Saludes JP (2009) Drug development from marine natural products. Nat Rev Drug Discov 8(1):69–85

Philander SGH (1990) El Niño, La Niña and the southern oscillation. Academic, San Diego, CA

Rogers AD, Sumaila UR, Hussain SS, Baulcomb C (2014) The high seas and us – understanding the value of high-seas ecosystems. Global Ocean Commission, Oxford, UK

Seppelt R, Dormann CF, Eppink FV, Lautenbach S, Schmidt S (2011) A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead. J Appl Ecol 48(3):630–636. doi:10.1111/j.1365-2664.2010.01952.x

Smale DA, Burrows MT, Moore P, O'Connor N, Hawkins SJ (2013) Threats and knowledge gaps for ecosystem services provided by kelp forests: a northeast Atlantic perspective. Ecol Evol 3(11):4016–4038. doi:10.1002/ece3.774

TEEB (2010) The economics of ecosystems and biodiversity: mainstreaming the economics of nature: a synthesis of the approach, conclusions and recommendations of TEEB. Progress Press. http://doc.teebweb.org/wp-content/uploads/Study%20and%20Reports/Reports/Synthesis%20report/TEEB%20Synthesis%20Report%202010.pdf. Accessed 27 Nov 2015

UNEP TEEB Office (n.d.) TEEB-inspired country studies. http://www.teebweb.org/areas-of-work/teeb-country-studies-2/. Accessed 28 Jan 2016

United States Environmental Protection Agency (2014) What are ecosystem services? EPA. http://enviroatlas.epa.gov/enviroatlas/Ecosystems/index.html. Accessed 04 Sept 2015

World Environment Center Europe eV (2014) Business approaches to natural capital valuation. WEC, Munich

Part II
Impacts of Sectoral Marine Activities

Chapter 4
Impact of Fishing Activities on Marine Life

Gerd Kraus and Rabea Diekmann

Abstract Trends in global Fisheries indicate an overall decline in productivity of world fishery resources and almost 30% of fish stocks world-wide are still overfished. In Europe the amount of sustainably harvested stocks strongly increased over the last 10 years. Nonetheless, with a fast growing world population the pressure on fish stocks will remain high. As fish stocks can unfurl high productivity only in healthy marine ecosystems, it is extremely important to minimise the negative impacts of fishing on target species and communities as well as benthic ecosystems and habitats. First of all, fishing exerts mortality on target species and reduces their natural abundance. When a fishery targets more than a single species in mixed fisheries, similar responses may be observed for all species in focus. Fishing can also impact non-target as well as rare and sensitive species via unintended by-catch and has indirect effects on ecosystems and habitats via food web interactions and physical damage degrading habitat quality. In this chapter, we provide a short overview on the specific effects of fishing on target and by-catch species, communities as well as benthos and benthic habitats.

Keywords Sustainable fisheries • Fishing impacts • Benthic ecosystems • Non-target species • Fisheries management

4.1 Status of Global and European Fisheries

According to FAO (2014) todays fisheries and aquaculture deliver more than 130 million tonnes of food to the seven billion people living on the planet making up 15% of their dietary protein. Aquatic production assures the livelihoods of 10–12%

G. Kraus (✉)
Thünen-Institute of Sea Fisheries, Hamburg, Germany
e-mail: gerd.kraus@thuenen.de

R. Diekmann
Thünen-Institute of Fisheries Ecology, Hamburg, Germany

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_4

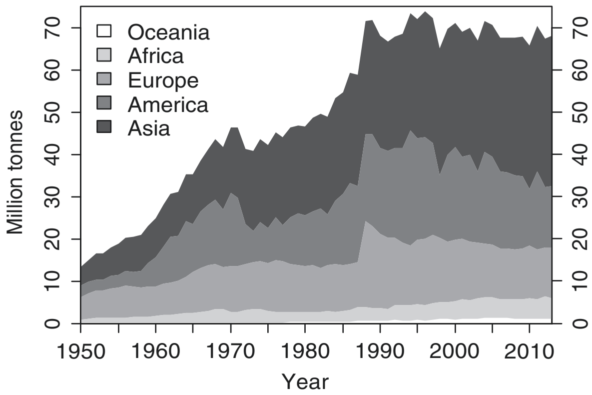


Fig. 4.1 Global marine capture (fish without invertebrates) production (in million tonnes) from 1950 to 2013 distinguishing production by continent (Source: http://www.fao.org/fishery/statistics/global-capture-production/)

of the world's population. In 2012 some 58.3 million people were engaged in the primary sector of capture fisheries and aquaculture and fish remains among the most traded food commodities worldwide representing 1% of world merchandise trade in value terms.

Global marine capture production (fish and invertebrates) fluctuated around 80 million tonnes since the mid 1980s. Recent reconstructions of global marine fisheries catches by Pauly and Zeller (2016) including catches by small scale artisanal fisheries, recreational fishers and discards indicated that this number is considerably lower than the true catches, which they estimated to have peaked at 130 million metric tonnes in 1996. Both studies revealed a slow, but steady decline of global catches since the peak in the mid 1990s, although FAO considers the situation a continuation of a more or less stable 30 year period reported previously (FAO 2014, Fig. 4.1 for marine fishes). As global fishing effort has increased by around 20% (in kilowatt days) over this period (Anticamara et al. 2011) and the global fishing fleet-contrary to the trend within Europe-has doubled (FAO 2010), there is strong indication for an overall decline in productivity of the world fishery resources.

The latest figures from FAO for 2012 suggest that 61% of the assessed stocks world-wide were harvested sustainably at or close to maximum sustainable yield levels (MSY, see Textbox 4.1), 28% were harvested unsustainably and 10% were underutilised. Given that almost 40% of the stocks could produce more yield because of non-optimal harvest, and a considerable portion of the catch is wasted due to discarding and processing loss, there appears to be scope for growth in yields, although the exact magnitude is difficult to estimate (Frid and Paramor 2012). But, as it is generally accepted that there are no major new fishing grounds to be exploited (Godfray et al. 2010) and primary production in the oceans already now constrains global fisheries catches (Chassot et al. 2010), the potential for growth is limited. Frid and Paramor (2012) estimated the potential maximum global yield to some 110 million tonnes per years, which is lower than the historic maximum catch of 130 million tonnes estimated by Pauly and Zeller (2016). As the latest IPCC projections predict an overall decline in ocean productivity under climate change (IPCC, AR5), the conservative estimate of Frid and Paramor (2012) might be even optimistic.

With the predicted world population increase to more than nine billion people by 2050, and the limited potential to increase capture fish production, the relative contribution of fisheries to global food security is set to decline. The overall pressure on fish stocks will nonetheless remain high as the global food and protein demand will continue to rise.

Textbox 4.1: Maximum Sustainable Yield (MSY)
Managing all fish stocks towards Maximum Sustainable Yield (MSY) is one of the central goals of the European Common Fisheries Policy. MSY is, theoretically, the largest yield (catch) that can be taken from a specific fish stock over an indefinite period under constant environmental conditions. A fishery that is managed according to the MSY principle adjusts the fishing mortality to a level that would lead on longer terms to a population size that is capable of producing maximum sustainable yield. As carrying capacity and environmental conditions in the ecosystem are not stable, thus affecting also the stability of the MSY biomass level, fisheries management adjusts fishing mortality to MSY levels and uses biomass trigger points for management action rather than setting fixed biomass MSY targets.

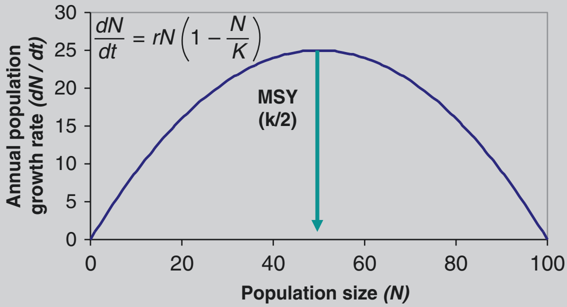


Figure Maximum sustainable yield is reflected by the peak of the annual production curve and can theoretically be obtained at a population size indicative of 0.5 times the carrying capacity K of the ecosystem. r is the intrinsic rate of population increase.

In Europe, fishing fleets have been constantly reduced over the last two decades, both, in terms of engine power and tonnage. As a consequence, large overcapacity was eliminated and the overall fishing capacity is now much more in line with fishing opportunities, thus reducing the incentive for illegal fishing operations and the pressure on policy and management to overshoot the scientific advice on annual fishing quotas. Looking at the status of Europe's fish stocks, the decline in fleet capacity has surely supported achieving the MSY management target as the percentage of stocks fished at MSY levels increased from 6% in 2004 to more than 50% of all fish stocks that underwent an analytical stock assessment in 2014 (European Commission 2015).

But as Europe's fisheries will be affected by the global developments outlined above, it will be a huge challenge for fisheries management to achieve sustainability targets, as already today management decisions are frequently driven by short term thinking, e.g. to buffer against immediate economic hardships, rather than by a long-term sustainability perspective. However, long-term sustainability is needed to keep ecosystems healthy and achieve good environmental status, which in turn is essential for commercially exploited fish stocks to unfurl high productivity and provide the high fishery yields needed for global food security.

4.2 Fishing Impacts

Already in the second half of the nineteenth century overfishing was high on the political agenda, when North Sea countries started to discuss the impact of a rapidly developing fishery on observed fluctuations in North Sea fish stocks (Smed and Ramster 2002). At local scales the fishing impact on target species was well acknowledged. However, at global scale fishery resources were considered an inexhaustible resource until well into the twentieth century, when global catches stabilised during the 1980s after a long period of steady increase (FAO 2014). Recognition of fishing impacts beyond target species on communities and the marine environment has even taken longer (see Dayton et al. 1995 for a review) and has only entered the political and societal debate, when scientists started developing implementation plans for a holistic ecosystem-based approach to fisheries management late during the 1990s (e.g. Link et al. 2002; Murawski 2000).

Nowadays, it is commonly accepted that fishing impacts the marine environment at various levels. These impacts are complex, often hard to measure and vary from one fishery to the next. First of all, fishing exerts mortality on target species and reduces their natural abundance. When a fishery targets more than a single species in mixed fisheries, similar responses may be observed for all species in focus. Fishing can also impact non-target as well as rare and sensitive species via unintended by-catch and has indirect effects on ecosystems and habitats via food web interactions and physical damage degrading habitat quality.

When poorly controlled, fisheries tend to develop excessive fishing capacity, leading to overfishing. In this case, the consequences of fishing dominate over the natural population or community development. The vulnerability of a species to overfishing however depends on behaviour and its life history characteristics, whereas the consequences for vulnerable species include intraspecific changes in population structure, growth, reproduction and genetic structure, as well as community effects on diversity, size-composition and trophic interactions (Jennings et al. 2001a). The amount of literature on the issue is massive and includes text books, book chapters and review studies on fishing impacts on benthic ecosystems and habitats (e.g. Jennings et al. 2001a; Jennings and Kaiser 1998; Kaiser and de Groot 2000), on sensitive and rare non-target species, such as elasmobranchs (e.g., Stevens et al. 2000; Dulvy et al. 2003), marine mammals (e.g., Read et al. 2006; Northridge 1984), birds (e.g., Tasker et al. 2000) or turtles (Wallace et al. 2013). Most recently, fishery induced trophic cascades have been discussed in the context of ecosystem regime-shifts (Terborgh and Estes 2010; Frank et al. 2005; Casini et al. 2008).

Here, we aim at providing a short overview on the specific effects of fishing on target and by-catch species, communities as well as benthic habitats. This summary covers a broad range of aspects, and as such cannot be comprehensive.

4.2.1 Impact of Fishing on Target Species

Estimating and projecting the impact of fishing on the population dynamics of target species is at the heart of traditional fishery science (Gulland 1977; Hilborn and Walters 1992). Vulnerability of a species to fishing depends on fishing gear, behaviour and life history characteristics. A very obvious relationship exists between mesh size of a net and the size of fish to be retained by the net. However, this simple relationship is strongly modified by morphometric characteristics of the target species (a spiny crab will behave completely different from an eel like fish), gear type and behaviour. Moreover, modern fishing gear takes advantage of behavioural aspects to reduce by-catch of unwanted species or to increase the catching efficiency.

Shoaling is a common behaviour in marine fish species to avoid predation, to increase foraging success, or for mating, but at the same time it increases efficiency of fishing operations. Small pelagic fish forming dense shoals are caught in huge quantities in seine fisheries, whereas dispersed mesopelagic species do not allow for economically viable fisheries (Jennings et al. 2001a). Several bottom-dwelling flatfishes like turbot, groupers or anglerfish are also not shoaling, but allow profitable fisheries due to their high commercial value despite generally low catch per unit effort.

Differences in life history characteristics define how well a species can resist to or recover from fishing mortality and thus have an influence on the vulnerability of a species to fishing mortality. Ecological theory suggests that long-lived, slow growing, late maturing, low fecund species would be more vulnerable to fishing compared to short-lived, fast growing, early maturing and highly fecund species due to their lower intrinsic rate of population growth (recovery potential). Consequently, high fishing intensity would favour ecosystems dominated by the latter type of species (Pauly et al. 1998). But also between populations of the same species and even within a population intensive fishing favours components that have a tendency to mature and reproduce early (Heino et al. 2002).

Observed dominant patterns in heavily fished populations are a strongly truncated size structure, a biased sex composition, a changed genetic structure as well as altered growth, maturity and spawning schedules, and sometimes lower relative fecundity reducing the overall spawning potential of the population. Depending on the vulnerability of a species to fishing, the severity of heritable and non-heritable life history responses will vary and the effects are often not independent of each other. For example, lower average size or age does affect timing and duration of the spawning season in Baltic cod (Tomkiewicz et al. 2005). Smaller cod shed fewer batches of eggs and appear later and leave the spawning grounds earlier compared to large specimens. A stock dominated by small individuals will thus have a lower reproductive potential plus a narrower window of opportunity for successful reproduction, which is a serious disadvantage in the frequently oxygen depleted Baltic Sea (Kraus et al. 2002).

Selective fishing can also change the sex ratio, either because of sexual dimorphism or when a fishery tackles aggregations, where either males or females dominate. Again Baltic cod is a good example, as the fishery tackles pre-spawning aggregations on spawning grounds. As males stay longer on the spawning grounds compared to females, they are exposed to higher fishing mortality over their lifetime, and consequently older age classes of Baltic cod are strongly dominated by females (Kraus et al. 2002, 2012). Therefore, at low population sizes females may struggle to find appropriate mating partners (Rowe et al. 2004). Also, relative fecundity is size dependent in many marine fish species with larger females displaying a higher number of eggs per unit of weight (Lambert et al. 2003, for a review see Hixon et al. 2014). Size selective fishing on hermaphrodite fish species changing sex at a specific size, can lead to local extinctions due to the complete removal of females or males. Another impact on reproductive traits has recently been shown for Northeast Arctic cod, where Opdal and Jørgensen (2015) demonstrated that the choice of spawning grounds was related to exploitation intensity.

Although life-history traits are plastic and vary in response to the environment, there is growing evidence that exploitation causes evolutionary changes in fish populations. Many life history traits like age/size at maturation and growth are heritable and will thus evolve in response to fishing (Heino et al. 2015). As fishing reduces population size, it may also reduce genetic variation, if there are not enough individuals to maintain the full range of variability (Hauser et al. 2002; Lage and Kornfield 2006). It is however difficult to differentiate between the effects of selective fishing on heritable traits and phenotypic plasticity. Sometimes phenotypic responses to fishing are compensated by genetic shifts in the population, e.g. earlier age at first maturity or increased fecundity at size compensating the loss of big, old, fecund females (Hidalgo et al. 2014; Conover et al. 2005; Jørgensen et al. 2007). Further, selection pressure towards slow growing individuals in intensively fished populations can dampen the positive effect of increased food availability on growth at low population sizes.

4.2.2 Discards and By-Catch of Non-Target Species

The probably still most comprehensive review of the by-catch and discard problem in fisheries was carried out by Alverson et al. (1994). The authors reviewed more than 800 scientific papers finally concluding that approximately 27 million metric tonnes of catches were discarded annually in commercial fisheries with generally low to very low survivability of the discarded specimens. Highest by-catch and discard rates were observed for shrimp trawl fisheries, lowest for pelagic fisheries targeting menhaden or clupeids. Figure 4.2 shows a traditional North Sea beam trawl vessel targeting brown shrimp and its typical diverse catch. Fish and other marine taxa are discarded because of regulatory (undersized fish, over quota catch, conservation requirements) or market forces (not fit for human consumption). It

Fig. 4.2 *Left*: A typical North Sea beam trawl vessel targeting brown shrimp *Crangon crangon*. *Right*: The catch composition in the North Sea brown shrimp fishery is characterised by a comparatively large amount of by-catch of non-target species and undersized shrimp

even happens that in order to maximise the profit of a fishing trip marketable fish is discarded, if more valuable catch comes in. Meanwhile this so called "high grading" is illegal on most fishing grounds world-wide including European waters, but often an effective control is missing.

Next to the ethical aspect and a waste of valuable protein, discarding adds an additional source of mortality to either already heavily exploited populations or species that are especially sensitive to additional mortality due to their longevity or low reproductive rates. As discards are rarely reported to full extend, they are not adequately accounted for in stock assessments adding uncertainty to estimates of population sizes (Borges et al. 2005).

Fisheries bycatch is also a global threat to highly migratory, long-lived marine taxa including turtles (Wallace et al. 2010, 2013), birds (Croxall et al. 2012; Lewison et al. 2012), marine mammals (Read et al. 2006), and sharks (Dulvy et al. 2003). The reason for their vulnerability resides not only in their longevity and low reproduction rates, but also because many of these species inhabit large distribution areas spanning across oceans and are thus touching various separately managed major fishing areas (Wallace et al. 2013). Reduction of unintended by-catch has been recognised as a major challenge for sustainable fisheries and non-governmental organisations and society put an increasing pressure on fisheries management to find solutions. A short outlook is provided in Sect. 4.3 "*Conclusions for ecosystem friendly fisheries*".

4.2.3 Impact of Fishing on Communities

At community level, fishing alters the structure of food webs and by this affects different aspects of biodiversity (Coll et al. 2016). High diversity supports ecosystem stability and resilience (Loreau and deMazancourt 2013), as it ensures that at any time there are species in the system that can react to altered conditions, fulfil new roles, and keep up essential ecosystem services (Jennings et al. 2001a). Spatially, biodiversity is primarily governed by biogeographic factors, but fishing modifies abundance of target species and thus influences dominance patterns. Theoretically, fishing can lead to biological extinction of species. For the marine realm this has not been described yet as economic extinction will occur first, but extirpation, the local loss of a population, has been already observed (Dulvy et al. 2003).

Typically, a heavily fished ecosystem undergoes a series of structural changes. At first, the larger individuals of the target species will diminish with the intraspecific consequences at population level described above. Larger specimens of other species tend to be reduced as well and the overall proportion of large individuals in the community will decline. Smaller species will tend to dominate. At global scale this effect has been described by Pauly et al. (1998) as "fishing down marine food webs". The state of marine ecosystems can be e.g. assessed by analysing the slopes of size spectra (Shin et al. 2005). Observed size spectra typically become steeper following intense exploitation of fishery resources. For example, size spectrum analysis in the North Sea indicated that the biomass of large fishes is around two orders of magnitude lower than expected in the absence of fisheries exploitation (Jennings and Blanchard 2004), although recently the situation has started to improve again (Engelhard et al. 2015).

Long-term consequences of high fishing intensity are persistent alterations of community composition and size spectra. Competition for prey, when e.g. small pelagic fish are targeted (e.g. Tasker et al. 2000), or the removal of top predators from the system can induce trophic cascades (Casini et al. 2008; Frank et al. 2005; Terborgh and Estes 2010). This can reduce the overall resilience of the ecosystem against future natural or human-made perturbations (Llope et al. 2011), or induce general reorganisations (Frank et al. 2005). In combination with other pressures fisheries has thus the potential to cause ecological regime-shifts (Scheffer et al. 2001; Scheffer and Carpenter 2003; Möllmann et al. 2015), which are defined as abrupt changes between contrasting persistent states (deYoung et al. 2008).

Although predation (fisheries removes predators and releases prey species from predation pressure) is generally believed to be one of the most important processes structuring marine ecosystems, empirical evidence of full top-down control in the marine realm is relatively scarce and the exact role and contribution of intensive fishing to community reorganisations and ecological regime shifts is still under debate (Möllmann et al. 2015). One reason might be that marine ecosystems are generally more connective compared to other aquatic and terrestrial ecosystems and most predator-prey relationships appear to be less tightly coupled. Conversi et al. (2015) argue that neither the concept of top-down nor bottom-up control is sufficient to explain the nature of regime shifts. They propose leaving behind the false dichotomy between biotic versus physical drivers of ecological regime shifts and rather focus on identifying mechanisms and combining processes that may cause the regime shifts or affect the resilience of an ecosystem.

4.2.4 Impacts of Fishing on Benthic Ecosystems and Habitats

Understanding fisheries effects on marine habitats and non-target species has been a topic of research for decades (Bergman and Hup 1992; Buhl-Mortensen et al. 2016; Crowder et al. 2008; de Groot 1984; Kaiser 1998; Kaiser and de Groot 2000). Generally, fisheries can have direct and indirect effects on benthic ecosystems. Indirectly the removal of fish and/or benthic species has the potential to alter the structure of the foodweb and thus ecosystem functioning. Direct impacts are usually related to the physical disturbance of the seafloor, which can change the seabed, remove organisms, cause inadvertent mortality or injury, and affect sediment biochemistry (Auster et al. 1996; Churchill 1989; Jennings and Kaiser 1998; Riemann and Hoffmann 1991; Schwinghamer et al. 1998; Thrush and Dayton 2002).

Overall, the degree and type of fisheries disturbance is dependent on a number of interacting factors. These include environmental properties such as habitat stability and the frequency of natural disturbance (Fig. 4.3), but also fishing characteristics, more specifically gear type, scale, intensity and frequency of fishing (Jennings et al. 2001a). On the level of individual fishing operations the interaction with the seafloor is determined by the gear design. Generally, commercial fishing gears can be divided into two different categories: Active gears, which are towed, and passive gears, where the target species move into or to the device. The latter encompass fish traps and pots as well as longlines, drift and set gill nets, and their impact on the seafloor is supposed to be low. Most of the active gear types are towed either in midwater, just above or in contact with the seafloor. From those the mobile bottom contacting gears, mainly otter trawls, beam trawls and dredges, are supposed to have the largest deteriorating effects on benthic ecosystems (Kaiser et al. 2006), and

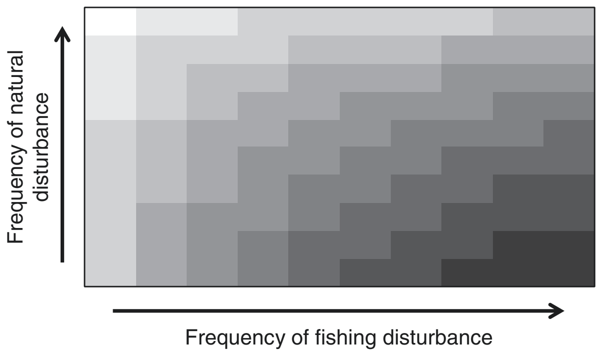


Fig. 4.3 Conceptual model of the relative impact of fishing pressure to benthic communities. The colour scale corresponds to the disturbance of benthic communities from lowest (*white*) to highest disturbance (*black*). However, the relative impact of fishing is also dependent on the degree of natural disturbance (y-axis). The latter corresponds often with sediment type and habitat stability, i.e. the highest natural disturbance is usually expected on sandy substrates, the lowest on hard substrate with e.g. boulders

in the following will deserve closer attention. These gears are deployed on every shelf sea around the world catching demersal fish and shellfish (Kaiser et al. 2000). Typically they use heavy otter boards or shoes to open the net and keeping the device close to the ground, and tickler chains, mats or groundropes to force the target species into the net. Gear design, width, weight and trawling speed determine e.g. the penetration depth and by this the footprint of fisheries on habitats (Eigaard et al. 2016). Bottom trawling can scour or flatten the seabed, or create furrows or scars (Churchill 1989; Schwinghamer et al. 1998). At the same time hydrodynamic interactions with the seafloor can increase nutrient concentrations, oxygen consumption and primary productivity (Riemann and Hoffmann 1991). The most obvious direct effect of dragging fishing gears over the seafloor is the removal of target and non-target species, and the mortality or damage of bottom living animals (Bergman and Hup 1992; Bergman and van Santbrink 2000). Consequently, a decrease of benthos biomass, size and diversity was frequently observed. In empirical studies, comparing parameters of a site before and after bottom trawling or between similar sites experiencing different levels of fishing effort, species-specific effects on density were found (Kenchington et al. 2006; Pitcher et al. 2009). Reasons for this can be first species morphology, which affects the vulnerability to trawling. Hard-shelled or vermiform organisms are e.g. considered to have a higher chance of survival than fragile species, by either escaping through the meshes or remaining un- or only slightly damaged on the seafloor (Blanchard et al. 2004; de Juan et al. 2007). Secondly, the position on or in the sediment has an influence on the vulnerability. Bergman and Hup (1992) revealed that the vertical distribution of a species in the sediment was an important factor determining survival. Even the size-dependent depth preference of e.g. *Echinocardium cordatum* was crucial, because densities of smaller individuals, which prefer upper sediment layers, decreased more significantly than larger individuals. Finally, the feeding type can influence the specific response to trawling. Numerous studies detected significant increases of motile scavengers in recently trawled areas (Collie et al. 1997; Kaiser and Spencer 1994; Rumohr and Kujawski 2000; Sparks-McConkey and Watling 2001), which were partly explained by the large amount of potential food due to discards in combination with damaged organisms on the seafloor.

These cumulative effects of trawling result in a change in the structure of benthic communities, largely favouring robust, opportunistic over fragile species and altering the age and thus size structure of populations. Consequently, a number of studies revealed functional trait shifts over gradients of trawling intensity (Jennings et al. 2001b; Hiddink et al. 2006; Tillin et al. 2006). Functional and absolute diversity is supposed to be higher in undisturbed areas, e.g. with more epifaunal sedentary suspension feeders or sessile polychaetes living in tubes (de Juan et al. 2007). In the contrary opportunistic traits dominate in benthic communities in heavily fished areas, i.e. recovery rates are high due to high fecundity, rapid growth, motility, or a scavenger feeding type. In the North Sea motorised bottom trawling has started already more than 100 years ago (Fock et al. 2014) and as expected persistent effects on benthic communities can be observed. As an example, in the early 20 century reef-like structures of the tube-building polychaete *Sabellaria spinulosa* had been common in the Dutch and German Wadden Sea. Nowadays these structures had disappeared and Riesen and Reise (1982) attributed this to the intensive bottom trawling in these areas. This indicates that small-scale experimental field studies investigating the direct effects of fishing cannot answer all questions and can miss important disturbance effects that occur at larger temporal or spatial scales. For this long-term and large-scale studies are rather needed to comply with the scale of the disturbance regime imposed by commercial fishing fleets (Kaiser et al. 2000). Historical effort data can partly overcome this shortcoming (Frid et al. 2000), but here the exact level of disturbance in the past is usually unknown and information about abundance, composition and size of species before intensive fishing began is sparse. Therefore, we still rely on comparative studies of areas exposed to different intensities of fishing (Collie et al. 1997; van Denderen et al. 2015a). Only in very recent years high resolution data of fishing effort had become available by using either the Vessel Monitoring System for fishing vessels or AIS Marine Traffic (http://www.marinetraffic.com), which enable us to give rather exact estimations of local trawling intensity (Gerritsen et al. 2013; Hintzen et al. 2010; van Denderen et al. 2015b). Building on this in combination with a biological trait approach, Rijnsdorp et al. (2016) now presented a framework for the quantitative assessment of trawling impact on the seabed and benthic ecosystem. Still, extensive knowledge about the distribution of benthic organisms and their recovery rates is necessary. Further, fishing is not the only physical disturbance of the seafloor. Next to other anthropogenic activities (such as aggregate extraction, dumping, cables, pipelines and windfarm development), sheer stress from tides, waves and currents, and not the least the activity of burrowing animals cause natural disturbance of varying intensity and frequency. This background variability influences the relative impact of fishing on benthic communities and habitats, assuming that impacts are lower where natural disturbance is high (Fig. 4.3) (Collie et al. 2000; Jennings and Kaiser 1998; Kaiser et al. 1998). This interaction between environmental and anthropogenic factors and the lack of adequate control sites due to the long history of fishing still hampers making general inferences regarding the significance and type of effects on a particular environment (Kenchington et al. 2001; Moritz et al. 2015; Szostek et al. 2016). Furthermore, even when significant impacts were revealed, results will pertain only to that gear or given substrate (Hughes et al. 2014). The number of studies published on the impact of fishing on the seabed and or benthic ecosystems grows steadily year-on-year (Buhl-Mortensen et al. 2016), but still our knowledge of how bottom trawling affect the seabed and the related biota is rudimentary. Nevertheless, it is well accepted that sensitive habitats, such as deep-sea ecosystems, cold water corals and shallow coral reefs deserve special protection from fishing.

4.3 Conclusions for Ecosystem Friendly Fisheries

Ecosystem friendly fisheries need to combine conservation, social and classical fisheries management objectives, e.g., maximising fishery yields or profits while minimising ecosystem impacts. At first glance, it is not readily obvious how these objectives could be reached at the same time, but the underlying mechanisms to achieve at least the conservation and classical fisheries management objectives are to a large degree congruent. For example, the MSY target in fisheries management requires fish stocks to unfurl long-term, high productivity, which can only be achieved in healthy and productive ecosystems and requires these fish stocks to be maintained at comparatively large stock levels. Similarly, the reduction of unintended by-catch and discards reduces the post harvesting effort in fisheries and at the same time addresses the conservation objective to minimise the ecosystem impact of fishing. For these two aspects, i.e. achieving the MSY-target and reducing by-catch and discards, fisheries and conservation objectives are not in contradiction to each other and achieving these goals would contribute a lot to the ecological sustainability of fisheries.

Managing fisheries towards the MSY goal is comparatively straightforward and can be achieved within current TAC-based ("total allowable catch") fisheries management frameworks, although there are a number of issues to be resolved in defining MSY-related biological reference points for management in a multi-species and mixed fisheries context (Kempf 2010; Thorpe et al. 2015). More challenging is the second aspect, i.e. reducing the unintended by-catch of non-target species and the physical impact of fishing gears on benthic habitats. From the management perspective this aspect can be addressed in various ways. To name a few: Sensitive habitats and their local communities benefit from closed areas; seasonal closures can prevent catching undersized fish on their nursery or feeding grounds; gear restrictions and modifications may increase the selectivity of a fishery in various ways; and financial and other incentives can help to change the behaviour of fishermen towards more sustainable fishing practises (Kraak et al. 2012).

Technical measures including gear restrictions and modifications will become extremely important instruments in the toolbox of fisheries management in the future and are underpinned by substantial advances in understanding target and non-target species' behaviour and the tremendous progress in marine and maritime technology. So-called smart-gears are one option that make use of avoidance or escape behaviour to minimise unintended catch. In separator trawls, e.g., the upward swimming target species are guided by bars into the net belly, while other by-caught species moving downward can escape through a large escape window in the bottom panel of the net (Fig. 4.4). Pulse trawls, where typically tickler chains are replaced with a series of electrical drag wires, send electrical pulses, which stun or shock target fish or shrimp out of the ground and into the net resulting in reduced physical disturbance of the seafloor, lower discard rates and fuel costs. However, it is still ambiguous in how far non-target marine organisms not retained in the net are affected by the electrical fields. In hook and line fisheries, understanding of foraging behaviour helps to attract target species or avoid catching the wrong species by the choice of bait. Technical solutions like a special circular hook shape prevent seabirds from being by-caught. Most recent gear technology innovations, though not yet commercially implemented, include using optic-acoustic sensors and image analyses software for species identification in combination with multi-opening-closing nets to separate wanted from unwanted catch.

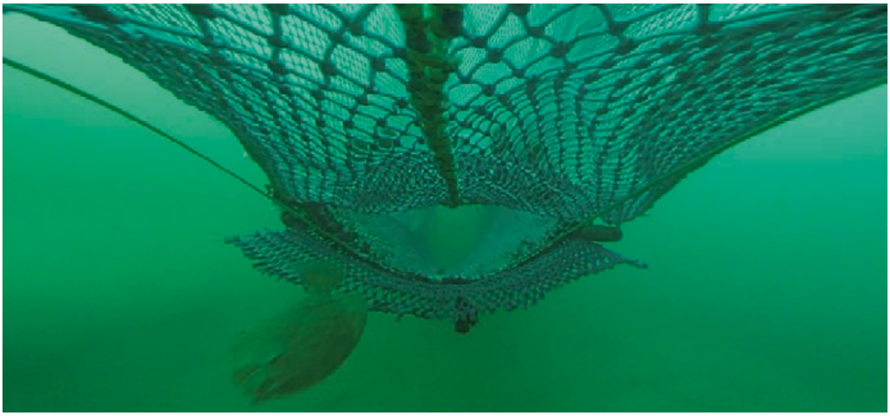


Fig. 4.4 Separator trawl in action. The net is equipped with guiding bars and a downward looking escape window in the net tunnel. Downward movement is a typical escape behaviour of several fish species (Photo © by Daniel Stepputtis, Thünen-Institute)

All in all, these new technical developments and the improved scientific understanding of animal behaviour can help to achieve the transition towards sustainability in fisheries (see also Chap. 33 by Serdy, this book). At the same time, there is a trade-off, as technological progress can greatly increase the efficiency of a fishery. It is therefore a major task of future fisheries management to balance technological innovations to improve selective fishing and uncontrolled increases in catching efficiency.

References

Alverson DL, Freeberg MH, Pope JG, Murawski SA (1994) A global assessment of fisheries bycatch and discards. FAO fisheries technical papers T339.

Anticamara JA, Watson A, Gelchua A, Pauly D (2011) Global fishing effort (1950–2010): trends, gaps, and implications. Fish Res 107:131–136

Auster PJ, Malatesta RJ, Langton RW, Watling L, Valentine PC, Donaldson CL, Langton EW, Shepard AN, Babb IG (1996) The impacts of mobile fishing gear on seafloor habitats in the Gulf of Maine (Northwest Atlantic): implications for conservation of fish populations. Rev Fish Sci 4:185–202

Bergman MJN, Hup M (1992) Direct effects of beamtrawling on macrofauna in a sandy sediment in the southern North Sea. ICES J Mar Sci 49(1):5–11

Bergman MJN, van Santbrink JW (2000) Mortality in megafaunal benthic populations caused by trawl fisheries on the Dutch continental shelf in the North Sea in 1994. ICES J Mar Sci 57:1321–1331

Blanchard F, LeLoc'h F, Hily C, Boutoute J (2004) Fishing effects on diversity, size and community structure of the benthic invertebrate and fish megafauna on the Bay of Biscay coast of France. Mar Ecol Prog Ser 280:249–260

Borges L, Rogan E, Officer R (2005) Discarding by the demersal fishery in the waters around Ireland. Fish Res 76:1–13

Buhl-Mortensen L, Neat F, Koen-Alonso M, Hvingel C, Holte B (2016) Fishing impacts on benthic ecosystems: an introduction to the 2014 ICES symposium special issue. ICES J Mar Sci 73(Suppl 1):i1–i4

Casini M, Lövgren J, Hjelm J, Cardinale M, Molinero J-C, Kornilovs G (2008) Multi-level trophic cascades in a heavily exploited open marine ecosystem. Proc R Soc B Biol Sci 275:1793–1801

Chassot E, Bonhommeau S, Dulvy NK, Melin F, Watson R, Gascuel D, Pape OL (2010) Global marine primary production constrains fisheries catches. Ecol Lett 13:495–505

Churchill JH (1989) The effect of commercial trawling on sediment resuspension and transport over the Middle Atlantic Bight continental shelf. Cont Shelf Res 9:841–864

Coll M, Shannon LJ, Kleisner KM, Juan-Jordá MJ, Bundy A, Akoglu AG, Banaru D, Boldt JL, Borges MF, Cook A, Diallo I, Fu C, Fox C, Gascuel D, Gurney LJ, Hattab T, Heymans JJ, Jouffre D, Knight BR, Kucukavsar S, Large SI, Lynam C, Machias A, Marshall KN, Masski H, Ojaveer H, Piroddi C, Tam J, Thiao D, Thiaw M, Torres MA, Travers-Trolet M, Tsagarakis K, Tuck I, van der Meeren GI, Yemane D, Zador SG, Shin Y-J (2016) Ecological indicators to capture the effects of fishing on biodiversity and conservation status of marine ecosystems. Ecol Indic 60:947–962

Collie JS, Escanero GA, Valentine PC (1997) Effects of bottom fishing on the benthic megafauna of Georges Bank. Mar Ecol Prog Ser 155:159–172

Collie JS, Hall SJ, Kaiser MJ, Poiner IR (2000) A quantitative analysis of fishing impacts on shelf-sea benthos. J Anim Ecol 69:785–798

Conover DO, Arnott SA, Walsh MR, Munch SB (2005) Darwinian fishery science: lessons from the Atlantic silverside. Can J Fish Aquat Sci 62:730–737

Conversi A, Dakos V, Gårdmark A, Ling S, Folke C, Mumby PJ, Greene C, Edwards M, Blenckner T, Casini M, Pershing M, Möllmann C (2015) A holistic view of marine regime shifts. Philos Trans R Soc B 370:20130279

Crowder LB, Hazen EL, Avissar N, Bjorkland R, Latanich C, Ogburn MB (2008) The impacts of fisheries on marine ecosystems and the transition to ecosystem-based management. Annu Rev Ecol Evol Syst 39:259–278

Croxall JP, Butchart SHM, Lascelles B, Stattersfield AJ, Sullivan B, Symes A, Taylor P (2012) Seabird conservation status, threats and priority actions: a global assessment. Bird Conserv Int 22:1–34

Dayton PK, Thrush SF, Agardy TM, Hofman RJ (1995) Environmental effects of fishing. Aquat Conserv Mar Freshwat Ecosyst 5:205–232

De Groot SJ (1984) The impact of bottom trawling on benthic fauna of the North Sea. Ocean Manage 9:177–190

De Juan S, Thrush SF, Demestre M (2007) Functional changes as indicators of trawling disturbance on a benthic community located in a fishing ground (NW Mediterranean Sea). Mar Ecol Prog Ser 334:117–129

van Denderen PD, Bolam SG, Hiddink JG, Jennings S, Kenny A, Rijnsdorp AD, van Kooten T (2015a) Similar effects of bottom trawling and natural disturbance on composition and function of benthic communities across habitats. Mar Ecol Prog Ser 541:31–43

van Denderen PD, Hintzen NT, van Kooten T, Rijnsdorp AD (2015b) Temporal aggregation of bottom trawling and its implication for the impact on the benthic ecosystem. ICES J Mar Sci 72:952–961

Dulvy NK, Sadovy Y, Reynolds JD (2003) Extinction vulnerability in marine fish populations. Fish Fish 4:25–64

Eigaard OR, Bastardie F, Breen M, Dinesen GE, Hintzen NT, Laffargue P, Mortensen LO, Nielsen JR, Nilsson HC, O'Neill FG, Polet H, Reid DG, Sala A, Sköld M, Smith C, Sørensen TK, Tully O, Zengin M, Rijnsdorp AD (2016) Estimating seabed pressure from demersal trawls, seines, and dredges based on gear design and dimensions. ICES J Mar Sci 73(Suppl 1):i27–i43

Engelhard GH, Lynam CP, García-Carreras B, Dolder PJ, Mackinson S (2015) Effort reduction and the large fish indicator: spatial trends reveal positive impacts of recent European fleet reduction schemes. Environ Conserv 42:227–236

European Commission (2015) Konsultation zu den Fangmöglichkeiten 2016 im Rahmen der Gemeinsamen Fischereipolitik. COM (2015) 239

FAO (2010) The state of world fisheries and aquaculture 2010, Rome, 197p

FAO (2014) The state of world fisheries and aquaculture 2014, Rome, 223p

Fock HO, Kloppmann MHF, Probst WN (2014) An early footprint of fisheries: changes for a demersal fish assemblage in the German Bight from 1902–1932 to 1991–2009. J Sea Res 85:325–335

Frank KT, Petrie B, Choi JS, Leggett WC (2005) Trophic cascades in a formerly cod-dominated ecosystem. Science 308:1621–1623

Frid CLJ, Paramor OAL (2012) Feeding the world: what role for fisheries? ICES J Mar Sci 69:145–150

Frid CLJ, Harwood KG, Hall SJ, Hall JA (2000) Long-term changes in the benthic communities on North Sea fishing grounds. ICES J Mar Sci 57:1303–1309

Gerritsen HD, Minto C, Lordan C (2013) How much of the seabed is impacted by mobile fishing gear? Absolute estimates from Vessel Monitoring System (VMS) point data. ICES J Mar Sci 70:523–531

Godfray HCJ, Beddington JR, Crute IR, Hadad L, Lawrence D, Muir JF, Pretty J, Robinson S, Thomas SM, Toulmin C (2010) Food security: the challenge of feeding 9 billion people. Science 327:812–818

Gulland JA (1977) Fish population dynamics. John Wiley & Sons, London

Hauser L, Adcock GJ, Smith PJ, Ramirez JHB, Carvalho GR (2002) Loss of microsatellite diversity and low effective population size in an overexploited population of New Zealand snapper (*Pagrus auratus*). Proc Natl Acad Sci U S A 99:11742–11747

Heino M, Dieckmann U, Godø OR (2002) Measuring probabilistic reaction norms for age and size at maturation. Evolution 56:669–678

Heino M, Díaz Pauli B, Dieckmann U (2015) Fisheries-induced evolution. Annu Rev Ecol Evol Syst 46:461–480

Hidalgo M, Olsen EM, Ohlberger J, Saborido-Rey F, Murua H, Piñeiro C, Stenseth NC (2014) Contrasting evolutionary demography induced by fishing: the role of adaptive phenotypic plasticity. Ecol Appl 24:1101–1114

Hiddink JG, Jennings S, Kaiser MJ, Queirós AM, Duplisea DE, Piet GJ (2006) Cumulative impacts of seabed trawl disturbance on benthic biomass, production, and species richness in different habitats. Can J Fish Aquat Sci 63:721–736

Hilborn R, Walters CJ (1992) Quantitative fisheries stock assessment: choice, dynamics and uncertaincy. Chapman and Hall, New York

Hintzen NT, Piet GJ, Brunel T (2010) Improved estimation of trawling tracks using cubic Hermite spline interpolation of position registration data. Fish Res 101:108–115

Hixon MA, Johnson DW, Sogard SM (2014) BOFFFFs: on the importance of conserving old-growth age structure in fishery populations. ICES J Mar Sci 71:2171–2185

Hughes KM, Kaiser MJ, Jennings S, McConnaughey RA, Pitcher R, Hilborn R, Amoroso RO, Collie J, Hiddink JG, Parma AM, Rijnsdorp A (2014) Investigating the effects of mobile bottom fishing on benthic biota: a systematic review protocol. Environ Evid 3:23

Jennings S, Blanchard JL (2004) Fish abundance with no fishing: predictions based on macroecological theory. J Anim Ecol 73:632–642

Jennings S, Kaiser MJ (1998) The effects of fishing on marine ecosystems. Adv Mar Biol 32:201–352

Jennings S, Kaiser MJ, Reynolds JD (2001a) Marine Fisheries Ecology. Blackwell Science Ltd., Oxford, UK, 432p

Jennings S, Pinnegar JK, Polunin NVC, Warr KJ (2001b) Impacts of trawling disturbance on the trophic structure of benthic invertebrate communities. Mar Ecol Prog Ser 213:127–142

Jørgensen C, Enberg K, Dunlop ED, Arlinghaus R, Boukal DS, Brander K, Ernande B, Erdmark A, Johnston F, Matsumura S, Pardoe H, Raab K, Silva A, Vainikka A, Dieckmann U, Heino M, Rijnsdorp AR (2007) Managing evolving fish stocks. Science 318:1247–1248

Kaiser MJ (1998) Significance of bottom-fishing disturbance. Conserv Biol 12:1230–1235

Kaiser MJ, de Groot SJ (2000) The effects of fishing on non-target species and habitats: Biological, conservation and socio-economic issues. Blackwell Sciences, Oxford. 399p

Kaiser MJ, Spencer BE (1994) Fish scavenging behaviour in recently trawled areas. Mar Ecol Prog Ser 112:41–49

Kaiser MJ, Edwards DB, Armstrong PJ, Radford K, Lough NEL, Flatt RP, Jones HD (1998) Changes in megafaunal benthic communities in different habitats after trawling disturbance. J Mar Sci 55:353–361

Kaiser MJ, Ramsay K, Richardson CA, Spence FE, Brand AR (2000) Chronic fishing disturbance has changed shelf sea benthic community structure. J Anim Ecol 69:494–503

Kaiser MJ, Clarke KR, Hinz H, Austen MCV, Somerfield PJ, Karakassis I (2006) Global analysis of response and recovery of benthic biota to fishing. Mar Ecol Prog Ser 311:1–14

Kempf A (2010) Ecosystem approach to fisheries in the European context – history and future challenges. J Appl Ichthyol 26(Suppl 1):102–109

Kenchington ELR, Prena J, Gilkinson KD, Gordon DC, MacIsaac K, Bourbonnais C, Schwinghamer PJ, Rowell TW, McKeown DL, Vass WP (2001) Effects of experimental otter trawling on the macrofauna of a sandy bottom ecosystem on the Grand Banks of Newfoundland. Can J Fish Aquat Sci 58:1043–1057

Kenchington ELR, Gilkinson KD, MacIsaac KG, Bourbonnais-Boyce C, Kenchington TJ, Smith SJ, Gordon DC Jr (2006) Effects of experimental otter trawling on benthic assemblages on Western Bank, northwest Atlantic Ocean. J Sea Res 56:249–270

Kraak SBM, Reid DG, Gerritsen HD, Kelly CJ, Fitzpatrick M, Codling EA, Rogan E (2012) 21st century fisheries management: a spatio-temporally explicit tariff-based approach combining multiple drivers and incentivising responsible fishing. ICES J Mar Sci 69:590–601

Kraus G, Tomkiewicz J, Köster FW (2002) Egg production of Baltic cod in relation to variable sex ratio, maturity and fecundity. Can J Fish Aquat Sci 59:1908–1920

Kraus G, Hinrichsen HH, Voss R, Tomkiewicz J, Teschner E, Köster FW (2012) Robustness of egg production methods as a fishery independent alternative to assess the Eastern Baltic cod stock (*Gadus morhua callarias* L.) Fish Res 117–118:75–85

Lage C, Kornfield I (2006) Reduced genetic diversity and effective population size in an endangered Atlantic salmon (*Salmo salar*) population from Maine, USA. Conserv Genet 7: 91–104

Lambert Y, Yaragina NA, Kraus G, Marteinsdottir G, Wright PJ (2003) Correlation between reproductive characteristics and environmental and biological indices as alternative methods of estimating egg production. J Northwest Atl Fish Sci 33:115–159

Lewison R, Oro D, Godley B, Underhill L, Bearhop S, Wilson R, Ainley D, Arcos J, Boersma P, Borboroglu P (2012) Research priorities for seabirds: improving conservation and management in the 21st century. Endanger Species Res 17:93–121

Link JS, Brodziak JKT, Edwards SF, Overholtz WJ, Mountain DG, Jossi JW, Smith TD, Fogarty MJ (2002) Marine ecosystem assessment in a fisheries management context. Can J Fish Aquat Sci 59:1429–1440

Llope M, Daskalov GM, Rouyer TA, Mihneva V, Grishin AN, Chan K-S, Stenseth NC (2011) Overfishing of top predators eroded the resilience of the Black Sea system regardless of the climate and anthropogenic conditions. Glob Chang Biol 17:1251–1265

Loreau M, deMazancourt C (2013) Biodiversity and ecosystem stability: a synthesis of underlying mechanisms. Ecol Lett 16:106–115

Moritz C, Gravel D, Savard L, McKindsey CW, Brêthes J-C, Archambault P (2015) No more detectable fishing effect on Northern Gulf of St Lawrence benthic invertebrates. ICES J Mar Sci Journal du Conseil 72(8):2457–2466

Möllmann C, Folke C, Edwards M, Conversi A (2015) Marine regime shifts around the globe: theory, drivers and impacts. Philos Trans R Soc B 370:20130260

Murawski SA (2000) Definitions of overfishing from an ecosystem perspective. ICES J Mar Sci 57:649–658

Northridge SP (1984) World review of interactions between marine mammals and fisheries. FAO fisheries technical paper, 251, 190p

Opdal AF, Jørgensen C (2015) Long-term change of a behavioural trait: truncated spawning distribution and demography in Northeast Arctic cod. Glob Chang Biol 21:1521–1530

Pauly D, Zeller D (2016) Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. Nat Commun 7:10244

Pauly D, Christensen V, Dalsgaard J, Froese R, Torres F Jr (1998) Fishing down marine food webs. Science 279:860–863

Pitcher CR, Burridge CY, Wassenberg TJ, Hill BJ, Poiner IR (2009) A large scale BACI experiment to test the effects of prawn trawling on seabed biota in a closed area of the Great Barrier Reef Marine Park, Australia. Fish Res 99:168–183

Read AJ, Drinker P, Northridge S (2006) Bycatch of marine mammals in U.S. and global fisheries. Conserv Biol 20:163–169

Riemann B, Hoffmann E (1991) Ecological consequences of dredging and bottom trawling in the Limfjord, Denmark. Mar Ecol Prog Ser 69:171–178

Riesen W, Reise K (1982) Macrobenthos of the subtidal Wadden Sea: revisited after 55 years. Helgoländer Meeresuntersuchungen 35:409–423

Rijnsdorp AD, Bastardie F, Bolam SG, Buhl-Mortensen L, Eigaard OR, Hamon KG, Hiddink JG, Hintzen NT, Ivanović A, Kenny A, Laffargue P, Nielsen JR, O'Neill FG, Piet GJ, Polet H, Sala A, Smith C, van Denderen PD, van Kooten T, Zengin M (2016) Towards a framework for the quantitative assessment of trawling impact on the seabed and benthic ecosystem. ICES J Mar Sci 73(Suppl 1):i127–i138

Rowe S, Hutchings JA, Bekkevold D, Rakitin A (2004) Depensation, probability of fertilization, and the mating system of Atlantic cod (*Gadus morhua* L.) ICES J Mar Sci 61:1144–1150

Rumohr H, Kujawski T (2000) The impact of trawl fishery on the epifauna of the southern North Sea. ICES J Mar Sci 57:1389–1394

Scheffer M, Carpenter SR (2003) Catastrophic regime shifts in ecosystems: linking theory to observation. Trends Ecol Evol 18:648–656

Scheffer M, Carpenter S, Foley J, Folke C, Walker B (2001) Catastrophic shifts in ecosystems. Nature 413:591–596

Schwinghamer P, Gordon DC, Rowell TW, Prena J, McKeown DL, Sonnichsen G, Guigné JY (1998) Effects of experimental otter trawling on surficial sediment properties of a sandy-bottom ecosystem on the Grand Banks of Newfoundland. Conserv Biol 12:1215–1222

Shin YJ, Rochet MJ, Jennings S, Field JG, Gislason H (2005) Using size-based indicators to evaluate the ecosystem effects of fishing. ICES J Mar Sci 62:384–396

Smed J, Ramster J (2002) Overfishing science, and politics: the background in the 1890s to the foundation of the International Council for the Exploration of the Sea. ICES Mar Sci Symp 215:13–21

Sparks-McConkey P, Watling L (2001) Effects on the ecological integrity of a soft-bottom habitat from a trawling disturbance. Hydrobiologia 456:73–85

Stevens JD, Bonfil R, Dulvy NK, Walker PA (2000) The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems. ICES J Mar Sci 57:476–494

Szostek CL, Murray LG, Bell E, Rayner G, Kaiser MJ (2016) Natural vs. fishing disturbance: drivers of community composition on traditional king scallop, *Pecten maximus*, fishing grounds. ICES J Mar Sci 73(Suppl 1):i70–i83

Tasker ML, Camphuysen CJ, Cooper J, Garthe S, Montevecchi WA, Blaber SJM (2000) The impacts of fishing on marine birds. ICES J Mar Sci 57:531–547

Terborgh J, Estes JA (2010) Trophic cascades. Island Press, Washington, DC. 464p

Thorpe RB, Le Quesne WJF, Luxford F, Collie JS, Jennings S (2015) Evaluation and management implications of uncertainty in a multispecies size-structured model of population and community responses to fishing. Methods Ecol Evol 6:49–58

Thrush SF, Dayton PK (2002) Disturbance to marine benthic habitats by trawling and dredging: implications for marine biodiversity. Annu Rev Ecol Syst 33:449–473

Tillin HM, Hiddink JG, Jennings S, Kaiser MJ (2006) Chronic bottom trawling alters the functional composition of benthic invertebrate communities on a sea-basin scale. Mar Ecol Prog Ser 318:31–45

Tomkiewicz J, Kraus G, Köster FW (2005) Timing of Baltic cod spawning and spawner demography. ICES CM Q:23

Wallace BP, Lewison RL, McDonald SL, McDonald RK, Kot CY, Kelez S, Bjorkland RK, Finkbeiner EM, Helmbrecht S, Crowder LB (2010) Global patterns of marine turtle bycatch. Conserv Lett 3:131–142

Wallace BP, Kot CY, DiMatteo AD, Lee T, Crowder LB, Lewison RL (2013) Impacts of fisheries bycatch on marine turtle populations worldwide: toward conservation and research priorities. Ecosphere 4:40

deYoung B, Barange M, Beaugrand G, Harris R, Perry RI, Scheffer M, Werner F (2008) Regime shifts in marine ecosystems: detection, prediction and management. Trends Ecol Evol 23: 402–409

Chapter 5
Mariculture

Thomas A. Wilding, Kenneth D. Black, Steven Benjamins, and Iona Campbell

Abstract Mariculture is the cultivation of marine species for human-benefit. Mariculture is a rapidly growing sector and is making an increasingly important contribution to global supplies of high-quality food. Mariculture can be divided into high- and low-input categories depending on the extent to which feed and medicines are a core part of the operation. Examples of high- and low-input mariculture operations include the cultivation of salmon and mussels respectively. Mariculture has a number of impacts on the marine environment. These impacts include the spread of non-native species, genetic modification of sympatrics, negative-interaction with predators, local-scale organic enrichment and habitat modification, effects of chemotheraputants on non-target organisms and the transfer of parasites/disease to native stocks. Some impacts of mariculture are relatively well understood, at least in some locations, but research is very much ongoing as new mariculture challenges, demands and opportunities arise. Regulation of mariculture varies widely between nations and there remain questions about the spatial extent, and nature, of unacceptable changes attributable to mariculture and how to incorporate mariculture into marine spatial planning.

Keywords Food • Salmon • Mussels • Farming • Impacts • On-native-species • Marine spatial competition • Biofuels

5.1 Introduction

Mariculture is the cultivation of fish, or other marine life, for food or other useful products for human-benefit. Mariculture occurs in the sea, or on land with seawater pumped ashore. Organisms suitable for mariculture can be divided into four main categories:

T.A. Wilding (✉) • K.D. Black • S. Benjamins • I. Campbell
SAMS, Scottish Marine Institute, Oban Argyll, UK
e-mail: Tom.Wilding@sams.ac.uk; Kenny.Black@sams.ac.uk; Steven.Benjamins@sams.ac.uk; Ionacampbell12@gmail.com

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_5

finfish, crustacea, molluscs and others. Mariculture is a rapidly growing sector with the primary drivers being the decline of wild-caught fish/shellfish in the face of growing demand for both basic protein and high-quality/luxury food items (FAO 2014a).

Global mariculture production reached ~25 million tonnes in 2012 equating ~40% of total aquaculture production (excluding marine algae) (FAO 2014a). Mariculture occurs on all continents (excluding Antarctica) with Asia (particularly China) being the main (81% of total) production centre. Global mariculture production increased, approximately linearly, over the period 1990–2012, at a rate of 2.4 million tonnes per year and, in 2014, was worth approximately $53B (FAO 2016). In 2012 the estimated number of jobs (direct and indirect) associated with aquaculture (both freshwater and marine) was ~36 million (FAO 2014b). Given that mariculture makes up ~40% of total aquaculture production (2012) (FAO 2014a) this suggests that ~14 million jobs are currently dependent on mariculture.

In terms of environmental impacts associated with mariculture, a useful categorisation is to divide the sector into high- and low-input operations. High-input mariculture includes the culture of predatory finfish (e.g. salmon) where feed is a major input and where predator/parasite control incurs a considerable cost. This contrasts with low-input mariculture where the feedstock is obtained from the water column and which includes filter-feeding species including bivalves such as mussels. High-input mariculture operations are usually 'intensive' in terms of the biomass supported per unit of water volume but this can also apply to low-input operations (e.g. suspended mollusc culture).

Low-input mariculture is generally perceived as being a more benign method of food production because waste generation is generally less and because there are fewer, if any, environmental issues in feed-stock sourcing. However, both high- and low-input mariculture inevitably cause changes in the receiving environment and these changes occur at a range of temporal and spatial scales that are linked to the production method, the scale of the mariculture operation and the nature of the receiving environment.

The impact of mariculture is a broad, diverse and multidisciplinary subject. Impacts occur at local- to regional-scales (Tett et al. 2011) to those that are distant and indirect e.g. from sourcing feedstocks (Naylor et al. 2009). Mariculture impacts affect various stakeholders (farmers, other-space users and consumers) in different ways (Alexander et al. 2016). These aspects have been extensively reviewed: within a 'driver-pressure- status-impact-response' framework mariculture impacts are described by Tett (2008) whilst the environmental impacts of bivalve mariculture is broadly reviewed in Kaiser et al. (1998) and, more recently, Keeley et al. (2009). The present work provides a synthesis of the subject and aims to bring it up to date. Our main focus in this overview is on Atlantic salmon (*Salmo salar*) and we limit our primary focus to those impacts occurring within the host water body. Comparisons are made to other species (particularly the blue mussel, *Mytilus* edulis) to provide a context and explore where differences and similarities occur and we briefly consider integrated mariculture and marine-biofuels. Our context is mainly Scottish but we draw on experience from a range of environments and locations. For the purposes of this review, the assumed culture condition for salmon is sea-based nets (Fig. 5.1) and, for mussels, suspended line culture (Fig. 5.2) (Wilding 2012).

Fig. 5.1 Example of salmon farm, Isle of Skye, Scotland, UK. Note the feed barge (centre, left) connected to the individual nets by feed-tubes along which feed is blown. Feeding is controlled automatically or by remote-control. Photo by T. Wilding

Fig. 5.2 Example of a mussel-farm, Loch Leven, Scotland. Individual mussel lines are supported underneath the black floats. This is a relatively small-scale operation within the Scottish context. Photo by T. Wilding

5.2 Mariculture and the Receiving Environment

The environmental impacts associated with any mariculture operation are fundamentally linked to the receiving environment. Siting mariculture operations is, inevitably, a compromise between the operators, other stakeholders and the environment. For salmon and mussels, operators need storm-sheltered waters to limit infrastructure and access costs. However, they also require exposure to reasonable, but not extreme, water-flow to ensure adequate ventilation (waste product removal, oxygen supply) and, in the case of filter-feeding crops, food delivery whilst limiting infrastructure costs (e.g. moorings). Mariculture operations require the water to be of sufficient depth to sustain nets/droppers of a viable size but not so deep as to make anchoring a problem (Kapetsky et al. 2013). In addition, farms need to be located where the water meets microbial and chemical-contamination criteria and is of a suitable temperature and salinity range. These requirements limit the space in which mariculture operations are currently technologically and economically viable and, as such, they compete with other maritime sectors (e.g. ports, shipping, amenity; Kapetsky et al. 2013). At the smallest scale, mariculture operations are artisanal and have no substantive impact outside their immediate vicinity. Modern operations are, generally, larger as companies seek scale-efficiencies and as markets grow. Modern salmon farms can hold well in excess of 10,000 tonnes at maximum biomass and modern mussel farms aim to produce ~10,000 tonnes per year (e.g. http://www.offshoreshellfish.com/) along ~1000 km of mussel line (Plew et al. 2005). As a consequence of this space competition and for environmental reasons (see Sect. 5.2.4) there is increasing interest in developing the technology/materials to enable the sector to occupy more exposed (dispersive) sites (Kapetsky et al. 2013). Currently, however, in order to meet environmental criteria, in Norway, Scotland, Chile and New Zealand, mariculture sites tend to be located in flooded glacial valleys (e.g. sea lochs and fjords) whilst in Spain mussel culture occurs in rias (flooded river valleys).

Mariculture can impact the environment in a number of ways. Here, these impacts are divided into six categories with salmon farming being implicated in all six and mussel farming being more environmentally benign (Table 5.1). Issues surrounding feedstock sourcing are not considered here (see Naylor et al. 2009).

Table 5.1 Relative importance of impacts from salmon and mussel farming

Issue	Salmon	Mussels
Introduction/spread of non-native species	3	3
Genetic modification of sympatrics	3	2
Interaction with predators	3	1
Eutrophication, organic enrichment and habitat modification	3	2
Chemotheraputants and non-target organisms	3	NA
Parasite transfer to wild stock	3	0

Scoring: 0—no meaningful impact; 1—impact of the environment on the sector, 2—some impact from the sector on the environment (or vice-versa) but not perceived as a high priority, 3—a high degree of perceived threat from the sector on one or more aspects of the environment. *NA* not appropriate/relevant

5.2.1 Introduction of Non-Native Species

The spread of non-native species is considered a major threat to our seas and, by 2008, mariculture was implicated in the introduction of 130 non-indigenous species (41% of the total number) of which ~70 were considered harmful (Molnar et al. 2008) (Kuhlenkamp and Kind, Chap. 25). Mariculture is implicated in non-native species introductions via three main routes: Route 1. Escape of non-native mariculture species which become feral (Cook et al. 2008). Feral mariculture species include the Pacific oyster (*Crassostrea gigas*) which now dominates certain intertidal areas (e.g. around Île de Ré, France, personal observations) and where the impact is a reduction in amenity use alongside a reduction in growth of non-feral cultured oysters (Dutertre et al. 2010) because of direct competition. The naturalisation and spread of mariculture species beyond their intended range may be attributable to climate change (Callaway et al. 2012). Route 2. Where non-native species (including pathogens) associated with the mariculture species, or infrastructure, are spread via the movement of mariculture-stock between farming operations (Cook et al. 2008) and Route 3. Via habitat provision—mariculture infrastructure (e.g. buoys, nets, ropes) provide an ideal habitat for some non-native species (Ashton et al. 2007). Careful management of mariculture is required to stop its involvement in the spread of non-native species (Cook et al. 2008) and reduce the economic losses it is suffering as a consequence of them (Aldred and Clare 2014; Cook et al. 2008).

5.2.2 Genetic Modification of Sympatrics

The loss of stock from sea-based mariculture operations, to the broader environment, is inevitable. Stock losses can occur following damage of the supporting infrastructure (e.g. nets and supporting ropes) and this can occur as a consequence of storm, predators and even deliberate sabotage (Jackson et al. 2015). In the case of salmon, escapees tend to return to their natural life-cycle and, depending on their size, migrate into rivers. Most farmed fish, particularly salmon, are bred to optimise their farm-based performance. There is concern that successful interbreeding of wild-fish and escapees will modify the wild-fish gene pool and, ultimately, decrease the fitness of wild-fish population (Bourret et al. 2011; Jonsson and Jonsson 2006).

For mussels (e.g. *Mytilus edulis*) the seed-stock is frequently sourced locally, from wild populations. Even where local sourcing occurs wild-stock genetic modification, from the reproductive efforts of the stock in culture, can still occur although the impact is likely to be less severe. For example, in Scotland (UK), *M. edulis* culture has been linked to the increase in prevalence of closely related *M. trossulus* (and hybrids) which has caused the industry to close in some locations (Michalek et al. 2016). The seed-stocks for non-native species, for example the Pacific oyster *Crassostrea gigas* in Europe, are generally produced in specialist hatcheries and this enables genetic selection to be undertaken. Where a non-native species is being cultured the concept of genetic modification of sympatrics does not apply but introduced mariculture species can hybridise with closely related wild-counterparts with unknown consequences (Xiang 2007).

5.2.3 Control of Predators—Acoustic Pollution

Maricultured species are often stocked in very high densities relative to the surrounding environment and are typically kept in confined spaces where escape options are limited. As a consequence mariculture sites often attract the attention of a range of predators, including marine mammals and seabirds. Such foraging opportunities may result in local changes in predator abundance and distribution as animals aim to exploit a novel food resource (Kirk et al. 2007; Žydelis et al. 2009). Main predators of farmed-salmon are seals and, for mussels, a variety of duck species. The economic losses attributable to predation can be considerable (Kirk et al. 2007; Nelson et al. 2006; Piroddi et al. 2011; Sepulveda and Oliva 2005). Reducing the impact of predators can take the form of preventing access, deterrence or lethal removal (e.g. shooting; Coram et al. 2014). Non-lethal methods are more societally acceptable methods of predator control and, in Scotland (UK), have included changes in infrastructure design to allow greater tensioning of the net, increasing the size of pens and reducing fish densities (Northridge et al. 2013) all of which reduce vulnerability to seal attacks. However, seal predation is still a major problem within the Scottish industry and there has been growing recourse to acoustic deterrents (Lepper et al. 2004). Acoustic deterrents aim to either elicit a perceived threat in the predator (which then hopefully avoids the source) or causes confusion or, if sufficiently loud, pain in the predator (Schakner and Blumstein 2013). Although such sounds can result in short-term aversion among predators the long-term efficacy of these devices is unclear, with strong potential for habituation and association of sound with an easily accessible food resource (the 'dinner-bell' effect; Anderson and Hawkins 1978; Jefferson and Curry 1996). Widespread use of acoustic deterrents results in considerable acoustic pollution of the surrounding environment and has been shown to lead to disturbance and habitat exclusion for several other marine mammal species (e.g. harbour porpoise; Brandt et al. 2013; Morton and Symonds 2002; Olesiuk et al. 2002). The effects of acoustic deterrents on other non-target species, including vocalising fish such as cod, are largely unknown (Goetz and Janik 2013).

Predation of cultured mussels by ducks is a major issue facing the industry. In Canada and Scotland, chasing the birds, using boats, was routinely used but this type of intervention has considerable costs, is only a short-term solution and, in Scotland at least, is now illegal. Acoustic deterrents have been used (Ross et al. 2001) and proven effective, but they too constitute noise-pollution with unknown ecological consequences (see above). The feeding opportunities afforded by mussel-lines has resulted in the enhancement of some bird populations (Žydelis et al. 2009) but whether this should be perceived as a positive impact is not clear. Bird predators dislodge large volumes of mussels during their foraging and those not consumed fall to the seabed with subsequent impacts (see Sect. 6.6). Whilst sea-mammals do become entangled in fishing gear and drown (Northridge et al. 2010) there is currently very little evidence of mammal or bird entanglement with mariculture structures (Young 2015) though if/when the industry moves offshore (Kapetsky et al. 2013) this potential should be re-evaluated.

5.2.4 Salmon-Farming, Eutrophication and Organic Enrichment

High-input mariculture (e.g. fish-farming) requires intensive feeding of fish that are held in relatively high densities. High-input mariculture results in high-levels of waste (fish-faeces and excretory products) entering the environment. One Norwegian study determined that approximately 400, 51 and 9.5 tonnes of carbon, nitrogen and phosphorous respectively were released into the environment for every 1000 tonnes of fish produced (Wang et al. 2012). The impact of these nutrients differs according to the receiving environment. Whilst fish-farm impacts might be difficult to detect if the production site is sufficiently dispersive, most fish- and mussel-farms are, at least, associated with a degree of nutrient and organic enrichment occurring in their immediate vicinity.

Elevated levels of inorganic nutrients (mainly nitrates and phosphates) in marine systems have long been implicated in eutrophication and the subsequent adverse consequences such as harmful algal blooms (Hallegraeff 1993) (van Beusekom, Chap. 22) which can devastate mariculture (Matsuyama and Shumway 2009). Whilst eutrophication, and its resultant problems, are not linked to fish-farming itself, there is considerable interest in combining seaweed and fish mariculture in ‘integrated multi-trophic aquaculture’ in order to capitalise on the enhanced growth of macroalgae around fish-farms (see Sect. 7.1).

Much of the organic enrichment attributable to fish-farming arises because fish-faeces sink and accumulate on the seabed. Where a new farm is established, the sediment underlying the farm will be altered and will attain a new equilibrium state that reflects the extent of organic enrichment (related to the scale and nature of the mariculture operation) and the environmental conditions prevalent at the site, particularly current exposure which disperses the organic material (Black et al. 2009; Black 1994). The impact of organic material on muddy-sediment macrofaunal assemblages is relatively well understood (Black 1998; Pearson and Rosenberg 1978; Pearson and Black 2001; Pearson and Stanley 1979; Wu 1995). The input of faecal material increases microbial oxygen demand and results in the depletion of a series of terminal electron receptors (in respiration) in the order oxygen, manganese, nitrates, iron oxides, sulphates and, ultimately, carbon dioxide (Schulz 2000). The reduction of sulphate generates hydrogen sulphide which is highly toxic to a majority of benthic infauna and, typically, such sites are characterised by a superabundance of sulphide tolerant species such as the polychaete *Capitella capitata*

(Pearson and Rosenberg 1978). Such sediments are considered 'highly impacted' but, at more extreme levels of organic enrichment, where oxygen is absent even at the sediment's surface, the sulphide-oxidising bacteria *Beggiatoa* sp. dominates at the expense of tolerant polychaetes and the sediment's assimilative capacity, in terms of carbon-cycling, is diminished. This is because anaerobic processes are slower than aerobic metabolism but also because extirpated bioturbating organisms would otherwise provide an additional stimulus to carbon degradation (Heilskov and Holmer 2001).

In Scotland, the regulation of fish-farms, from an environmental perspective, has been largely dependent on the modelled benthic footprint based on thresholds related to the macrobenthic infaunal indices (e.g. infaunal trophic index, ITI) set with the objective of maintaining bioturbation function (Cromey et al. 2002a, b). The determination of metrics such as the ITI relies on manual sorting and identification of specimens collecting around the farm using a benthic grab (e.g. Wilding and Nickell 2013) and is time consuming and expensive (approx. £1M per year across the Scottish industry) and requires considerable taxonomic expertise. Recent developments in metabarcoding, using next generation sequencing technologies, have been applied to fish-farm monitoring and look very encouraging (Pawlowski et al. 2014; Lejzerowicz et al. 2015). Metabarcoding is the identification of organisms (e.g. those retained in a grab) by means of extracting multispecies DNA from the sampled sediment and identifying those species present based on sequencing diagnostic genes (to give a 'molecular taxonomy'). DNA metabarcoding can be completed within a week of sampling using current technology. The development of this approach will reduce industry costs and, very importantly, allow near-real-time benthic condition assessments allowing better regulation and maximisation of site biomass potential.

The consequences of fish-farming on megabenthic organisms, including those requiring a hard-substratum, is much less well researched than for macrobenthos because, historically, most farms were located over mud and because megabenthic/hard-substratum communities are harder to monitor (Wilding et al. 2012). Given the push towards locating mariculture over more dispersive sites (see Chap. 6) this constitutes an increasingly important data gap. Research in Scotland has demonstrated that moderate organic enrichment may have beneficial effects (in terms of food provision, either directly or indirectly) to megabenthos but only up-to a distance-to-farm threshold which is site specific (Wilding et al. 2012).

5.2.5 Salmon-Farming, Chemotheraputants and Non-Target Organisms

One of the major problems affecting salmonid culture in areas hosting native salmonids is infection with lice. Lice are crustacean ectoparasites that, in high densities, cause serious skin-lesions which both weaken the host fish and makes it more susceptible to disease. The high densities of farmed salmon and their long-term presence at a given site make salmon farms very susceptible to lice infestations. There are two main issues related to lice and the perceived importance of these differs between countries: (1) concern that farm-lice infestations transfer to wild-stocks (Costello 2006, 2009) and (2) that chemical-based lice-control methods have negative impacts on non-target organisms. The farmed-lice contagion issue is particularly prevalent in Norway (Torrissen et al. 2013) where fish lice numbers, on farmed fish, are closely monitoring and where control is required where lice exceed certain thresholds (Liu and Bjelland 2014). Similar regulations are also in place in Scotland (SSPO 2015) but there is little information in the public domain regarding enforcement and aggregated lice data which are available evidences occasions where lice levels are greatly in excess of targets in Norway.

In order to reduce the impact of lice on farmed salmon a number of treatment methodologies (chemical and biological) have been developed. Chemical controls can be classified into two types: infeed and bath (Burridge et al. 2010). Infeed treatments, such as emamectin benzoate (EMB), are delivered by treating feed-pellets which are fed to the fish in the normal way, usually over a period of week. EMB enters the fishes' tissue and is taken up by feeding lice which, if the dose is sufficient, are killed. EMB is eliminated by the fish, over an extensive period (at least 200 days) following treatment. EMB is insoluble and particle affinitive and accumulates on the seabed with faecal material. Other chemotheraputants, such as the pyrethroids and organophosphates, are applied topically in 'bath' treatments which occur within the nets which are temporally enclosed by a tarpaulin. Following treatment, the tarpaulin is released and the 'bath' contents and fish are released back into the fish-cage and the treatment disperses into the receiving water body and is rapidly highly diluted. The environmental impacts of bath treatments on, for example pelagic zooplankton are, consequently, likely to be hard to detect (Willis et al. 2005) even though high sensitivity in crustacean zooplankton has been reported for some lice-treatment chemicals (Fiori 2012). As with most chemical treatments, continued use is associated with the development of resistance in the target organism (Burridge et al. 2010) and the need for an increased dose to be effective. This effect has been observed in Scotland (where EMB use doubled over the period 2003–2012) and elsewhere for many years in relation to EMB (Lees et al. 2008) and other chemicals (e.g. hydrogen peroxide; Burridge et al. 2010; Treasurer et al. 2000). Burridge et al. (2010) noted EMB was associated with premature moulting in *Homarus americanus* but it was considered that wider-scale impacts were unlikely. However, Waddy et al. (2010) demonstrated that chronic EMB exposure, to levels much lower that the 'no observable effect level' were very damaging to lobsters. Monitoring work in Scotland has shown EMB to be present at much higher concentrations, and at much greater distances, than predicted by models, and at levels above the environmental quality standard (Berkeley et al. n.d.). The effect of the increased use of EMB, in response to the development of resistance and withdrawal of other chemicals, and its far-field transport, on non-target crustacea, remains poorly understood. Fish-farms also use a plethora of other chemicals in their routine operation. These chemicals include various biocides, antibiotics (Halling-Sørensen et al. 1998), and various copper-based anti-fouling chemicals (Fitridge et al. 2012) among others (Burridge et al. 2010; Tett 2008).

Biological control of lice offers considerable potential in the face of increased resistance to chemical control and increasing concern about the environmental consequences of chemicals on non-target organisms. Biological control of lice can be achieved using ‘cleaner-fish’. In the NE Atlantic (Scotland and Norway) cleaner fish are predominantly of the Labridae (wrasse) family. In Scotland and Norway wrasse were, initially, sourced from the wild and, as demand grew, this resulted in overfishing (Darwall et al. 1992; Torrissen et al. 2013). Where wrasse are bred specifically as cleaner-fish (Torrissen et al. 2013) their escape may pose similar environmental issues as those of escaped salmon in terms of genetic modification of native stocks. Cleaner-fish such as wrasse have very specific requirements in order to thrive and these must be met by the farmer if lice control is to be successful. Wrasse, for example, require shelters to protect them from bird predators (wrasse are inactive during darkness and vulnerable to predation at this time) and the salmon themselves. They are also vulnerable to extremes of temperature and salinity and require supplementary food where the lice are insufficiently abundant. There are also issues in matching the size of the wrasse and farmed fish, and the wrasse needs to be fed and trained not to take the farmed-fishes’ feed (Treasurer 2013). There remains an issue of supply as, at the recommended ~4% stocking density, 1.4 and 10 million wrasse will be required for the Scottish and Norwegian industries respectively (Treasurer 2013). Providing a reliable supply of cleaner-fish, and maintaining them in a healthy state whilst co-residing with salmon, is an active area of research (Treasurer and Feledi 2014).

5.2.6 Mussel-Farming, Plankton Alteration and Benthic Habitat Alteration

Mussels have an impressive filtration capacity and, where available, filter more particles than they ingest. The excess filtered material is mucus-wrapped and ejected as pseudo-faeces (Newell 2004). Ejected faecal and pseudofaecal material (collectively ‘biodeposits’) sinks and accumulates on the seabed to an extent dependent on site characteristics. The accumulated biodeposits constitute organic enrichment (Newell 2004) and the impacts are similar to those occurring around high-input fish-farms (see Sect. 6.4) but are generally less severe (Wilding 2012). The filtration capacity of mussels is such that their culture in high densities can make meaningful and large-scale changes in planktonic assemblages in the host water body (Grant et al. 2007, 2008; Jiang and Gibbs 2005) and, consequently, changes in light penetration through the water column. Changes in light penetration potentially affect both micro-and macro-phytobenthos (Newell 2004). The redistribution of organic matter by the introduction of mussel farms also has the potential to effect nutrient cycling in the host water body and promote denitrification/nutrient extraction where used carefully (Hughes et al. 2005; Stadmark and Conley 2011).

The culture of bivalves, including mussels, inevitably results in losses of stock to the seabed. This can be because of storms, overstocking, bird-predation or the direct dumping of unwanted stock. Detached mussels attract benthic predators/scavengers including crabs and starfish. In Scotland starfish were estimated to be ten times more abundant than at background levels in close proximity to mussel lines (Wilding and Nickell 2013) and this effect has been associated with increased reproductive success in starfish with unknown consequences (Inglis and Gust 2003). Empty shells, in various states of degradation (shell-hash) typifies production sites, can be several cm thick with >20 kg/m being recorded in some locations (Wilding and Nickell 2013). Shell hash is associated with varying quantities of trapped organic particles (including biodeposits) and, consequently, enhanced macrobenthic populations (Hartstein and Rowden 2004; Wilding and Nickell 2013).

5.3 Management Requirements

The local scale (100–500 m) impacts of salmon and mussel mariculture operations are relatively well understood (with some notable exceptions, e.g. the effects of chronic chemotheraputant use), reflecting the relative ease of detecting meaningful change over this spatial scale within a realistic sampling programme. Much less well understood are the larger-scale (ecosystem) consequences of mariculture (Holmer et al. 2008) though there is evidence of long-lasting, bay-scale impacts (Pohle et al. 2001). Within the Scottish context, other important industries that share space with mariculture sites are other mariculture operations (other fish-farms, mussel/oyster farms), commercial fishing, commercial shipping and amenity access (e.g. tourist yachting). In any management of impact from multiple sources there should be an allocation of pressures (e.g. nutrient release) through a planning process (Tett et al. 2011). However, within Scotland, the total environmental assimilative capacity is assessed and consents are given, on a first-come-first-served basis, until the threshold is reached. Mariculture operates within a system of ongoing change (e.g. natural trends and those attributable to large-scale anthropogenic sources such as climate change). For these reasons, larger-scale impacts are harder to detect and, importantly, harder to attribute to any one site or industry. Under these circumstances, large-scale (e.g. sea-loch or region) models can be useful and have been applied to predictively quantify salmon mariculture impacts in restricted exchange environments (Tett et al. 2011). In an assessment of the global-scale (life-cycle) assessment of salmon farming Pelletier and Tyedmers (2007) showed considerable regional differences in material/energy costs per unit of production and that the feed-stock source was the principal factor determining overall cost.

The degree of regulation of mariculture operations generally reflects the environmental regulatory culture in the host nation (Holmer et al. 2008) (Taylor and Wolff, Chap. 34). In Scotland, regulations regards the maximum biomass permitted at any given farm site is currently a major factor limiting the growth of the Scottish salmon-farming industry and is reducing its international competitiveness. However, at the time of writing fish-farm regulation is changing through the adoption of the 'Depositional Zone Regulation' (DZR) in line with the European Union's Water

Framework Directive (Tett 2008). As a consequence of this change the regulator will specify a descriptive maximum biomass for a given site, and allow increases above this level where these are demonstrably sustainable.

5.3.1 Improving Sustainable Management

One method of enhancing the sustainability of mariculture operations might include the adoption of Integrated Multi-trophic Aquaculture (IMTA; Chopin et al. 2001). IMTA is built on the principle of waste recycling, where wastes from higher trophic species (e.g. salmon) are captured by extractive species (e.g. mussels, macroalgae), which assimilate it into more valuable products (Chopin et al. 2001; Reid et al. 2009; Wang et al. 2012). Co-cultivation of high- and low-input mariculture species within the same water body has been practised on a large-scale in China since the 1980s. The largest of these sites is Sannggou Bay in the Shandong province of China in the Yellow Sea, which spans >100 km^2 and produces >240,000 t of seafood from >30 species (Fang et al. 2016). Within this water body fish in cages are grown with bivalves (scallops and clams), seaweeds (*Saccharina* and *Gracillaria* spp.), abalone and sea cucumbers. Evidence from this area has demonstrated reduced impacts through reduced waste accumulation and increased growth where species are integrated (Fang et al. 2016). This has also been reflected in European and North American IMTA systems, which have shown that kelp grown on long-lines adjacent to salmon in net pens have increased growth (Wang et al. 2014) but whether this can mitigate against the nutrient output from farms remains uncertain (Jansen et al. 2015). The extent of the real economic and environmental benefits of IMTA remains to be proven.

An alternative situation that could benefit from (non-integrated) multi-trophic aquaculture occurs in highly diluted systems where cultivated species (e.g. salmon and mussels) are considered within the larger water-body in the context of regional environmental carrying capacity (Hughes and Black 2016). This solution may not only be more productive in reducing the environmental impact of marine aquaculture expansion, but will help diversify the system away from reliance on monocultures.

5.3.2 Macroalgae and Biofuels

With the global drive to find a sustainable source of biofuel, attention has turned to macroalgae cultivation to provide an alternative feedstock (Ahmad et al. 2011; Borines et al. 2011; Bruton et al. 2009; Hughes et al. 2012). Macroaglae cultivation in Europe is currently driven by both the need for fossil fuel alternatives, and the production of high value extracts used in the food and pharmaceutical sectors. Currently, first generation biofuels are derived from starch, sugar, animal fats and vegetable oils and compete with global food production for the already limited agricultural resources. Biofuels produced from non-food crops have developed into a second generation fuel sector, from feedstocks such as waste vegetable oil and grasses. Although second generation biofuels don't directly compete with crop production for food, they still compete for arable land and water resources. As a result, third generation of biofuels derived from algae, primarily microalgae have become preferable as they provide fuel in much greater quantities than both first and second generation biofuels (Ahmad et al. 2011; Singh et al. 2011). One of the major restrictions of biofuel production from microalgae is their requirement for large volumes of water and fertilisers, although techniques could be improved for cost-effective production. Mariculture of macroalgae offers an alternative to microalgae (Kraan 2013), as they are currently cultivated in the oceans they do not compete for land, they do not require freshwater and are naturally fertilised by the nutrients available in the water column. Cultivation of macroalgae on a scale required for biofuel production has proven technically and economically difficult (Hughes et al. 2012; Kraan 2013). If macroalgae cultivation is to expand across Europe, it is important to understand the potential negative impacts this may have on the environment, before extensive production is established. Potential impacts will likely be a result of changes in the environment which are induced by hanging long-lines of macroalgae. These changes are largely comparable to long line shellfish culture, such as reduced flow, increased shading and organic enrichment from tissue loss. However, in contrast with shellfish cultivation which remove Particulate Organic Matter (POM) and release pseudofeaces into the water column, macroalgae will cause localised removal of dissolved inorganic nutrients and will exude some of those nutrients back into the water column.

Optimising seaweed culture is active research area and is being piloted in several parts of the world. Should this industry develop outside its traditional Asian setting, several significant environmental and economic challenges are likely to remain despite the relatively benign nature of farming. In common with the enormous changes to the landscape, habitats and biodiversity that have accompanied the wide establishment of grassland as animal fodder in terrestrial systems, the adoption of large scale macroalgal culture will necessarily cause changes to benthic and pelagic marine ecosystems. Marine spatial planning at the scale of seaboards is a significant challenge to policy formulation (Ounanian et al. 2012) although it is possible that synergies between competing users can be found to optimise resource use (Lacroix and Pioch 2011).

5.4 Outlook

The sea overs massive potential as a location for food production and mariculture will become an increasingly important sector providing food and energy to an expanding human population. Intensive mariculture (e.g. salmon) offers considerable potential to produce high-quality 'luxury' food for wealthy consumers but, in common with all intensive farming methods, will frequently interact negatively with the receiving environment. Whilst larger-scale, less-intensive crops, such as mussels and macroalgae offer considerable potential for low-input, lower-cost mariculture, their physical size means that they have considerable scope for negatively interacting with other users of the sea. Optimising the balance between the needs of societies' consumers whilst maintaining environmental ecosystems upon which they depend is a key challenge facing policy makers and regulators.

References

Ahmad AL, Yasin NHM, Derek CJC, Lim JK (2011) Microalgae as a sustainable energy source for biodiesel production: a review. Renew Sustain Energy Rev 15:584–593

Aldred N, Clare AS (2014) Mini-review: impact and dynamics of surface fouling by solitary and compound ascidians. Biofouling 30:259–270

Alexander KA, Freeman S, Potts T (2016) Navigating uncertain waters: European public perceptions of integrated multi trophic aquaculture (IMTA). Environ Sci Pol 61:230–237

Anderson SS, Hawkins AD (1978) Scaring seals by sound. Mammal Rev 8:19–24

Ashton GV, Willis KJ, Cook EJ, Burrows M (2007) Distribution of the introduced amphipod, Caprella mutica Schurin, 1935 (Amphipoda: Caprellida: Caprellidae) on the west coast of Scotland and a review of its global distribution. Hydrobiologia 590:31–41

Berkeley A, Schlicke T, Hills A, Best J (n.d.) Modelling of emamectin benzoate (EmBZ) seabed residues – briefing note. Available from SEPA by request

Black KS (1994) Bio-physical factors contributing to erosion resistance in natural cohesive sediments. Intercoh '94 – 4th Nearshore and estuarine cohesive sediment transport conference, Wallingford, England

Black KD (1998) The environmental interactions associated with fish culture. In: Black KD, Pickering AD (eds) Biology of farmed fish. Sheffield Academic Press, Sheffield, pp 284–326

Black KD, Cromey CJ, Dale A, Nickell TD (2009) Modelling benthic effects of large salmon cage farms in Scotland. Scottish Assocition for Marine Science, Oban, p 97

Borines MG, McHenry MP, de Leon RL (2011) Integrated macroalgae production for sustainable bioethanol, aquaculture and agriculture in Pacific island nations. Biofuel Bioprod Bior 5: 599–608

Bourret V, O'Reilly PT, Carr JW, Berg PR, Bernatchez L (2011) Temporal change in genetic integrity suggests loss of local adaptation in a wild Atlantic salmon (Salmo salar) population following introgression by farmed escapees. Heredity 106:500–510

Brandt MJ, Hoeschle C, Diederichs A, Betke K, Matuschek R, Witte S, Nehls G (2013) Far-reaching effects of a seal scarer on harbour porpoises, Phocoena phocoena. Aquat Conserv Mar Freshw Ecosyst 23:222–232

Bruton T, Lyons H, Lerat Y, Stanley MS, Rasmussen MB (2009). A review of the potential of marine algae as a source of biofuel in Ireland. http://www.seai.ie/Publications/Renewables_Publications_/Bioenergy/Algaereport.pdf, 88p

Burridge L, Weis JS, Cabello F, Pizarro J, Bostick K (2010) Chemical use in salmon aquaculture: a review of current practices and possible environmental effects. Aquaculture 306:7–23

Callaway R, Shinn AP, Grenfell SE, Bron JE, Burnell G, Cook EJ, Crumlish M, Culloty S, Davidson K, Ellis RP, Flynn KJ, Fox C, Green DM, Hays GC, Hughes AD, Johnston E, Lowe CD, Lupatsch I, Malham S, Mendzil AF, Nickell T, Pickerell T, Rowley AF, Stanley MS, Tocher DR, Turnbull JF, Webb G, Wootton E, Shields RJ (2012) Review of climate change impacts on marine aquaculture in the UK and Ireland. Aquat Conserv Mar Freshw Ecosyst 22: 389–421

Chopin T, Buschmann AH, Halling C, Troell M, Kautsky N, Neori A, Kraemer GP, Zertuche-Gonzalez JA, Yarish C, Neefus C (2001) Integrating seaweeds into marine aquaculture systems: a key toward sustainability. J Phycol 37:975–986

Cook EJ, Ashton G, Campbell M, Coutts A, Gollasch S, Hewitt C, Liu H, Minchin D, Ruiz G, Shucksmith R (2008) Non-native aquaculture species releases: implications for aquatic ecosystems. In: Holmer M, Black K, Duarte CM, Marba N, Karakassis I (eds) Aquaculture in the ecosystem. Springer, Berlin, pp 155–184

Coram A, Gordon J, Thompson D, Northridge S (2014) Evaluating and assessing the relative effectiveness of non-lethal measures, including acoustic deterrent devices, on marine mammals. Marine Scotland Report available at http://www.gov.scot/Resource/0046/00462305.pdf. Last accessed July 2016

Costello MJ (2006) Ecology of sea lice parasitic on farmed and wild fish. Trends Parasitol 22: 475–483

Costello MJ (2009) How sea lice from salmon farms may cause wild salmonid declines in Europe and North America and be a threat to fishes elsewhere. Proc R Soc Lond B Biol Sci 276:3385–3394

Cromey CJ, Nickell TD, Black KD (2002a) DEPOMOD – modelling the deposition and biological effects of waste solids from marine cage farms. Aquaculture 214:211–239

Cromey CJ, Nickell TD, Black KD, Provost PG, Griffiths CR (2002b) Validation of a fish farm waste resuspension model by use of a particulate tracer discharged from a point source in a coastal environment. Estuaries 25:916–929

Darwall WRT, Costello MJ, Donnelly R, Lysaght S (1992) Implications of life-history strategies for a new wrasse fishery. J Fish Biol 41:111–123

Dutertre M, Beninger PG, Barille L, Papin M, Haure J (2010) Rising water temperatures, reproduction and recruitment of an invasive oyster, Crassostrea gigas, on the French Atlantic coast. Mar Environ Res 69:1–9

Fang J, Zhang J, Xiao T, Huang D, Liu S (2016) Integrated multi-trophic aquaculture (IMTA) in Sanggou Bay, China. Aquac Environ Interact 8:201–205

FAO (2014a) FAO global aquaculture production volume and value statistics database updated to 2012. FAO Fisheries and Aquaculture Department, March 2014. ftp://ftp.fao.org/fi/stat/Overviews/AquacultureStatistics2012.pdf

FAO (2014b) Improving governance of aquaculture employment. A global assessment. FAO fisheries and aquaculture technical paper 575. http://www.fao.org/3/a-i3128e.pdf

FAO (2016) Statistical query result. Global aquaculture production online query: all continents, marine fishing areas, marine environment, all species, Year = 2014, Value = USD. http://www.fao.org/figis/servlet/TabSelector

Fiori E (2012) PhD thesis: Phytoplankton response to environmental variables and organic pollutants. Laboratory Cultures and Numerical Simulations Experiments, University of Bologna

Fitridge I, Dempster T, Guenther J, de Nys R (2012) The impact and control of biofouling in marine aquaculture: a review. Biofouling 28:649–669

Goetz T, Janik VM (2013) Acoustic deterrent devices to prevent pinniped depredation: efficiency, conservation concerns and possible solutions. Mar Ecol Prog Ser 492:285

Grant J, Bugden G, Horne E, Archambault MC, Carreau M (2007) Remote sensing of particle depletion by coastal suspension-feeders. Can J Fish Aquat Sci 64:387–390

Grant J, Bacher C, Cranford PJ, Guyondet T, Carreau M (2008) A spatially explicit ecosystem model of seston depletion in dense mussel culture. J Mar Syst 73:155–168

Hallegraeff GM (1993) A review of harmful algal blooms and their apparent global increase. Phycologia 32:79–99

Halling-Sørensen B, Nors Nielsen S, Lanzky PF, Ingerslev F, Holten Lützhøft HC, Jørgensen SE (1998) Occurrence, fate and effects of pharmaceutical substances in the environment – a review. Chemosphere 36:357–393

Hartstein ND, Rowden AA (2004) Effect of biodeposits from mussel culture on macroinvertebrate assemblages at sites of different hydrodynamic regime. Mar Environ Res 57:339–357

Heilskov AC, Holmer M (2001) Effects of benthic fauna on organic matter mineralization in fish-farm sediments: importance of size and abundance. ICES J Mar Sci 58:427–434

Holmer M, Hansen PK, Krakassis I, Borg JA, Schembri PJ (2008) Monitoring of environmental impacts of marine aquaculture. In: Holmer M, Black K, Duarte CM, Marba N, Karakassis I (eds) Aquaculture in the ecosystem. Springer, Berlin, pp 47–85

Hughes AD, Black KD (2016) Going beyond the search for solutions: understanding trade-offs in European integrated multi-trophic aquaculture development. Aquac Environ Interact 8:191–199
Hughes DJ, Cook EJ, Sayer MDJ (2005) Biofiltration and biofouling on artificial structures in Europe: the potential for mitigating organic impacts. Oceanogr Mar Biol Annu Rev 43:123–172
Hughes AD, Black KD, Campbell I, Davidson K, Kelly MS, Stanley MS (2012) Does seaweed offer a solution for bioenergy with biological carbon capture and storage? Greenhouse Gases Sci Technol 2:402–407
Inglis GJ, Gust N (2003) Potential indirect effects of shellfish culture on the reproductive success of benthic predators. J Appl Ecol 40:1077–1089
Jackson D, Drumm A, McEvoy S, Jensen Ø, Mendiola D, Gabiña G, Borg JA, Papageorgiou N, Karakassis Y, Black KD (2015) A pan-European valuation of the extent, causes and cost of escape events from sea cage fish farming. Aquaculture 436:21–26
Jansen HM, Handa A, Cranford P, Bannister R, Bergvik M, Broch OJ, Forbord S, Husa V, Olsen Y, Reitan KI, Skjermo J, Strand O (2015) Exploitation of nutrients from salmon aquaculture: what is the potential for IMTA in Norway. J Shellfish Res 34:644–644
Jefferson TA, Curry BE (1996) Acoustic methods of reducing or eliminating marine mammal-fishery interactions: do they work? Ocean Coast Manage 31:41–70
Jiang WM, Gibbs MT (2005) Predicting the carrying capacity of bivalve shellfish culture using a steady, linear food web model. Aquaculture 244:171–185
Jonsson B, Jonsson N (2006) Cultured Atlantic salmon in nature: a review of their ecology and interaction with wild fish. ICES J Mar Sci 63:1162–1181
Kaiser MJ, Laing I, Utting SD, Burnell GM (1998) Environmental impacts of bivalve mariculture. J Shellfish Res 17:59–66
Kapetsky JM, Aguilar-Manjarrez J, Jenness J (2013) A global assessment of potential for offshore mariculture development from a spatial perspective. FAO fisheries and aquaculture technical paper. no. 549. FAO, Rome, 181p. http://www.fao.org/docrep/017/i3100e/i3100e00.htm
Keeley N, Forrest B, Hopkins G, Gillespie P, Clement D, Webb S, Knight B, Gardner JPA (2009) Sustainable aquaculture in New Zealand: review of the ecological effects of farming shellfish and other non-finfish species. Ministry of Fisheries, Cawthron report no. 1476, 150p plus appendices
Kirk M, Esler D, Boyd WS (2007) Morphology and density of mussels on natural and aquaculture structure habitats: implications for sea duck predators. Mar Ecol Prog Ser 346:179–187
Kraan S (2013) Mass-cultivation of carbohydrate rich macroalgae, a possible solution for sustainable biofuel production. Mitig Adapt Strateg Glob Chang 18:27–46
Lacroix D, Pioch S (2011) The multi-use in wind farm projects: more conflicts or a win-win opportunity? Aquat Living Resour 24:129–135
Lees F, Baillie M, Gettinby G, Revie CW (2008) The efficacy of emamectin benzoate against infestations of *Lepeophtheirus salmonis*on farmed Atlantic Salmon (*Salmo salar*. L) in Scotland, 2002–2006. PLoS One 3:e1549
Lejzerowicz F, Esling P, Pillet L, Wilding TA, Black KD, Pawlowski J (2015) High-throughput sequencing and morphology perform equally well for benthic monitoring of marine ecosystems. Sci Rep 5:13932
Lepper P, Turner V, Goodson A, Black K (2004) Source levels and spectra emitted by three commercial aquaculture anti-predation devices. In: Proceedings of seventh European conference on underwater acoustics, ECUA
Liu Y, Bjelland HV (2014) Estimating costs of sea lice control strategy in Norway. Prev Vet Med 117:469–477
Matsuyama Y, Shumway S (2009) Impacts of harmful algal blooms on shellfisheries aquaculture. In: Allan, Burnell (eds). New technologies in aquaculture: improving production efficiency, quality and environmental management, Shellfish Aquaculture, Woodhead Publishing, pp 580–609, doi:10.1533/9781845696474.3.580
Michalek K, Ventura A, Sanders T (2016) Mytilus hybridisation and impact on aquaculture: a minireview. Mar Genomics 27:3–7

Molnar JL, Gamboa RL, Revenga C, Spalding MD (2008) Assessing the global threat of invasive species to marine biodiversity. Front Ecol Environ 6:485–492

Morton AB, Symonds HK (2002) Displacement of Orcinus orca (L.) by high amplitude sound in British Columbia, Canada. ICES J Mar Sci 59:71–80

Naylor RL, Hardy RW, Bureau DP, Chiu A, Elliott M, Farrell AP, Forster I, Gatlin DM, Goldburg RJ, Hua K, Nichols PD (2009) Feeding aquaculture in an era of finite resources. Proc Natl Acad Sci U S A 106:15103–15110

Nelson ML, Gilbert JR, Boyle KJ (2006) The influence of siting and deterrence methods on seal predation at Atlantic salmon (Salmo salar) farms in Maine, 2001–2003. Can J Fish Aquat Sci 63:1710–1721

Newell RIE (2004) Ecosystem influences of natural and cultivated populations of suspension-feeding bivalve molluscs: a review. J Shellfish Res 23:51–61

Northridge S, Cargill A, Coram A, Mandleberg L, Calderan S, Reid B (2010) Entanglement of minke whales in Scottish waters; an investigation into occurrence, causes and mitigation. Final report to Scottish Government CR/2007/49. http://www.smru.st-and.ac.uk/documents/347.pdf

Northridge S, Coram A, Gordon J (2013) Investigations on seal depredation at Scottish fish farms. Scottish Government, Edinburgh. http://www.smru.st-and.ac.uk/documents/1758.pdf

Olesiuk PF, Nichol LM, Sowden MJ, Ford JKB (2002) Effect of the sound generated by an acoustic harassment device on the relative abundance and distribution of harbor porpoises (Phocoena phocoena) in retreat passage, British Columbia. Mar Mamm Sci 18:843–862

Ounanian K, Delaney A, Raakjaer J, Ramirez-Monsalve P (2012) On unequal footing: stakeholder perspectives on the marine strategy framework directive as a mechanism of the ecosystem-based approach to marine management. Mar Pol 36:658–666

Pawlowski J, Esling P, Lejzerowicz F, Cordier T, Visco JA, Martins CIM, Kvalvik A, Staven K, Cedhagen T (2016) Benthic monitoring of salmon farms in Norway using foraminiferal metabarcoding. Aquac Environ Interact 8:371–386.

Pearson TH, Black K (2001) Environmental impacts of aquaculture. In: Black K (ed) Environmental impacts of aquaculture. Sheffield Academic Press, Sheffield, pp 1–31

Pearson T, Rosenberg R (1978) Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr Mar Biol Annu Rev 16:229–311

Pearson TH, Stanley SO (1979) Comparative measurement of the redox potential of marine sediments as a rapid means of assessing the effect of organic pollution. Mar Biol 53:371–379

Pelletier N, Tyedmers P (2007) Feeding farmed salmon: is organic better? Aquaculture 272:399–416

Piroddi C, Bearzi G, Christensen V (2011) Marine open cage aquaculture in the eastern Mediterranean Sea: a new trophic resource for bottlenose dolphins. Mar Ecol Prog Ser 440:255–U277

Plew DR, Stevens CL, Spigel RH, Hartstein ND (2005) Hydrodynamic implications of large offshore mussel farms. IEEE J Ocean Eng 30:95–108

Pohle G, Frost B, Findlay R (2001) Assessment of regional benthic impact of salmon mariculture within the Letang Inlet, Bay of Fundy. ICES J Mar Sci 58:417–426

Reid GK, Liutkus M, Robinson SMC, Chopin TR, Blair T, Lander T, Mullen J, Page F, Moccia RD (2009) A review of the biophysical properties of salmonid faeces: implications for aquaculture waste dispersal models and integrated multi-trophic aquaculture. Aquac Res 40:257–273

Ross BP, Lien J, Furness RW (2001) Use of underwater playback to reduce the impact of eiders on mussel farms. ICES J Mar Sci 58:517–524

Schakner ZA, Blumstein DT (2013) Behavioral biology of marine mammal deterrents: a review and prospectus. Biol Conserv 167:380–389

Schulz HD (2000) Redox measurements in marine sediments. In: Schüring J, Schulz HD, Fischer WR, Böttcher J, Duijnisveld WHM (eds) Redox: fundamentals, processes and applications. Springer, Berlin, Heidelberg, pp 235–246

Sepulveda M, Oliva D (2005) Interactions between South American sea lions Otaria flavescens (Shaw) and salmon farms in southern Chile. Aquac Res 36:1062–1068

Singh A, Nigam PS, Murphy JD (2011) Renewable fuels from algae: an answer to debatable land based fuels. Bioresour Technol 102:10–16
SSPO (2015) Code of good practice – seawater lochs. SSPO. http://thecodeofgoodpractice.co.uk/chapters/chapter-4-seawater-lochs/. Accessed July 2016
Stadmark J, Conley DJ (2011) Mussel farming as a nutrient reduction measure in the Baltic Sea: consideration of nutrient biogeochemical cycles. Mar Pollut Bull 62:1385–1388
Tett P (2008) Fish farm wastes in the ecosystem. In: Holmer M, Black K, Duarte CM, Marba N, Karakassis I (eds) Aquaculture in the ecosystem. Springer, Berlin, pp 1–46
Tett P, Portilla E, Gillibrand PA, Inall M (2011) Carrying capacity and assimilative capacities: the ACExR-LESV model for sea loch aquaculture. Aquac Res 42:51–67
Torrissen O, Jones S, Asche F, Guttormsen A, Skilbrei OT, Nilsen F, Horsberg TE, Jackson D (2013) Salmon lice – impact on wild salmonids and salmon aquaculture. J Fish Dis 36:171–194
Treasurer J (2013) Use of wrasse in sea lice control. Report commissioned by SARF. ISBN: 978-1-907266-56-0. http://www.sarf.org.uk/projects/
Treasurer J, Feledi T (2014) The physical condition and welfare of five species of wild-caught wrasse stocked under aquaculture conditions and when stocked in Atlantic Salmon, Salmo salar, production cages. J World Aquacult Soc 45:213–219
Treasurer JW, Wadsworth S, Grant A (2000) Resistance of sea lice, Lepeophtheirus salmonis (Krøyer), to hydrogen peroxide on farmed Atlantic salmon, Salmo salar L. Aquac Res 31:855–860
Waddy SL, Merritt VA, Hamilton-Gibson MN, Aiken DE (2010) Effect of emamectin benzoate on the molt cycle of ovigerous American lobsters Homarus americanus is influenced by the dosing regimen. Aquat Biol 11:47–52
Wang X, Olsen LM, Reitan KI, Olsen Y (2012) Discharge of nutrient wastes from salmon farms: environmental effects, and potential for integrated multi-trophic aquaculture. Aquac Environ Interact 2:267–283
Wang XX, Broch OJ, Forbord S, Handa A, Skjermo J, Reitan KI, Vadstein O, Olsen Y (2014) Assimilation of inorganic nutrients from salmon (Salmo salar) farming by the macroalgae (Saccharina latissima) in an exposed coastal environment: implications for integrated multi-trophic aquaculture. J Appl Phycol 26:1869–1878
Wilding TA (2012) Changes in sedimentary redox associated with mussel (*Mytilus edulis* L.) farms on the west-coast of Scotland. PLoS One 7(9):e45159
Wilding TA, Nickell TD (2013) Changes in benthos associated with mussel (*Mytilus edulis* L.) farms on the west-coast of Scotland. PLoS One 8:e68313
Wilding TA, Cromey CJ, Nickell TD, Hughes DJ (2012) Salmon farm impacts on muddy-sediment megabenthic assemblages on the west coast of Scotland. Aquac Environ Interact 2:145–156
Willis KJ, Gillibrand PA, Cromey CJ, Black KD (2005) Sea lice treatments on salmon farms have no adverse effects on zooplankton communities: a case study. Mar Pollut Bull 50:806–816
Wu RSS (1995) The environmental impact of marine fish culture: towards a sustainable future. Mar Pollut Bull 31:159–166
Xiang J-H (2007) Mariculture-related environmental concerns in the People's Republic of China. In: Bert TM (ed) Ecological and genetic implications of aquaculture activities. Springer, Netherlands, pp 219–228
Young MO (2015) Marine animal entanglements in mussel aquaculture gear. Masters thesis, University of Akureyri, University Centre of the Westfjords, Iceland. http://skemman.is/stream/get/1946/22522/50582/1/CMMthesis_final_Madeline_Young.pdf
Žydelis R, Esler D, Kirk M, Sean Boyd W (2009) Effects of off-bottom shellfish aquaculture on winter habitat use by molluscivorous sea ducks. Aquat Conserv Mar Freshwat Ecosyst 19:34–42

Chapter 6
Shipping

Alan Simcock

Abstract Shipping has been an important part of the world economy for at least 4000 years. With the advent of steamships in the nineteenth century, international trade blossomed. Recent developments, particularly in containerization, have increased the economic significance of shipping. As ships have increased in size, and the amount of trade that they carry has increased, the risks to the environment have likewise increased. These risks involve pollution from oil, hazardous and noxious substances, sewage, garbage, antifouling treatments, noise and wrecks. Over the past 40 years, increasing efforts have been made to manage these risks. These have been successful in respect of ship losses and oil pollution, but other areas remain of concern.

Keywords Cargo • Ferry • Garbage • Hazardous • HNS • MARPOL • Noise • Noxious • Oil • Passenger • Pollution; Sewage • Shipping • Vessel

6.1 Structure and State of the Shipping Sector

6.1.1 Structure of Shipping

Shipping has been fundamental to large parts of the world's economy for at least 4000 years: the Bronze Age largely relied on long-distance imports of tin to achieve its successes in introducing metal tools. From the fifteenth century CE, the development of trade routes across the Atlantic, Indian and Pacific Oceans transformed the world. The introduction of steamships in the nineteenth century CE produced an increase of several orders of magnitude in world trade. Because of the importance of shipping to the global economy, the United Nations has created a specialised agency, the International Maritime Organization (IMO) to consider the issues that it raises.

A. Simcock
Joint Coordinator, United Nations World Ocean Assessment I, Richmond, Surrey, UK
e-mail: ajcsimcock@aol.com

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_6

In the last 60 years, the introduction of standardized containers has transformed general cargo shipping, which previously had to be loaded package by package with relatively long times to turn ships around and high labour costs. The convenience of being able to handle practically all forms of general cargo in this way is a major factor in producing the massive expansion of long-distance maritime transport. For a long time (1990–2005), growth in containerized cargo transport was on average 3.4 times the growth in world GDP (UNCTAD 2014). At the same time, carriage of bulk cargoes has increased with the demand for fuel, ores and grain (UNCTAD 2015).

An imbalance in cargo movements between developed and developing countries existed until recently: cargo volumes loaded in the ports of developing countries far exceeded the volumes of goods unloaded. This reflected the difference in volume of exports from developing countries (dominated by raw materials) and their imports (substantially finished goods). Over the past four decades, this has changed, unloadings in the ports of developing countries have steadily climbed, reaching parity with loadings in 2013, driven by the fast-growing import demand in developing regions, fuelled by their industrialization and rapidly rising consumer demand (UNCTAD 2015).

Long-distance cargo capacity is largely traded on a global market, which is focused on certain cities with well-established local shipbroking networks, such as Athens (Piraeus) in Greece; Hong Kong and Shanghai in China; London in the United Kingdom and New York in the United States. This market covers both ships operated principally by those who own them, and ships whose owners generally expect to charter them out to other firms to operate. Ships can easily switch between these categories, depending on the levels of supply and demand in the market.

Overall, the pattern has been one of bigger ships offered by fewer companies. Although, in general, the level of service for cargo carriage by regular sailings, as shown by the UNCTAD Liner Shipping Connectivity Index, has improved over the past decade, the result of concentrating cargo in bigger vessels owned by bigger companies has been to reduce the level of competition (UNCTAD 2015). It seems probable that there will be further concentration through collaboration in the scheduling of sailings and allocation of cargo to sailings. (SCD 2014; Lloyds List 2014).

As a result of the growth in passenger air transport over the past half century, passenger traffic is now largely confined to short-distance ferries and cruise ships. Maritime ferry traffic has been transformed by the introduction of sea-going "roll-on/roll-off" (RO/RO) ferries for road vehicles from the 1940s and 1950s. For short sea crossings, this has had as great an effect as the introduction of container traffic for longer sea voyages. For passenger traffic, the use of RO/RO ferries for coaches has expanded the market substantially (Wergeland 2012).

There is a marked divergence between the State of registration and the nationalities of the owners of the vessels employed in maritime trade. Well over half of the global gross tonnage[1] of merchant vessels over 100 gross tonnage is registered with States which have "open registers" (which usually have less stringent requirements on the nationality and pay of crews): Panama (22% of the global total), Liberia (12%),

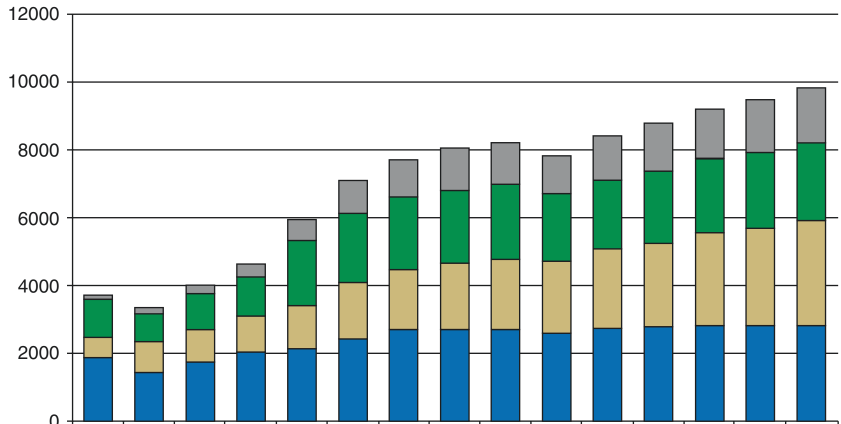
[1] "Gross tonnage" is a measure of the "moulded volume of all enclosed spaces of the ship" (International Convention on the Tonnage Measurement of Ships, 1969, and is calculated from the volume of the ship multiplied by a reduction factor which increases with the size of the ship.

the Marshall Islands (9%) and Hong Kong (China) (8%) account for over half of the total global gross tonnage. In contrast, the five States whose nationals own or control over half of the ships of over 1000 gross tonnage are Greece (15% of the global total), Japan (14%), China (12%), Germany (8%) and the Republic of Korea (5%). Since international agreements on shipping usually require acceptance by States with a specified proportion of the world's ships on their registers, there is thus a mismatch between formal responsibility and economic interests (Simcock et al. 2017).

6.1.2 *Scale of Shipping*

Long-distance cargo transport by sea is now crucial to the global economy. As Fig. 6.1 shows, over the past quarter-century, transport of this kind have substantially more than doubled in quantity carried: the index of world seaborne trade has increased by about 233% over that period, compared with an increase of about 150% in world Gross Domestic Product (UNCTAD 2015).

Sea transport also carries much freight on shorter routes. In Europe, in 1999 43% of the total freight tonne-miles within Europe (including both international and national traffic) were estimated to be carried on short-sea journeys, and efforts are in hand to increase this. The "America's Marine Highway Program" in the USA has a similar goal. Both these aim to reduce road congestion and air pollution (EC 1999; MARAD 2014; USMA 2014). Elsewhere, containerization is leading to rapid growth in short-sea coastal freight movements: for example, in Brazil, the volume of containers carried in coastwise traffic grew by 3,050% between 1999 and 2008 (Dias 2009).



	1980	1985	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Container	102	152	234	371	598	969	1076	1193	1249	1127	1280	1393	1464	1544	1631
Other dry cargo	1123	819	1031	1125	1928	2009	2112	2141	2173	2004	2022	2112	2150	2218	2272
Five major bulks	608	900	988	1105	1295	1709	1814	1953	2065	2085	2335	2486	2742	2923	3112
Oil and gas	1871	1459	1755	2050	2163	2422	2698	2747	2742	2642	2772	2794	2841	2829	2826

Fig. 6.1 International seaborne trade for selected years 1980–2014. Note: The "five major bulks" are iron ore, grain, coal, bauxite/alumina and phosphate rock. Source: UNCTAD (2015)

Passenger carriage on cruise ships has grown rapidly and steadily: in 1990, there were around 3.8 million cruise journeys by individuals; in 2013, there were 21.6 million (CMW 2014).

6.1.3 Regional Spread

The different main trades have substantially different patterns and distribution of sailings: the container routes are concentrated in the East/West belt around the southern part of the northern hemisphere and are very regular in their sailings, while both the five main bulk dry cargoes (iron ore, coal, grain, bauxite/alumina and phosphate rock) and the oil and gas trade are focused on the sources of these cargoes. Their sailings are also affected by changes in the market prices for these commodities. The mineral cargoes, in particular, have strong emphases on routes from Africa, South America, Australia and Indonesia to eastern Asia (Kaluza et al. 2010). Significant changes in maritime traffic routes could result from developments in extracting hydrocarbons from the earth: the growth of the shale gas industry of the United States of America, for example, is leading to major falls in United States imports, and growth of United States exports, with consequent changes in trade routes (EPA 2014a). Figure 6.2 shows the overall concentration of shipping routes in January 2016, based on satellite observations of signals from ships' Automatic Identification Systems (AIS).

Global warming is creating the possibility of shipping routes from the Far East to Europe and eastern North America (at least in summer) around the north coasts of Eurasia and North America. More ships are using these routes, because of the substantial cost savings (up to 35%), but the risks from lack of navigational aids and other support are substantial (Laulajainen 2009; COMNAP 2005; TRB 2012).

For non-cargo shipping, ferries are very much concentrated in the Caribbean (11% of world ferry passengers), the Mediterranean (21%) and South-East Asia (44%) (Wergeland 2012). For passenger shipping on cruises, the main areas are the

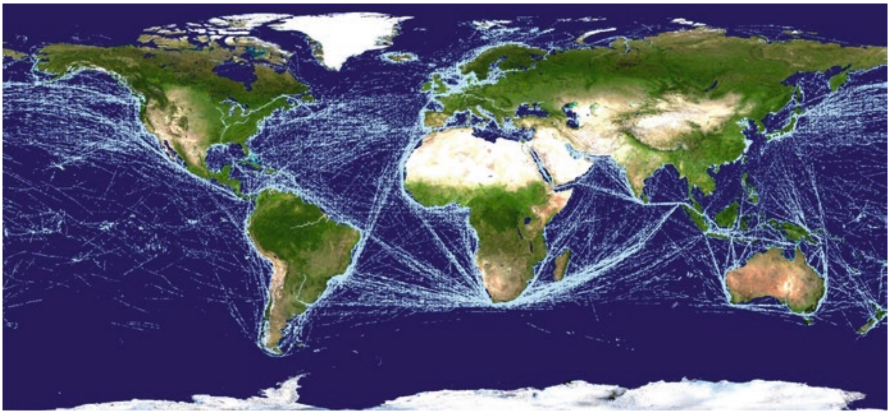


Fig. 6.2 World shipping routes, January 2016. Source: European Space Agency (2016)

Caribbean (34% of the market in 2013), the Mediterranean (22%) and the Baltic and northern Europe (11%). Over half the passengers were from the USA, and another quarter from Europe (CLIA 2014).

6.1.4 Economic Aspects

The economic significance of shipping can be seen from the relationship between international cargo traffic and the growth of the world economy (see Sect. 6.1.2). The economics of shipping itself, however, are more problematical. The long period of rapid growth encouraged massive investment in increasing the size of the global fleet. The 2008 financial crisis reduced demand, but new ships continued to be delivered. The resulting overcapacity and consequent severe competition meant that many shipping lines became unprofitable. Economic recovery is slowing restoring equilibrium, but further economic uncertainty may lead to shortages of shipping capacity in a few years' time (UNCTAD 2015).

6.2 Impacts of Shipping on the Marine Environment

6.2.1 Introduction

The impacts of shipping on the marine environment can be divided into the catastrophic and the chronic. Catastrophic impacts on the marine environment result from disasters involving the ship, and may lead to its total loss: for example, collisions, fires, foundering and wrecks. Chronic impacts are those that result from the day-to-day operation of ships, without calling into question the ship's integrity or continued functioning (Donaldson 1994).

6.2.2 Oil

Oil spills from shipping have a wide range of impacts. Catastrophic discharges of large amounts of hydrocarbons will produce large oil slicks with consequentially massive impacts. Smaller slicks will have lesser impacts, but may be equally serious if they are repeated frequently. Many smaller slicks result from chronic discharges. The impacts of both catastrophic and chronic discharges range from covering seabirds with oil (which can lead to death), through killing and tainting fish and shellfish and making the stock of fish farms unusable to covering beaches and rocky shores with oil (which can adversely affect tourism). In specific cases, problems can be caused for industries that rely on an intake of seawater (such as marine salt production, desalinization plants and coastal power stations) and coastal installations (such as marinas, ports and harbours) (ITOPF 2015).

In summarising general experience with oil spills, the study on the environmental impact of the spill of 85,000 tonnes of crude oil in the 1993 Braer catastrophe (Ritchie and O'Sullivan 1994) drew attention to three important features of major oil spills:

(a) There is an initial, very serious impact, usually with extensive mortality of seabirds, marine mammals, fish and benthic biota and coastal pollution;
(b) In many circumstances, however, marine ecosystems will recover relatively quickly from oil spills: crude oil loses most of its toxicity within a few days of being spilled at sea, mortality of marine biota declines rapidly thereafter, sublethal effects are of limited long-term significance and marine ecosystems recover well where there are nearby sources of replacement biota;
(c) Nevertheless, the local circumstances of an oil spill will be very significant. Rocky shores will be worse affected than sandy coasts. The impact on seabirds, marine mammals and sessile biota will also obviously be worse if the spill occurs in areas where they are present in large numbers at the season when the spill occurs—the location of breeding and nursery areas and migration routes and other regular concentrations being particularly important.

The ambient temperature is one of the local circumstances that are most significant for the duration of the impact and the timing of recovery. In warmer areas, the bacteria that break down hydrocarbons are more active, and the effects will disappear more quickly. In spite of the size (about one million tonnes) of the discharges (not including the airborne deposits from the burning of a further 67 million tonnes), the effect on the coasts of Kuwait and Saudi Arabia of the discharges from oil wells during the Gulf War in 1991 was largely disappearing within 18 months. These coasts had largely recovered within 5 years. However, oil appears to have persisted in salt marshes and at lower depths in the lower sediments as a result of their anaerobic condition (Readman et al. 1992; Jones et al. 1994; Otsuki et al. 1998; Barth 2001). In colder areas, on the other hand, bacterial activity is much lower, and the effects of oil spills persist much longer. The impact of the Exxon Valdez disaster in Alaska, in which 35,000 tonnes of oil were spilt in 1989, was still measurable 20 years later (Kendall et al. 2001; EVOSTC 2010).

The risks of environmental damage from oil transport by sea are clearly linked to the amount transported. That amount, in terms of quantities carried and the distances covered, grew rapidly after the Second World War to a peak of about 10,000 billion tonne-miles immediately before the 1974 increases in oil prices. Those increases produced a drop in the amount of transport over the next decade of about 50%. Since about 1985, however, the amount of oil transport by sea has risen continuously (with a brief remission after the 2008 financial crisis) to reach 10,000 billion tonne-miles again by 2014 (ITOPF 2015).

The risks from this transport have, however, substantial reduced over the same period: the number of incidents resulting in spills of more than 7 tonnes has fallen from a peak of over 100 in 1974 to less than 5 in 2014. As well as the number of incidents, there has been a massive reduction in the amount of oil involved: the estimated amounts of oil spilled worldwide in spills of more than 7 tonnes has fallen from an average of around 300,000 tonnes a year in the 1970s to around 3000 tonnes a year in recent years (ITOPF 2015).

Nevertheless, a significant problem remains, especially near major shipping routes. A study has shown that even low levels of oil fouling in Magellanic penguins (*Spheniscus magellanicus*) appear to be sufficient to interfere with reproduction (Fowler et al. 1995). One way in which the extent of the remaining problem can be seen is from observations on shorelines of the proportion of the dead seabirds found there which have been contaminated by oil. Diving seabirds are very sensitive to oil pollution: once such a bird is polluted with oil, it is likely to die from hypothermia and/or inability to forage. In the MARPOL North-Western Europe Special Area (see Sect. 6.6.2 below), about 40% of the common guillemots (*Uria aalge*) found dead on beaches near the major shipping routes in the southern North Sea were contaminated with oil, compared with about 4% around the Orkney Islands (OSPAR 2010). Similar reports have been made about the oiling of seabirds in other areas with high levels of shipping: in the MARPOL Southern South Africa Waters Special Area, studies note that, on the basis of the proportion of the population that has been affected, the African penguin is considered to have suffered more from oiling than any other seabird species globally (Wolfaardt et al. 2009; Garcia-Borboroglu et al. 2013). In the Straits of Malacca, there is a serious problem with illegal discharges of oil: during the five-year period from 2000 to 2005, there were 144 cases of oil spills into the sea; of this number, 108 cases were due to illegal discharges from ships (BOBLME Malaysia 2011). In the waters around south-eastern South America, used both by coastwise local shipping and large vessels travelling between the Atlantic and Pacific Oceans, a study showed that between 1980 and 1994 some 22,000 adult and some 20,000 juvenile Magellanic penguins were being killed each year by oil from discharges from ships passing through the foraging areas for their colonies on the coast (Gandini et al. 1994). Some reports suggest that the solution adopted in 1997 of requiring coastal shipping to follow routes further out to sea may have reduced this problem: over the years 2001–2007, the number of oiled penguins observed annually was around 100 (Argentina 1998; Boersma 2008). Further north, on the Atlantic coast of Canada, there are also reports of substantial numbers of seabirds being killed by oil. A conservative estimate is put at 300,000 birds a year, with appreciable effects on the populations of species commonly suffering this fate (Canada 2011).

6.2.3 Hazardous and Noxious Substances and Other Cargoes Capable of Causing Harm

Oil is not the only ship's cargo capable of causing damage. Much depends on the quantities involved—large quantities of nearly any cargo can have an adverse impact, at least on the local environment. The international rules (see Sect. 6.6.2 below) require precautions against damage from a wide range of other cargoes. The impacts will, of course, depend on the nature of the cargo. The harmful impact of most of the relatively inert substances carried in bulk (coal, ore, grain) is most likely to be the smothering of the seabed and coastline. Some chemical cargoes, however, will be inherently harmful.

Data on marine pollution incidents involving hazardous and noxious substances are scarce (FSI 2012). A 2010 study looking at 312 reported incidents of this kind between 1965 and 2009, mainly in the North Atlantic, concluded that reports had become much more frequent since about 2000, with the advent of the internet. It found that about 33% of the cases involved bad weather or structural damage, 30% collision or grounding, 11% fire or explosion and only 6% failures in loading or unloading. Only about half the cases involved discharges into the sea. The three most common substances involved were iron ore, sulphuric acid and caustic soda (Cedre 2010).

The increased use of containers means that a substantial amount of hazardous or noxious substances is being carried in containers. In 2011 a group of container owners set up a voluntary system to report incidents involving containers, such as fires and spillages, with a view to analysing the data to see if any patterns emerged which could be useful for risk reduction. The Container Notification Information System now covers about 60% of all container slot capacity. Data on the number of incidents have not yet been published, but the published conclusions on incidents causing, or likely to cause, injury or loss of life, damage to ships and other assets and environmental damage show that for 2015 52% of the reported incidents resulted from leakage, 30% involved containers where the contents had been mis-declared and 26% involved hazardous or noxious cargos. No particular global pattern of loading ports emerged from the incidents (CINS 2014).

Containers lost overboard are another source of potential pollution from hazardous and noxious substances. Some estimates have suggested that the numbers of such containers could be in the thousands annually. However, the World Shipping Council, based on a survey to which 70% of the global container shipping capacity responded, estimated in 2011 that about 350 containers are lost overboard each year, excluding mass losses of 50 or more containers as a result of a major ship disaster. If those mass losses are included, the number of containers lost rises to about 650 a year out of about 100 million carried annually (WSC 2011). On the other hand, it must be remembered that even one container lost overboard can have a lasting and widespread effect on the marine environment: a container holding 28,800 plastic yellow ducks, red beavers, blue turtles and green frogs was lost in 1992 in the middle of the Pacific. The toys have been washed up not only all around the Pacific, but also as far away as the Hebrides in the United Kingdom in 2003 (Ebbesmeyer and Scigliano 2009).

6.2.4 Sewage

The problems from the discharge of sewage (in the narrow sense of human and animal urine and fæcal waste) from ships are the same as those for similar discharges from land (for which see Chap. 16). Basically, the problems are the introduction of nutrients into the sea, and the introduction of waterborne pathogens. These are issues of particular importance for coastal waters. Away from land, the oceans are capable of assimilating and dealing with raw sewage through natural bacterial action.

6.2.5 Garbage

There is no doubt that a substantial part of the marine debris considered in Chap. 23 originates from ships. The damage to the environment from this marine debris is described in that chapter. This debris is constituted by waste from the normal operations of the ship that is thrown overboard. All the serious (and not entirely understood) consequences of marine debris described in that chapter therefore apply to this chronic form of discharge from ships. Because of the large numbers of passengers that they carry, cruise ships generate a high proportion of the garbage generated at sea—in 1995, the United States National Research Council estimated that cruise ships produced 24% of the solid waste generated on board ships, although they represented only 1% of the world fleet (NRC 1995). Because of the scale of the challenge, most large cruise ships now incinerate on board each day a high proportion of the waste that they generate (75–85% of garbage is generally incinerated on board on large ships (EPA 2008)).

6.2.6 Air Pollution

Since the replacement of sail by steam and then diesel, ships have been making emissions to the air. By the early 1990s it was becoming apparent that, in some parts of the world, emissions of nitrogen oxides (NO_x) and sulphur oxides (SO_x) from ships were becoming a serious element in air pollution for coastal States with heavy shipping traffic in their coastal waters (OSPAR 2000). Even short-term exposure to NO_x produces adverse respiratory effects, including airway inflammation, in healthy people and increased respiratory symptoms in people with asthma. It also reduces resistance to respiratory infections (Knelson and Lee 1977; Lee 1980; EPA 2014b). Airborne NO_x is also a substantial source of nitrogen inputs into coastal waters, and can thus contribute to excessive levels of nutrients (OSPAR 2010: see also Chap. 22). Exposure to SO_x likewise weakens resistance to respiratory infections, and is linked to higher rates of mortality in humans. It is also a contributor (with land-based emissions) to acid rain, which can harm forests and fresh waters (Rall 1974; Greaver et al. 2012).

SO_x emissions from ships have been worsening for decades, as a result of the increasing restrictions on the levels of sulphur in hydrocarbon fuels used on land: as restrictions have reduced the extent to which fuel oils with higher sulphur content can be used on land, so such fuel oils have become more attractive for use at sea, because there were no restrictions and the reduced demand on land lowered the price.

NO_x and SO_x, together with volatile organic compounds (VOCs), can also react in sunlight to produce smog, which affects many major cities: for coastal cities, emissions from ships can contribute to this problem (EPA 2014c).

In addition, shipping was seen as a further source of chlorofluorocarbons and other substances which were contributing to the depletion of the ozone layer, and thus increasing ultraviolet radiation on the earth's surface (GESAMP 2001).

Estimates in 1997 of total global NO_x emissions from shipping suggested that they were equivalent to 42% of such emissions in North America and 74% of those in European OECD countries, and that total global SO_x emissions from shipping were equivalent to 35% of such emissions in North America and 53% of such emissions in European OECD countries. The global emissions of both NO_x and SO_x were concentrated in the northern hemisphere (Corbett and Fischbeck 1997). Emissions from shipping have therefore been seen as a significant contributory source of air pollution in many parts of the world.

The burning of fossil fuel by ships is also a significant component of the world's emissions of "greenhouse gases"—especially carbon dioxide (CO_2). An IMO study concluded that international shipping emitted 885 million tonnes of CO_2 in 2007–2.8% of the global emissions of CO_2. Emissions fell to 796 million tonnes by 2012 with the drop in shipping as a result of the economic crisis, but are likely to recover (IMO 2014a).

6.2.7 Anti-Fouling Treatments

Ships have always been at risk of marine organisms (such as barnacles) taking up residence on their hulls. This increases the resistance of the hull in its passage through water, and thus slows its speed and increases the fuel requirement. With fuel being around half the operating cost of a vessel, this can be a significant extra cost. Historically, the response involved taking the ship out of water and scraping the hull. Because of the inconvenience and cost of this, various treatments developed, mostly involving the application copper sheeting or copper-based paints. In the 1960s, organic compounds of tin were developed, which were shown to be very effective when applied as paints to ships' hulls, with the tin compounds leaching into the water. The most effective was tributyl tin (TBT) (Santillo et al. 2001). By the late 1970s they were commonly used on commercial and recreational craft from developed countries. In the late 1970s and early 1980s, oyster (*Crassostrea gigas*) harvests in Arcachon Bay, France, failed. Subsequent research identified that TBT was the cause. At the same time, research in the United Kingdom showed that TBT was an endocrine disruptor in a marine whelk species (*Nucella lapillus*) causing masculinisation (imposex) in females and widespread population decline (Gibbs and Bryan 1986).

6.2.8 Wrecks

The seabed is littered with the remains of shipwrecks, some dating as far back as the second millennium BCE. The main impact on the marine environment comes from more recent wrecks, since the introduction of fuel oil as the source of the motive force. Such more recent wrecks will usually contain bunkers, which will eventually leak, and become a new source of oil pollution of the sea. Likewise, cargoes may present dangers of pollution from oil or hazardous substances. There are a number of other problems: first, and depending on its location, a wreck may constitute a hazard to navigation. Secondly, substantial costs are likely to be involved in the location, marking and removal of hazardous wrecks.

6.2.9 Invasive Species

Invasive non-native species are a major and growing cause of biodiversity loss. They can cause health problems, damage infrastructure and facilities, disrupt capture fisheries and aquaculture and destroy habitats and ecosystems. In some cases, the transport by shipping is clear. For example, in 1991 and 1992, the bacterium that causes cholera (*Vibrio cholerae*) was found in ballast water from five cargo ships in ports in the United States along the Gulf of Mexico (McCarthy and Khambaty 1994). In other cases, it can be inferred. These problems are further discussed in Chap. 25.

6.2.10 Noise

The marine environment is subject to a wide array of human-made noise from activities such as commercial shipping, oil and gas exploration and the use of various types of sonar. This human activity is an important component of oceanic background noise and can dominate in coastal waters and shallow seas. Long-term measurements of ocean ambient sound indicate that low frequency anthropogenic noise has been increased, primarily due to commercial shipping, both as a result of increases in the amount of shipping and as a result of developments in vessel design (particularly of propellers), which have not prioritised noise reduction. Shipping noise is centred in the 20 to 200 Hz frequency band. Noise at these low frequencies propagates efficiently in the sea, and can therefore affect marine biota over long distances. Baleen whales use the same frequency band for some of their communication signals. A variety of other marine animals are known to be affected by anthropogenic noise in the ocean. Negative impacts for least 55 marine species (cetaceans, fish, marine turtles and invertebrates) have been reported in scientific studies. The effects can range from mild behavioural responses to complete avoidance of the affected area. A 1993 study concluded that "low-frequency noise levels increased by more than 10 dB in many parts of the world between 1950 and 1975," corresponding to about 0.55 dB per year. A 2002 study indicated an increase of approximately 10 dB over 33 years (about 0.3 dB per year). Subsequent measurements up to 2007 confirmed this but suggest that, in some places at least, the subsequent rate of increase has slowed or stopped. It is generally agreed that anthropogenic noise can be an important stressor for marine life and is widely regarded as a global issue that needs addressing (NRC 2003; Tyack 2008; Andrew et al. 2011; UNEP 2012).

6.3 Cumulative Effects

As demonstrated in Fig. 6.2, shipping affects the marine environment around the world. As discussed in the sections on the impacts of shipping on the marine environment, there is no doubt that shipping noise and oil pollution from ships' activities affect a broad spectrum of the marine environment. Marine garbage also contributes significantly to the global problems of marine debris. Leaving aside the impact of major marine catastrophes, however, it is extremely difficult to measure the extent to which these various impacts are contributing to the worldwide adverse impacts of human activities on the marine environment. The individual impact of any one ship is marginal, but the collective impact of concentrated shipping lanes can be significant (see the discussion of the impact of oil pollution on the common guillemot in Sect. 6.2.2).

6.4 Costs of Environmental Degradation

Because the events from shipping that cause environmental degradation are scattered across the whole globe, it is a major problem to ascertain the environmental damage that they have caused and to evaluate it. In one area, however, it is possible to begin to see the scale of the damage that can be caused by catastrophic shipping events. After the 1967 Torrey Canyon disaster, many States sought to make it easier for those suffering economic damage to obtain reparation. The 1969 International Convention on Civil Liability for Oil Pollution Damage and the 1971 International Convention on the Establishment of an International Fund for Compensation for Oil Pollution aimed to achieve this. These Conventions were revised in 1992 and the revisions came into force in 1996. By October 2016, 114 States (representing 95% of the world's merchant fleet) were parties to both the 1992 Conventions, and 24 States have become parties to a supplementary protocol providing for additional compensation if the damage exceeds the limits of the 1992 Convention. The economic effect of the Conventions is basically to transfer the economic consequences of an oil spill from the coastal State to the States in which undertakings receive cargoes of oil. This is done either through the insurance costs which the cargo carriers have to incur and include in the costs of the voyages or (to the extent that the damage exceeds the amount insured and the coastal State participates in the funds) through the contributions paid to the funds by those that receive oil cargoes and are located in the States parties.

The damage that can be compensated under these arrangements extends to: property damage, costs of clean-up operations at sea and on shore, economic losses by fishermen or those engaged in mariculture, economic losses in the tourism sector and costs for reinstatement of the environment. From 1972 up to the end of 2013, the Funds had dealt with 149 incidents. The largest amounts of compensation paid out were for the *Erika* (off the coast of France—€128 million) and the *Prestige* (off the coast of Spain—€122 million) (IOPCF 2014).

6.5 International Agreements and Management Requirements

As the foregoing demonstrates, shipping can impact on the environment in many ways. The fundamental feature of all environmental impacts of shipping is that much international shipping is mobile over great distances—that is its whole point. Much shipping activity will therefore traverse many jurisdictions and much will also be in areas beyond all national jurisdiction. Even within national jurisdictions, moreover, ships have the rights of innocent passage, with limited circumstances in which the coastal jurisdictions can intervene. While ships are always subject to the jurisdiction of their flag State, practical considerations limit the extent to which such jurisdiction can be applied when the ship is away from the flag State's ports.

In codifying the abilities of States to control the impact of shipping on the environment, the United Nations Convention on the Law of the Sea (UNCLOS 1982) places great emphasis on the establishment of global standards by the appropriate international organization—in practice, the IMO. Through the IMO, and with its support, a whole range of international conventions and other regulations and standards have been established, covering most of the forms of environmental impact from shipping.

For most of the major threats to the ocean from shipping, the International Convention on the Prevention of Pollution from Ships (adopted in 1973, adapted in 1978 to facilitate its entry into force, and known as MARPOL 1973/78) provides the technical specifications for preventing and reducing the threats. It entered into force for the provisions relating to oil and noxious liquids in bulk in 1983. Under the IMO, a further range of international instruments have been developed since then, some in the form of annexes to MARPOL, others in the form of free-standing instruments. These are discussed below.

However, it is not only international conventions specifically focused on the environment that are relevant to managing the impact of shipping on the environment. The Convention on the International Regulations for Preventing Collisions at Sea (COLREG 1972, as amended), the International Convention on Safety of Life at Sea (SOLAS 1974 as amended),. and the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW 1978 as amended) are also of the highest significance, since it is through these conventions and their supporting guidelines and standards that so much progress has been made in reducing maritime catastrophes, and with them their impact on the environment. By ensuring the safe construction of vessels and their safe operation by means of requiring construction standards, safe navigation methods, and the proper training and deployment of the crew, these conventions have played a major role. At the same time, the IMO has agreed a wide range of traffic management schemes, to help prevent collisions and to protect particularly sensitive sea areas (PSSAs) (IMO 2016a, b). Over the long term, losses of ships have fallen from about 1 in 100 ships in 1912 to about 1 in 670 ships in 2009, in spite of a 200% increase in the size of the global fleet (Allianz 2012).

6.6 Regulation

The starting point for the effective sustainable environmental management of shipping thus has to be the international rules that have been adopted.

6.6.1 Oil

The problem of pollution from oil was the starting point of MARPOL, and the rules to prevent it are in its Annex I. The Annex covers the construction of oil tankers, their operation, what discharges of oily water are permitted, the equipment that must be used and the record-keeping required about any discharges. These requirements have been strengthened over time. In particular, it required the phasing out of single-hulled oil tankers by, at the latest, 2015.

MARPOL Annex I not only prohibits any discharge into the sea of oil or oily mixtures from any ships in the waters around Antarctica, but also provides for the designation of Special Areas, in which more stringent limits on the discharge of oily water apply. As a counterpart to the designation of Special Areas, coastal States in a Special Area must be parties to MARPOL and must provide appropriate reception facilities for oily waste. An important feature of Special Areas is that the maximum permitted level of oil in water discharged is 15 parts per million. In a number of States, the legal system considers that any visible slick on the sea surface must have been caused by a discharge above this level (for examples, see NSN 2012). Special Areas have been designated, and are in force, in the Mediterranean Sea, the Baltic Sea, the Black Sea, the "Gulfs Area",[2] the Antarctic Area (south of 60°S), North-West European Waters and Southern South African waters. Three further areas have been designated, but are not yet in force because the coastal States have not all notified IMO that adequate reception facilities are in place: the Red Sea, the Gulf of Aden and the Oman area of the Arabian Sea (IMO 2016c).

International agreements are also in place to provide compensation for damage from oil spills (see Sect. 6.4 above).

6.6.2 Hazardous and Noxious Cargoes

MARPOL covers the risk of pollution from hazardous and noxious cargoes through measures including through requiring compliance with the International Maritime Solid Bulk Cargoes Code, the International Maritime Dangerous Goods Code, the International Code for the Safe Carriage of Grain in Bulk and the International Code for the Construction and Equipment of Ships carrying Dangerous Chemicals in Bulk (IMO 2016d).

[2] The "Gulfs Area" is the sea area between the Arabian Peninsula and the mainland of Asia.

Efforts to set up an international agreement to deal with compensation for liability and damage from hazardous and noxious ships' cargoes were started as long ago as 1984. A convention was agreed in 1996 but, despite further efforts, no scheme is yet in force to provide international support where a hazardous or noxious cargo causes economic damage (IMO 2016e).

6.6.3 Sewage

Through Annex IV, MARPOL also prohibits the discharge of sewage into the sea within a specified distance of the nearest land, unless ships have in operation an approved sewage treatment plant (IMO 2016f). This distance is three nautical miles where the sewage is given prior primary treatment and 12 nautical miles if untreated.

Because of the problems of eutrophication, amendments to MARPOL in 2011 introduced the Baltic Sea as a special area under Annex IV and added new discharge requirements for passenger ships while in a special area. In effect, when adequate reception facilities are in place, passenger ships capable of carrying more than 12 passengers may only discharge sewage if nitrogen and phosphorus have been removed to specified standards (MEPC 2012).

"Grey water" (that is, waste water from baths, showers, sinks, laundries and kitchens) is not covered by MARPOL Annex IV. Some States (for example, the United States in respect of Alaska) have introduced controls over the discharge of sewage and grey water from larger passenger ships putting into their ports because the local conditions (in Alaska, particularly the water temperature) make the breakdown of any contaminants it may contain quite slow (EPA 2014a). Furthermore, some States, particularly small island developing States, have difficulties in managing sewage discharged ashore from cruise ships and from the large numbers of such ships visiting their ports. These challenges for small island developing States are discussed further in Chap. 17.

6.6.4 Garbage

Through Annex V, MARPOL seeks to eliminate and reduce the amount of garbage being discharged into the sea from ships. Although the Annex is not a compulsory part of the requirements of MARPOL, 15 States, with combined merchant fleets constituting no less than 50% of the gross tonnage of the world's merchant shipping, became parties to enable its entry into force on 31 December 1988. Experience showed that the requirements in the original version of Annex V were not adequately preventing ships' garbage from polluting the sea. United Nations General Assembly resolution 60/30 invited IMO to review the Annex. This was done and a revised version entered into force in 2013. Alongside this, IMO adopted guidelines to promote effective implementation. The revised Annex V prohibits generally the discharge of all garbage into the sea, with exceptions related to food waste, cargo residues, cleaning agents and additives and animal carcasses. It also provides for Special Areas where the exceptions are much more restricted. The Special Areas comprise the Mediterranean Sea, the Baltic Sea, the Black Sea, the Red Sea, the "Gulfs" area, the North Sea, the Antarctic area (south of 60°S) and the Wider Caribbean Region (including the Gulf of Mexico and the Caribbean Sea) (IMO 2016g).

Providing adequate waste reception facilities in ports and ensuring that those facilities are used is important. The greatest effort to promote use of waste-reception facilities has been in Europe, by requiring ships to deliver garbage on shore before leaving port, and removing any economic incentive to avoid doing so. Under this approach, with a few exceptions, all ships are required to deliver their garbage to the port waste-reception facility before leaving port, and the cost of such facilities is to be recovered from ships using the ports, with all ships (again with some exceptions) contributing substantially towards the cost of those facilities (EU 2000). This substantially removes any economic advantage from not using them. This has resulted in a significant (about 50%) increase between 2005 and 2008 in the amount of garbage delivered on shore in European Union ports (EMSA 2010).

6.6.5 Air Pollution

In 1997 a new annex to MARPOL (Annex VI) was adopted to limit the main air pollutants contained in ships' exhausts, including NO_x and SO_x. It also prohibits deliberate emissions of ozone-depleting substances and regulates shipboard incineration and emissions of VOCs from tankers. Following its entry into force in 2005, it was revised in 2008 to reduce progressively up to 2020 (or, in the light of a review, 2025) global emissions of NO_x, SO_x and particulate matter, and to introduce emission control areas (ECAs) to reduce emissions of those air pollutants further in designated sea areas (IMO 2016h). These requirements can be achieved either by using bunkers with lower sulphur content (which may have higher prices) or by installing exhaust scrubbers. Some shipping companies have announced fuel surcharges to meet extra costs which they attribute to the new requirements, but these are proving difficult to maintain in the face of over-capacity (Container Management 2016).

In 2011, action under Annex VI of MARPOL was extended to address the emission of "greenhouse gases" (particularly CO_2) from ships. The new requirements, effective from the start of 2013, make the Energy Efficiency Design Index (EEDI) mandatory for new ships, and the Ship Energy Efficiency Management Plan (SEEMP) is made a requirement for all ships (IMO 2016i).

6.6.6 Antifouling Treatments

Bans on TBT on boats less than 25 m long first started in the 1980s. In 1990, the IMO recommended that Governments should eliminate the use of antifouling paints containing TBT. This resolution was intended as a temporary restriction until the IMO could implement a more far-reaching measure. The International Convention on the Control of Harmful Anti-fouling Systems on Ships was adopted in 2001. This prohibited the use of organotin compounds as biocides in anti-fouling paints. This Convention came into force in 2008, and has been ratified by 69 States, representing 84.41% of the gross tonnage of the world's merchant fleet (IMO 2016j). There are many enforcement problems with this Convention. There is also a legacy problem in that dry docks and port berths may have deposits of old anti- fouling paint in the sediments on their bottoms. As and when this sediment has to be removed, disposal into the sea will be a problem, since it may remobilise the TBT remains (Bray and Langston 2007).

6.6.7 Wrecks

The Nairobi International Convention on the Removal of Wrecks, 2007, aims to resolve the issues related to wrecks. It sets out rules on how to determine whether a wreck presents a hazard, makes the owner of the ship liable for costs of removal and marking (subject to the rules on limits for liability for marine damage) and requires compulsory insurance to cover such costs for ships registered in, or other ships entering or leaving, States parties to the Convention. The Convention entered into force in 2015. So far there are 30 contracting States, representing 60% of the gross tonnage of the world's merchant fleet (IMO 2016k).

6.7 Response

When there is a maritime catastrophe, especially one that affects a coastline, there is usually a need to take action to clean up the resulting mess. Since the wreck of the *Torrey Canyon* on the Seven Stones off Cornwall in the United Kingdom in 1967, a wide range of response techniques has developed.

6.7.1 Oil

Local circumstances will determine the appropriate response to an oil spill. In relatively calm water, it is often appropriate to contain an oil spill with floating booms and use skimmers to retrieve as much oil as possible. With such equipment, it is possible to recover a large proportion of the spill—two-thirds of the 934 tonnes spilt from the Fu Shan Hai in the Baltic in 2003 were recovered (HELCOM 2010). The other major approach is the use of chemical dispersants. Opinion is divided on the appropriateness of using them: some States regard them as appropriate in many cases, depending on the meteorological circumstances, the local environment and the nature of the oil spill; other States regard them as unacceptable (for examples, see the different opinions in BONN 2014).

Effective response to oil spills requires a good deal of organization and equipment. The international framework for this is provided by the 1990 International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC Convention). This entered into force in 1995, and 109 States are now parties. The IMO plays an important role in coordination and in providing training (IMO 2016l). Coastal States have to bear the capital cost of establishing adequate response capability, but may be able to recover operational costs if and when that capacity is deployed to deal with an oil spill. Developing countries can have difficulties in mobilising the resources for investment in the necessary facilities (Moller et al. 2003).

6.7.2 Hazardous Substances

Following on from the International Convention on Oil Pollution Preparedness, Response and Cooperation (OPRC), a protocol dealing with preparedness and response to incidents involving hazardous and noxious substances was adopted in 2000. This follows the same model as the OPRC Convention. It came into force in 2007, but so far only 37 States have become parties (IMO 2016m).

6.8 Enforcement

The best forms of regulation are of no effect without adequate enforcement. UNCLOS gives flag States, port States and coastal States a range of powers to enforce internationally agreed rules and standards.

Flag States have the primary responsibility for ensuring that the ships on their registers comply with the requirements of international rules and standards. There has been wide concern that, in many cases, this responsibility has not been properly discharged. The IMO has therefore got agreement to amend the most significant international conventions to set up an audit scheme for member States. With effect from 2016, this scheme aims to determine the extent to which States give full and complete effect to their obligations and responsibilities under these instruments (IMO 2016n).

Port States are entitled to make sure that ships voluntarily entering their ports are complying with a range of requirements under the IMO conventions. These requirements relate largely to equipment and records, but can be significant for some environmental questions—for example, whether the controls on oil discharges are recorded as being properly applied. Ports are often competing with their neighbours. This makes it economically important for the port-States to be certain that their enforcement actions are not disadvantaging the competitive positions of their ports. Port-State inspection is, therefore, carried out in many regions in accordance with memorandums of understanding between the States of the region. Memorandums of understanding (MoU) have been set up covering most ocean regions: Europe and the north Atlantic (Paris MoU—27 States); Asia and the Pacific (Tokyo MoU—19 States and territories); Latin America (Acuerdo de Viña del Mar—15 States); Caribbean (Caribbean MoU—14 States and territories); West and Central Africa (Abuja MoU—14 States); the Black Sea region (Black Sea MoU—6 States); the Mediterranean (Mediterranean MoU—10 States); the Indian Ocean (Indian Ocean MoU—17 States); and the Riyadh MoU (part of the Persian Gulf—6 States). These port-State inspection organizations publish details of the results of their inspections, which can have economic significance for ship operators, since cargo consignors tend not to want to use shipping lines which have a poor performance.

Coastal States have limited powers to control the activities of ships exercising their rights of innocent passage. Nevertheless, surveillance by coastal States can play a significant role in improving enforcement. This is particularly so in the case of oil discharges, especially in Special Areas (see Sect. 6.6.1 above). Any visible oil slick in a Special Area represents, for many legal systems, a breach of the applicable rules. Aerial surveillance can thus link a ship to a slick that it is causing and report the vessel to its destination port for enforcement action. Aerial surveillance can be greatly assisted by satellite imagery, which can enable the aerial surveillance to be focused on areas where problems appear to be emerging. This form of surveillance appears to have played a significant role in the reduction in the numbers of oil slicks, for example in the North Sea and adjacent waters (BONN 2013, 2014).

6.9 Conclusions

Shipping is a vital component of the world economy. As the world economy has become increasingly globalized, the role of shipping has become more important. The economic crisis of 2008 produced some reductions in the levels of shipping, but those have recovered and growth has resumed, though not at quite the previous rate. Shipping has provided means for many States rich in primary resources to export those resources, and for many States that are developing their economies to export their products. Gradually, the balance of the tonnage of goods loaded in developed and in developing countries is becoming more equal. Increasing human wealth will therefore continue to be a driver in increasing the scale of shipping that is needed.

The pressures that shipping imposes on the environment are significant and widespread. In total they contribute substantially to the cumulative pressures that humans are imposing on the rest of the marine environment, and that are affecting the harvest from the sea and the maintenance of biodiversity. Over the past 40 years, global rules and standards have been developed to regulate most of these. Steps are now being taken to make the enforcement of these rules and standards more uniform throughout the world. However, there is still a significant number of States and territories that have not been able to become parties to the various international conventions and agreements that embody these rules and standards. Furthermore, enforcement of these rules and standards is patchy, though steps are now being taken that may improve such enforcement.

References

Allianz Global Corporate & Specialty SE (2012) with Cardiff University, Safety and Shipping 1912 to 2012. http://www.agcs.allianz.com/assets/PDFs/Reports/AGCS_safety_and_shipping_report.pdf. Accessed 22 July 2014

Andrew RK, Howe BM, Mercer JA (2011) Long-time trends in ship traffic noise for four sites off the north American west coast. Acoust Soc Am 129:642

Argentina (1998) Prefectura Naval Argentina, Ordenanza No 13/98 (Rutas de los buques que transportan hidrocarburos y sustancias nocivas líquidas en granel en navegación marítima nacional), 8 January

Barth H (2001) The coastal ecosystems 10 years after the 1991 Gulf War oil spill (unpublished). http://www.uni-regensburg.de/Fakultaeten/phil_Fak_III/Geographie/phygeo/d ownloads/barthcoast.pdf. Accessed 21 June 2014

BOBLME Malaysia (2011) Bay of Bengal large marine ecosystem project, country report on pollution – Malaysia. http://www.boblme.org/documentRepository/BOBLME-2011-Ecology-07.pdf. Accessed 17 Mar 2014

Boersma PD (2008) Penguins as marine sentinels. BioScience 58(7):597–607

BONN (2013) Bonn agreement, annual report on aerial surveillance for 2012. http://www.bonnagreement.org/eng/html/welcome.html. Accessed 31 May 2014

BONN (2014) Bonn agreement, counter-pollution manual. http://www.bonnagreement.org/eng/html/welcome.html. Accessed 31 May 2014

Bray S, Langston WJ (2007) Tributyltin pollution on a global scale—an overview of relevant and recent research: impacts and issues, WWF, Godalming

Canada (2011) Environment Canada, birds oiled at sea. http://www.ec.gc.ca/mbc-com/default.asp?lang=En&n=C6E52970-1. Accessed 20 Apr 2014

Cedre (2010) Centre de documentation, de recherche et d'expérimentation sur les pollutions accidentelles des eaux. Bulletin de information du Cedre No. 27. ISSN: 1247-603X

CINS (Container Incident Notification System Organization) (2014) Analytics. http://www.cinsnet.com/resources/analytics/. Accessed 30 Sept 2016

CLIA (Cruise Lines International Association) (2014) State of the cruise industry report. http://www.cruising.org/sites/default/files/pressroom/Infographic.pdf. Accessed 5 July 2014

CMW (Cruise Market Watch) (2014) Growth. http://www.cruisemarketwatch.com/growth/. Accessed 8 July 2014

COLREG (1972) The convention on the international regulations for preventing collisions at sea, United Nations. Treay Series 1050(15824)

COMNAP (Council of Managers of National Antarctic Programmes) (2005) International coordination of hydrography in Antarctica: significance to safety of Antarctic ship operations. In: XXX Antarctic consultative meeting, New Delhi, 2007 (HCA7-INF5)

Container Management (2016) Drastic measures. http://container-mag.com/2015/06/23/drastic-measures-needed-halt-collapse-rates/. Accessed 27 Oct 2016

Corbett JJ, Fischbeck PS (1997) Emissions from ships. Science 278:823–824

Dias M (2009) O Desenvolvimento do Transporte de Contêineres na Cabotagem Brasileira. www.antaq.gov.br/portal/SeminarioCabotagem.asp. Accessed 4 July 2014

Lord Donaldson of Lymington (1994) Safer ships, cleaner seas: report of Lord Donaldson's inquiry into the prevention of pollution from merchant shipping (Command Paper Cm 2560), Her Majesty's Stationery Office, London, UK

Ebbesmeyer C, Scigliano E (2009) Flotsametrics and the floating world: How one man's obsession with runaway sneakers and rubber ducks revolutionized ocean science. Collins, London. ISBN: 9780061971150

EC (European Commission) (1999) The development of short sea shipping in Europe: a dynamic alternative in a sustainable transport chain, (COM(1999) 317 final)

EMSA (European Maritime Safety Agency) (2010) Horizontal assessment report – port reception facilities (Directive 2000/59/EC), 2010. http://ec.europa.eu/transport/modes/maritime/consultations/doc/prf/emsa- report.pdf. Accessed 6 June 2014

EPA (USA Environmental Protection Agency) (2008) Cruise ship discharge assessment report, document EPA842-R-07-005

EPA (USA Environmental Protection Agency) (2014a) Sewage and graywater standards development. http://water.epa.gov/polwaste/vwd/sewage_gray.cfm. Accessed 14 Aug 2014

EPA (USA Environmental Protection Agency) (2014b) Nitrogen oxides—health. http://www.epa.gov/oaqps001/nitrogenoxides/health.html. Accessed 21 July 2014

EPA (USA Environmental Protection Agency) (2014c) Southern California air quality. http://www.epa.gov/Region9/socal/air/index.html. Accessed 21 July 2014

EU (European Parliament and the Council of the European Union) (2000) Directive of 27 November 2000 on port reception facilities for ship-generated waste and cargo residues. Directive 2000/59/EC as amended

EVOSTC (Exxon Valdez Oil Spill Trustee Council) (2010) Status of injured resources and services. http://www.evostc.state.ak.us/index.cfm?FA=status.injured. Accessed 20 June 2014

Fowler GS et al (1995) Hormonal and reproductive effects of low levels of petroleum fouling in magellanic penguins (*Spheniscus Magellanicus*). The Auk 112, section 2

FSI (IMO Sub-committee on Flag State Implementation) (2012) Casualty statistics and investigations—report by IMO Secretariat, IMODOCS FSI 20/5/4

Garcia-Borboroglu P, Boersma PD, Reyes LM, Skewgar E (2013) Petroleum pollution and penguins: marine conservation tools to reduce the problem. Paper presented at the annual meeting of the international marine conservation congress. George Madison University, Fairfax, VA. http://citation.allacademic.com/meta/p296486_index.html. Accessed 30 June 2014

GESAMP (2001) Joint group of experts on the scientific aspects of marine pollution, a sea of troubles. Arendal, Norway. ISBN: 82-7701-019-9

Gandini P, Boersma D, Frere E, Gandini M, Holik T, Lichtschein V (1994) Magellanic penguins (Spheniscus magellanicus) affected by chronic petroleum pollution along the coast of Chubut, Argentina. Auk 111(1):20–27

Gibbs PE, Bryan GW (1986) Reproductive failure in populations of the Dog-Whelk, Nucella Lapillus, caused by imposex induced by tributyltin from antifouling paints. J Mar Biol Assoc U K 66(4):767–777

Greaver TL, Sullivan TJ, Herrick JD, Barber MC, Baron JS, Cosby BJ, Deerhake ME, Dennis RL, Dubois J-JB, Goodale CL, Herlihy AT, Lawrence GB, Liu L, Lynch JA, Novak KJ (2012) Ecological effects of nitrogen and sulfur air pollution in the US: what do we know? Front Ecol Environ 10(7):365–372

HELCOM (Helsinki Commission) (2010) Ecosystem health of the baltic sea 2003–2007: HELCOM initial holistic assessment. In: Baltic sea environment proceedings no. 122, Helsinki. ISSN: 0357-2994

IMO (International Maritime Organization) (2014a) Third IMO greenhouse gases study 2014. http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third%20Greenhouse%20Gas%20Study/GHG3%20Executive%20Summary%20and%20Report.pdf. Accessed 22 July 2016

IMO (International Maritime Organization) (2014b) Water management. http://www.imo.org/OurWork/Environment/BallastWaterManagement/Pages/Default.aspx. Accessed 20 Nov 2014

IMO (International Maritime Organization) (2016a) Ships' routing. http://www.imo.org/en/OurWork/Safety/Navigation/Pages/ShipsRouteing.aspx. Accessed 8 July 2016

IMO (International Maritime Organization) (2016b) Particularly sensitive sea areas. http://www.imo.org/en/OurWork/Environment/PSSAs/Pages/Default.aspx. Accessed 30 Sept 2016

IMO (International Maritime Organisation) (2016c) Special areas under MARPOL. http://www.imo.org/en/OurWork/Environment/SpecialAreasUnderMARPOL/Pages/Default.aspx. Accessed 21 June 2016

IMO (International Maritime Organization) (2016d) Carriage of chemicals by ship. http://www.imo.org/OurWork/Environment/PollutionPrevention/ChemicalPollution/Pages/Default.aspx. Accessed 30 Sept 2016

IMO (International Maritime Organization (2016e) Compensation regime for hazardous and noxious cargoes. http://www.imo.org/en/MediaCentre/PressBriefings/Pages/05-HNS2010.aspx. Accessed 30 Sept 2016

IMO (International Maritime Organization) (2016f) Prevention of pollution by sewage from ships. http://www.imo.org/OurWork/Environment/PollutionPrevention/Sewage/Pages/Default.aspx. Accessed 7 June 2016
IMO (International Maritime Organization) (2016g) Prevention of pollution by garbage from ships. http://www.imo.org/en/OurWork/Environment/PollutionPrevention/Garbage/Pages/Default.aspx. Accessed 30 Sept 2016
IMO (International Maritime Organization) (2016h) Prevention of air pollution from ships. http://www.imo.org/OurWork/Environment/PollutionPrevention/Air Pollution/Pages/Air-Pollution.aspx. Accessed 22 July 2016
IMO (International Maritime Organization) (2016i) Low carbon shipping and air pollution control. http://www.imo.org/en/MediaCentre/HotTopics/GHG/Pages/default.aspx. Accessed 30 Sept 2016
IMO (International Maritime Organization) (2016j) International anti-fouling convention. http://www.imo.org/en/About/conventions/listofconventions/pages/international-convention-on-the-control-of-harmful-anti-fouling-systems-on-ships-(afs).aspx
IMO (International Maritime Organization) (2016k) International convention on the removal of wrecks. http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/Nairobi-International-Convention-on-the-Removal-of-Wrecks.aspx
IMO (International Maritime Organization) (2016l) International convention on oil pollution preparedness, response and co-operation 1990. http://www.imo.org/About/Conventions/ListOfConventions/Pages/International-Convention-on-Oil-Pollution-Preparedness,-Response-and-Co-operation- (OPRC).aspx. Accessed 31 May 2016
IMO (International Maritime Organization (2016m) Status of conventions. http://www.imo.org/en/About/Conventions/StatusOfConventions/Pages/Default.aspx. Accessed 12 July 2016
IMO (International Maritime Organization) (2016n) IMO Member state audit scheme. http://www.imo.org/en/OurWork/MSAS/Pages/AuditScheme.aspx. Accessed 30 Sept 2016
IOPCF (International Oil Pollution Compensation Funds) (2014) Annual report. http://www.iopcfunds.org/uploads/tx_iopcpublications/annualreport2014_e.pdf. Accessed 30 Sept 2016
ITOPF (International Tanker Owners Federation) (2015) Information and statistics. http://www.itopf.com/knowledge-resources/data-statistics/statistics/. Accessed 30 Sept 2016
Jones DA et al (1994) Intertidal recovery in the Dawhat ad-Dafi and Dawhat al-Musallamiya region (Saudi Arabia) after the Gulf war oil spill. Cour Forsch-Inst Senckenberg (166):27–33
Kaluza P, Kölzsch A, Gastner MT, Blasius B (2010) The complex network of global cargo ship movements. J R Soc Interface (48):1093–1103
Kendall SJ, Erickson WP, Lance BK, Irons DB, McDonald LL (2001) Twelve years after the Exxon Valdez Oil Spill. The Condor 103(4):896–902
Knelson JH, Lee RE (1977) Oxides of nitrogen in the atmosphere: origin, fate and public health implications. Ambio 6(2/3):126–130
Laulajainen R (2009) The Arctic Sea route. Int J Ship Trans Log 1(1):55–73
Lee SD (ed) (1980) Nitrogen oxides and their effects on health. Ann Arbor Science Publishers, MI
Lloyds List (2014) CMA CGM, UASC and China Shipping unveil rival to 2M, G6 and CKYHE, Tuesday 09 Sept 2014
MARAD (2014) USA Department of Transportation, Maritime Administration, America's Marine Highway Program. http://www.Marad.Dot.Gov/ships_shipping_landing_page/mhi_home/mhi_home.htm. Accessed 20 June 2014
MARPOL (1973/78) The international convention for the prevention of pollution from ships. United Nations. Treaty Series 1340(22484)
McCarthy SA, Khambaty FM (1994) International dissemination of epidemic *cholerae* by cargo ship ballast and other nonpotable waters. Appl Environ Microbiol 60:7
MEPC (IMO Marine Environment Protection Committee) (2012) Resolution MEPC.227(64), IMO Document MEPC 64/23/Add.1, Annex 22
Moller TH, Molloy FC, Thomas HM (2003) Oil spill risks and the state of preparedness in the regional seas. Int Oil Spill Conf Proc 2003(1):919–922

NRC (USA National Research Council) (1995) Clean ships, clean ports, clean oceans: controlling garbage and plastic wastes at sea. National Academy Press: Washington, DC

NRC (USA National Research Council—Committee on Potential Impacts of Ambient Noise in the Ocean on Marine Mammals) (2003) Ocean noise and marine mammals. National Academies Press, Washington, DC

NSN (North Sea Network) (2012) North sea manual on maritime oil pollution offences, London. ISBN: 978-1-906840-45-7

OSPAR (OSPAR Commission) (2000) Quality status report on the North-East Atlantic, London, 2000. ISBN: 0-946956-52-9

OSPAR (OSPAR Commission) (2010) Quality status report 2010, London. ISBN 978-1-907390-38-8

Otsuki A, Abdulraheem MY, Reynolds RM (eds) (1998) Offshore environment of the ROPME sea area after the war-related oil spill—results of the 1993–94 Umitaka-Maru Cruises, Tokyo, 1998. ISBN: 4-88704-123-3

Rall DP (1974) Review of the health effects of sulfur oxides. Environ Health Perspect (8): 97–121

Readman JW, Fowler SW, Villeneuve J-P, Cattini C, Oregioni B, Mee LD (1992) Oil and combustion-product contamination of the Gulf marine environment following the war. Nature (358):662–665

Ritchie W, O'Sullivan M (eds) (1994) The environmental impact of the wreck of the Braer, Scottish Office Environment Department, Edinburgh. ISBN: 07480-0900-0

Santillo D, Johnston P, Langston WJ (2001) Tributyltin (TBT) antifoulants: a tale of ships, snails and imposex. In: Harremoes P, Gee D, MacGarvin M, Stirling A, Keys J, Wynne B et al (eds) Late lessons from early warnings: the precautionary principle. Environment issue report, no. 22. European Environment Agency, Copenhagen

SCD (Supply Chain Digest) (2014) http://www.scdigest.com/ontarget/14-07-23-3.php?cid=8310. Accessed 26 July 2014

Simcock A, Kamara OK Chapter 17 - Shipping. In Innis L. and Simcock A (coordinators), The First Global Integrated Marine Assessment - World Ocean Assessment I, United Nations and Cambridge University Press, 2017

SOLAS (1974) The international convention for the safety of life at sea, United Nations. Treaty Series 1184(18961)

STCW (1978) International convention on standards of training, certification and watchkeeping for seafarers, United Nations. Treaty Series 1361

TRB (Transportation Research Board) (2012) Safe navigation in the U.S. Arctic—summary of a conference, Seattle. http://onlinepubs.trb.org/onlinepubs/conf/CPW11.pdf. Accessed 3 July 2014

Tyack PL (2008) Implications for marine mammals of large-scale changes in the marine acoustic environment. J Mammal 89(3):549–558

UNCLOS (1982) United Nations convention on the law of the sea, United Nations. Treaty Series 1833(31363)

UNCTAD (2014) Secretariat of the United Nations Conference on Trade and Development (UNCTAD), Review of maritime transport 2014, New York and Geneva. ISBN: 978-92-1-112872-7. http://unctad.org/en/PublicationsLibrary/rmt2014_en.pdf

UNCTAD (2015) Secretariat of the United Nations Conference on Trade and Development (UNCTAD), Review of maritime transport 2015, New York and Geneva. ISBN: 978-92-1-112872-7. http://unctad.org/en/PublicationsLibrary/rmt2015_en.pdf

UNEP (United Nations Environment Programme) (2012) Convention on biological diversity, subsidiary body on scientific, technical and technological advice, scientific synthesis on the impacts of underwater noise on marine and coastal biodiversity and habitats (SBSTTA document 16/INF/12)

USMA (USA Maritime Administration) (2014) Marine Highway Fact sheet. http://www.marad.dot.gov/documents/AMH_Fact_Sheet_V11.pdf. Accessed 7 July

Wergeland T (2012) Ferry passenger markets. In: Talley WK (ed) The Blackwell companion to maritime economics. http://onlinelibrary.wiley.com/doi/10.1002/9781444345667.ch9/summary. Accessed 2 July 2014

Wolfaardt AC et al (2009) Review of the rescue, rehabilitation and restoration of oiled seabirds in South Africa, especially African penguins *Spheniscus demersus* and Cape gannets *Morus capensis*, 1983–2005. Afr J Mar Sci 31(1):31–54

WSC (World Shipping Council) (2011) Containers lost at sea. http://www.worldshipping.org/industry-issues/safety/Containers_Overboard Final.pdf. Accessed 31 May 2014

Chapter 7
Impacts of Coastal Developments on Ecosystems

Christian Winter

Abstract In this chapter a brief overview of direct and indirect human impact to coastal systems is given. The concept of coastal morphodynamics as relevant drivers of coastal ecosystems is explained and the interactions of important processes in different spatio-temporal scales are introduced. In several examples it is shown how coastal developments act as perturbations to the dynamic equilibria of natural coastal environments. Important uncertainties in system understanding are identified and their relevance for the interpretation of model predictions is stressed out. Numerical models serve as common tools for coastal development impact assessment, and the more and more user friendly design of modelling systems will increase their use in the future. This calls for an increased awareness and very careful interpretation of model results considering model applicability and model prediction skills. Management should thus follow an adaptive approach, which involves learning and monitoring of the evolution of coastal systems. This also involves regular re-assessments of past predictions and the identification of needs for model development.

Keywords Model skill • Dynamic equilibrium • Validation • Coastal engineering • Adaptive management

7.1 Introduction

Coastal zones are most dynamic environments in which various land and sea processes interact. A large variety of coastal landforms exist with their geomorphology depending on the geological setting, their Holocene sedimentological evolution, their exposure to natural forcing conditions, and history of anthropogenic influence (Short 1999; Winter and Bartholomä 2006; Masselink et al. 2011).

C. Winter
Center for Marine Environmental Sciences MARUM, University of Bremen, Bremen, Germany
e-mail: cwinter@marum.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_7

Many coastlines are not in a natural state but highly impacted by human use as coastal areas are attractive to people for several reasons. This leads to an ever increasing concentration of global population and developments in the coastal realm (Creel 2003; Small and Nicholls 2003; Goudarzi 2006). Furthermore it is obvious that the majority of the global population is dependent on services provided at and by the land-sea interface. Human uses of coastal zones include settlement (United Nations 2014; Pelling and Blackburn 2014), traffic (Finkl 2012; Davenport and Davenport 2006), trade and transport (Yap and Lam 2013; Meinesz et al. 1991), water supply and sewage (Finkl and Charlier 2003; Turner et al. 1998), recreation (Hall 2001; Wong 1998; Gössling 2003), food (Pomeroy and Berkes 1997; Barg 1992; Arkema et al. 2015), and energy (Alvarez Silva et al. 2016; Henderson et al. 2003; Antonio 2010).

Commonly at coastal environments a high variability of meteorological and hydrodynamic conditions influence the local natural geomorphology and must be taken into account in the design of coastal developments: Winds, waves, wind driven currents and tides are the main forcing agents which may super-impose and partly reveal certain periodicity. In addition extreme events like floods, storms, and tsunamis are experienced (Nicholls 2004; Nicholls et al. 2007; MCInnes et al. 2003; Herrling and Winter 2014; Adger et al. 2005). Under increasing human population, economy, and expected increase of forcing conditions as a result of climate change the vulnerable coastal zones are under high pressure. It is the task of coastal management to derive measures to secure value and functions of the coastal zones. However, past experience has shown that local engineering solutions may be not sustainable, or may even have negative effects at the site or elsewhere (Pilkey and Dixon 1996). Management thus must aim at a sustainable development of coastal zones based on detailed knowledge of different involved systems, their interaction, the underlying processes and their response to external forcing (Pawlukiewicz et al. 2007; Gaydos et al. 2008).

In the coastal zone different systems of prominent role may be identified, each defined by interactions, relations, and interdependencies of their associated forcings, processes and characteristics:

- Ecosystems involve inter-dependent organisms, such as plants and animals within a coastal habitat that are linked together through nutrient cycles and energy flow and are influenced by chemical and physical conditions of their environment (e.g. Alongi 1998).
- Geo-physical systems involve the dynamics of acting forces on structures, fluids, sand and other materials. The main entities of these systems encompass driving hydrodynamic processes, resulting transports, and their geomorphological effects on habitat conditions (Barbier et al. 2011).
- Socio-economic systems encompass demographic and economic characteristics of a wide variety of coastal management issues as e.g. urbanisation, environmental protection, coastal constructions, recreation, exploitation of natural resources, etc. Most often socio-economic considerations drive human impact to coastal geo-physical and ecosystems (Costanza et al. 1997; Barbier et al. 2011).

In the following the different physical forcing mechanisms between coastal systems and the concept of a dynamic equilibrium between coastal systems are explained. Morphodynamics processes may be seen as the main physical forcing mechanism of ecosystems. Although process interactions generally are understood in an empirical sense, the prediction of coastal morphodynamics is difficult because of lacks in fundamental process knowledge, the non-linearity of process interactions and uncertainty in future forcing conditions.

7.2 Dynamic Equilibrium of Coastal Systems

Generally systems are characterised by their parts and composition, their drivers, processes and output, and their inter-connectivity. The various parts of a system and also the different systems by themselves have functional as well as structural relationships between each other. At the coast physical systems involve the dynamic characteristics of the geomorphology and the transport of energy and matter. They are described by variables like water depth, velocity, wave height, shear stress, viscosity, concentration, sediment particle size, etc. The composition of these variables results in the transport of material and changes in morphology (Roelvink 2006; Kösters and Winter 2014). Also biological and micro-biological processes can influence transport conditions and must be taken into account in the geo-physical context (Ahmerkamp et al. 2015; Malarkey et al. 2015).

Wind and the movement of coastal waters (mainly driven by winds, short waves and tides) induce the transport of sediments (erosion, transport, deposition) and thus drive the evolution of the sea bed. In turn currents and transport patterns are influenced by the coastal morphology. Commonly cited is the work of Wright and Thom (1977) who termed this 'mutual adjustment of fluid dynamics and topography involving sediment transport' as morphodynamics. De Vriend (1991) understands the term morphodynamics more generally as the 'dynamic behaviour of alluvial boundaries'. This dynamic behaviour is the result of the feedback loop of hydrodynamics, sediment transport and resulting bed evolution driven by time variant or stationary boundary conditions. These driving boundary conditions may also be artificial like construction activities, removal or dispersal of sediments, or others.

Coastal processes occur and interact in a large bandwidth of spatio-temporal scales. Cowell and Thom (1994) classified time scales at which coastal processes operate: Instantaneous time scales involve the evolution of systems during a single cycle of the forces that drive morphological change (waves, tides) from few seconds to many days or weeks. Event time scales are concerned with coastal evolution as a response to forcing processes operating across time spans ranging from that of an individual event, through to seasonal variation from a few days to many years. Engineering time scales describe coastal evolution under natural forcing and its response to human impact from few months to decades. Geological or geomorphological time scales operate over decades to millennia and cover the evolution in response to mean trends in the forcing conditions like coastline retreat as a result of sea level rise.

As the natural forcing conditions continuously vary in time, no steady state or static equilibrium of any coastal system can be expected. A system is in a dynamic equilibrium in certain spatiotemporal scales, if no trends are observed and system behaviour can be related to the forcing conditions. This holds for coastal systems like embayed beaches, i.e. beaches in between rigid headlands which do not exchange sediments with neighbouring coastal cells (Reniers et al. 2004; Blossier et al. 2016; Daly et al. 2014, 2015). Dependent on the period and magnitude of change in boundary conditions and the overall system stability the system may reveal immediate reaction, or remain in a dynamic equilibrium.

7.3 Uncertainties in Process Knowledge and Implications to Coastal Modelling

The dynamics of ecosystems, habitats and morphodynamics in coastal environments are complex and many processes and their coupling are still not fully understood. Thus their future evolution and the reaction of the system to human impact cannot be predicted correctly. This holds for all systems, also for fluid dynamics like flow and wave motion, which can be derived from first principles and thus theoretically be calculated by computer simulations. However, limitations in computational power and uncertainties in the initial and boundary conditions can only be overcome by parameterisations and simplifications and thereby reduce the theoretically possible direct simulation to an approximation. This especially holds for nearshore wave processes (Peregrine 1983; Robertson et al. 2013). The stability of the fluid-bed interface, i.e. the interaction of water and the sand is a two-phase problem, which as yet has no known deterministic solution. Sediment transport calculations thus are based on empirical formulations, i.e. extrapolation of observed system behaviour to other environments (Van Rijn 2007). Uncertainty in process knowledge is high especially for interactions between microbial, biological and physical processes at the sea bed. Anyway, based on theoretical and empirical considerations, a wide range of modelling approaches have been formulated to relate, interpolate, extrapolate and interpret measured data and to simulate system states. These models comprise conceptual, empirical, data-driven stability concepts and numerical process-based approaches. Several empirical relationships have been formulated for the description of boundary-layer properties of the fluid and bed, critical stages of erosion and deposition, sediment transport on the bed and in suspension which typically scales with the fluid motion to some power, and the formation of bedforms of various sizes. If these are embedded in a system of computational modules for the calculation of fluid motions and bed evolution, the simulation of morphodynamics is possible (Roelvink 2011). However, it must be always considered, that by definition, any empirical relationship is only valid for the system under consideration and the range of observations it is based upon. The application of the same to other environments and other boundary conditions thus introduces uncertainty and requires thorough evaluation of model skill based on field data (Winter 2007). Results of numerical models nowadays are a common base of decision support in environmental impact studies, and the development towards easier application of modelling systems will increase their use in the future. This calls for an increased awareness and very careful interpretation of model results considering model suitability and applicability (verification) and model prediction skills (validation). The prediction of the reaction of ecosystems to physical forcing still is of limited validity (Folmer et al. 2016).

7.4 Coastal Developments and Their Impact to Coastal Systems

Most of the global coasts are directly or indirectly influenced by coastal developments of different kind. In the following exemplary coastal development schemes are described. Direct impacts on ecosystems by tourists, constructions, pollution, introduction of invasive species are differentiated from indirect impacts on coastal ecosystems which comprise changes in habitat conditions by shifts in hydrodynamic and transport conditions: Enhanced hydraulic energy commonly leads to the export of fine particles, thus a coarsening of sediments or even sediment loss, with corresponding changes to habitats. In contrast a reduction in hydraulic energy may lead to deposition of fine sediments (silts, clays) and higher turbidity with other effects on coastal ecosystems.

Coastal environments are amongst the most attractive locations for living and tourism. **Tourism** is the largest and fastest growing economic sector in the world. Accommodation, infrastructure and traffic locally increase and recreational activities themselves have major impact to the coastal systems (Simcock, Chap. 17). Traffic, pollution, waste, and water needs increase with major impacts to local infrastructure and ecosystem habitats. The increasing popularity of cruise ships amplifies tourism related impact to coastal systems (Hall 2001; Gössling 2003; Davenport and Davenport 2006).

Nourishments are frequently applied to avoid coastal erosion of island or mainland beaches by replacement of sand or gravel deficits. Typically sand is brought to the backshore, onto the beach, or into foreshore areas to replace eroded material. The material may be liquefied offshore and pumped to the site, or brought by transport barges or trucks to the beach. Also sand may be deposited in the foreshore for a distribution by natural forcing conditions. Nourishments are commonly accepted as comparatively natural or soft coastal engineering scheme. This holds if the sand that is introduced to the system and the slope corresponds to the natural system, and enough time is available for the re-establishment of habitats. As commonly the cause for coastal erosion is not eliminated, the success of beach nourishment is only temporary, and frequent re-nourishments are needed. Physical impacts may include burial of bottom habitats, increased sedimentation, changes in bathymetry and elevated turbidity levels. At the beaches indigenous biota can be affected directly, or by loss of prey as infauna communities may not survive nourishments and need time for recovery. Also nesting, breeding, and nursing species are disturbed directly by operations. In the burrow source areas benthic assemblages are removed directly and local habitats are destroyed by removal of bed material (CBNP 1995; Dean 2002; Hanson et al. 2002; Stive et al. 2013).

Seawalls are local hard engineering coastal defence structures which are built along coastlines to resist high water levels and waves. Seawalls may be designed in different shapes (vertical, curved, revetments) and materials (boulders, concrete, steel piling). Well-designed seawalls are durable and effective to protect the coastline against flooding. The structures however are static and thus impede any natural evolution of the shoreline and cross-shore sediment exchange. In contrast to natural sloping beaches which form and deform according to the local wave climate, seawalls may even enhance erosive trends by reflection of wave energy. Changes in local wave climate, sediment transport and morphology can have negative effects on local (shoreline and foreshore) and downdrift habitats and ecosystems. A recent study reports that in environments in the vicinity of seawalls supported 23% lower biodiversity and 45% fewer organisms than natural shorelines (Gittman et al. 2016). Dependent on design sea walls may or not withstand extreme events like tsunamis, storm surges, and enhanced sea level rise (Mendelsohn 2000; Nicholls and Cazenave 2010).

Following an approach of dynamic equilibrium of enclosed coastal cells, **groynes** are rigid structures which are built at river banks and coastlines perpendicular or at low angles to the main flow or wave action. Groynes can be constructed from stones, concrete, blocks, wood, or steel, and may be partly permeable. In their function the alongshore flow and sediment transport is interrupted. At river banks groynes (or spur dikes) are built to force the main flow and transport energy into the central part of the river, which shall hinder sedimentation; thereby reducing costs for maintenance of the design depth. At open coasts groynes are set-up as countermeasures for coastline erosion: The wave action is dissipated and alongshore transported sediment is trapped in between or upwind of the groynes. If well designed according to type or he transport regime groynes can successfully avoid local coastal erosion. However the interruption of the longshore drift of sediment can cause enhanced erosion downdrift of the structures (Nicholls and Cazenave 2010).

To allow access to and maneuvererabilty of ports and navigational safety in fairways deepening by **dredging** is another common coastal engineering measure. Excavating of bed material is usually carried out by dredging vessels of which different types may be differentiated (grab, suction, bucket, water injection). Capital dredging is carried out for reaching a new state or design depth, whereas maintenance dredging maintains design depths; e.g. by dredging the crests of large subaqueous dunes which protrude into the design water depth. Immediate environmental impacts of dredging operations include increased turbidity, release of pollutants into the water column at the extraction and dumping sites (Vogt, Chap. 10). Dredging changes the morphology and thus the physical properties of the channel, mainly by reducing hydraulic roughness to the downstream freshwater flow, or the incoming tidal currents. Changes in transport regime can follow from river deepening, thus influencing transport of salinity, sediments, or other conservative substances thereby influencing ecosystems along the river and coasts line, up to severe regime shifts. The estuary of the Ems in Germany is a prominent example of a now hyperturbid environment, which is assumed to have changed from a healthy ebb dominant state to a flood dominant type as a reaction to a reduction of hydraulic roughness by dredging. The import of mud to the estuary leads to an increase in turbidity, and loss of biota because of light and oxygen reduction (De Jonge 1992; Krebs and Weilbeer 2008; Winterwerp et al. 2013).

Ports are locations of prominent impact to coastal morphology, transport and ecosystems. Typically major capital and maintenance dredging operations must be carried out frequently to ensure navigable water depths and safe ship traffic. Harbour basins may suffer from enhanced deposition of fine sediments (siltation) as here the natural flow energy is reduced. On the other hand hard quay walls and local deepening may enhance flow speed. Ecosystem impact is expected in several aspects for river and coastal waters as e.g. change in transport of sediments, and density, pollution, and introduction of invasive species. For the environment also air quality and noise pollution by ship exhaust, and cargo transport traffic must be considered (Darbra et al. 2005). For the port of Rotterdam an exemplary study has detailed environmental impact by exhaust emissions, noise, ballast water, sewage and garbage, dust, antifouling, and feeder traffic, and how these are managed in the framework of global, European, and local environmental initiatives (OECD 2010).

7.5 Conclusion

Natural coasts are dynamic environments of constant change, and are continuously shaped by driving forces of different time and length scales. Coastal ecosystems have adapted to the diversity of habitats in various climatic, hydrodynamic, and sedimentary conditions. With growing human activities at global coasts pressures on coastal ecosystems increase. Direct impact of coastal developments are manifold and comprises threats like constructions, pollution, traffic, overfishing, etc. Indirect effects on ecosystems are connected to the immediate or delayed reaction of coasts to the fixation of coastlines by engineering measures. Shore protection schemes prevent erosion or floodings, structures allow for traffic, shipping, and safety but also do not allow the coast to develop and form adapted natural shapes and habitats. Dredging of waterways changes the hydrodynamic characteristics of tidal channels and estuaries, thereby changing habitat conditions. Long term changes in sea level and increased storminess are expected to have an increased effect if the natural response from beaches and coastal systems is impeded (Ranasinghe 2016).

Limited system understanding, predominately of the interaction between physical and ecosystems makes the prediction of local and far field effects of coastal developments difficult. Management thus should always follow an adaptive approach, which is driven by the aim for an in-depth understanding of natural processes, and involves learning and monitoring of the evolution of coastal systems. This also involves regular re-assessments of past predictions in order to identify model shortcomings and define needs for necessary model development.

References

Adger WN, Hughes TP, Folke C, Carpenter SR, Rockström J (2005) Social-ecological resilience to coastal disasters. Science 309(5737):1036–1039

Ahmerkamp S, Winter C, Janssen F, Kuypers MMM, Holtappels M (2015) The impact of bedform migration on benthic oxygen fluxes. J Geophys Res Biogeosci 120:2229–2242

Alongi DM (1998) Coastal ecosystem processes. CRC Press, Boca Raton, FL. 419p

Alvarez Silva O, Osorio A, Winter C (2016) Practical global salinity gradient energy potential. Renew Sust Energ Rev 60:1387–1395

Antonio FDO (2010) Wave energy utilization: a review of the technologies. Renew Sust Energ Rev 14(3):899–918

Arkema KK, Verutes GM, Wood SA, Clarke-Samuels C, Rosado S, Canto M et al (2015) Embedding ecosystem services in coastal planning leads to better outcomes for people and nature. Proc Natl Acad Sci U S A 112(24):7390–7395

Barbier EB, Hacker SD, Kennedy C, Koch EW, Stier AC, Silliman BR (2011) The value of estuarine and coastal ecosystem services. Ecol Monogr 81(2):169–193

Barg UC (1992) Guidelines for the promotion of environmental management of coastal aquaculture development (No. 328). FAO

Blossier B, Bryan KR, Daly CJ, Winter C (2016) Nearshore sandbar rotation at single-barred embayed beaches. J Geophys Res Oceans 121(4):2286–2313

CBNP: Committee on Beach Nourishment and Protection (1995) Beach nourishment and protection. National Academies Press, Washington, DC: 352

Costanza R, d'Arge R, De Groot R, Faber S, Grasso M, Hannon B, et al (1997) The value of the world's ecosystem services and natural capital. Nature 387(6630):253–260

Cowell PJ, Thom BG (1994) Morphodynamics of coastal evolution. Cambridge University Press, Cambridge and New York

Creel L (2003) Ripple effects: population and coastal regions. Population Reference Bureau, Washington, DC

Daly CJ, Bryan KR, Winter C (2014) Wave energy distribution and morphological development in and around the shadow zone of an embayed beach. Coast Eng 93:40–54

Daly CJ, Winter C, Bryan KR (2015) On the morphological development of embayed beaches. Geomorphology 248:252–263

Darbra RM, Ronza A, Stojanovic TA, Wooldridge C, Casal J (2005) A procedure for identifying significant environmental aspects in sea ports. Mar Pollut Bull 50(8):866–874

Davenport J, Davenport JL (2006) The impact of tourism and personal leisure transport on coastal environments: a review. Estuar Coast Shelf Sci 67(1):280–292

De Jonge VN (1992) Tidal flow and residual flow in the ems estuary. Estuar Coast Shelf Sci 34(1):1–22

De Vriend HJ (1991) Mathematical modelling and large-scale coastal behaviour: Part 2. Predictive models. J Hydraul Res 29(6):741–753

Dean RG (2002) Beach nourishment: theory and practice, vol 18. World Scientific, Singapore

Finkl CW (2012) Coastal Hazards. Springer Science and Business Media, New York. 840p

Finkl CW, Charlier RH (2003) Sustainability of subtropical coastal zones in southeastern Florida: challenges for urbanized coastal environments threatened by development, pollution, water supply, and storm hazards. J Coast Res 19(4):934–943

Folmer EO, van Beusekom JE, Dolch T, Gräwe U., Katwijk MM, Kolbe K, Philippart CJ (2016) Consensus forecasting of intertidal seagrass habitat in the Wadden Sea. J Appl Ecol 53(6):1800–1813

Gaydos JK, Dierauf L, Kirby G, Brosnan D, Gilardi K, Davis GE (2008) Top 10 principles for designing healthy coastal ecosystems like the Salish Sea. EcoHealth 5(4):460–471

Gittman RK, Scyphers SB, Smith CS et al (2016) Ecological consequences of shoreline hardening: a meta-analysis. BioScience 66(10):763–773

Gössling S (2003) Tourism and development in tropical islands: political ecology perspectives. Edward Elgar, Northhampton, MA

Goudarzi S (2006) Flocking to the coast: world's population migrating into danger. Live Science

Hall CM (2001) Trends in ocean and coastal tourism: the end of the last frontier? Ocean Coast Manag 44(9):601–618

Hanson H, Brampton A, Capobianco M, Dette HH, Hamm L, Laustrup C et al (2002) Beach nourishment projects, practices, and objectives—a European overview. Coast Eng 47(2): 81–111

Henderson AR, Morgan C, Smith B, Sørensen HC, Barthelmie RJ, Boesmans B (2003) Offshore wind energy in Europe—a review of the state-of-the-art. Wind Energy 6(1):35–52

Herrling G, Winter C (2014) Morphological and sedimentological response of a mixed-energy barrier island tidal inlet to storm and fair-weather conditions. Earth Surf Dynam 1:745–782

Kösters F, Winter C (2014) Exploring German bight coastal morphodynamics based on modelled bed shear stress. Geo-Mar Lett 34(1):21–36

Krebs M, Weilbeer H (2008) Ems-dollart estuary. Die Küste 74:252–262

Malarkey J, Baas JH, Hope JA, Aspden RJ, Parsons DR, Peakall J et al (2015) The pervasive role of biological cohesion in bedform development. Nat Commun 6:6257

Masselink G, Hughes MG, Knight J (2011) Introduction to coastal processes and geomorphology. Hodder Education, London, p 416

McInnes KL, Walsh KJE, Hubbert GD, Beer T (2003) Impact of sea-level rise and storm surges on a coastal community. Nat Hazards 30(2):187–207

Meinesz A, Lefevre JR, Astier JM (1991) Impact of coastal development on the infralittoral zone along the southeastern Mediterranean shore of continental France. Mar Pollut Bull 23: 343–347

Mendelsohn R (2000) Efficient adaptation to climate change. Clim Chang 45(3–4):583–600

Nicholls RJ (2004) Coastal flooding and wetland loss in the 21st century: changes under the SRES climate and socio-economic scenarios. Glob Environ Chang 14(1):69–86

Nicholls RJ, Cazenave A (2010) Sea-level rise and its impact on coastal zones. Science 328(5985):1517–1520

Nicholls RJ, Wong PP Burkett VR, Codignotto J, Hay J, McLean R, Ragoonaden S, Woodroffe CD (2007). Coastal systems and low-lying areas, in Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (ed) Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change, Cambridge, UK, Cambridge University Press, 315–356

OECD (2010) Environmental impacts if international shipping: a case study of the prot of Rotterdam, OECD, Environment Directorate, 30p

Pawlukiewicz M, Gupta PK, Koelbel C (2007) Ten principles for coastal development. ULI–The Urban Land Institute, Washington, DC. 42p

Pelling M, Blackburn S (2014) Megacities and the coast: risk, resilience and transformation. Routledge, UK. 248p

Peregrine DH (1983) Breaking waves on beaches. Annu Rev Fluid Mech 15(1):149–178

Pilkey OH, Dixon KL (1996) The corps and the shore. Island Press, Washington, DC. 272p

Pomeroy RS, Berkes F (1997) Two to tango: the role of government in fisheries co-management. Mar Policy 21(5):465–480

Ranasinghe R (2016) Assessing climate change impacts on open sandy coasts: a review. Earth Sci Rev 160:320–332

Reniers AJ, Roelvink JA, Thornton EB (2004) Morphodynamic modeling of an embayed beach under wave group forcing. J Geophys Res Oceans 109(C1):1–22
Robertson B, Hall K, Zytner R, Nistor I (2013) Breaking waves: review of characteristic relationships. Coast Eng J 55(01):1350002
Roelvink JA (2006) Coastal morphodynamic evolution techniques. Coast Eng 53(2):277–287
Roelvink JA (2011) A guide to modeling coastal morphology, vol 12. World Scientific, Singapore
Short A (1999) Handbook of beach and shoreface morphodynamics. John Wiley and Sons Ltd, Chichester. Ch 7
Small C, Nicholls RJ (2003) A global analysis of human settlement in coastal zones. J Coast Res 19(3):584–599
Stive MJ, de Schipper MA, Luijendijk AP, Aarninkhof SG, van Gelder-Maas C, van Thiel de Vries JS et al (2013) A new alternative to saving our beaches from sea-level rise: the sand engine. J Coast Res 29(5):1001–1008
Turner RK, Lorenzoni I, Beaumont N, Bateman IJ, Langford IH, McDONALD AL (1998) Coastal management for sustainable development: analysing environmental and socio-economic changes on the UK coast. Geogr J:269–281
United Nations (2014) Department of economic and social affairs, population division
Van Rijn LC (2007) Unified view of sediment transport by currents and waves: I. Initiation of motion, bed roughness, and bed-load transport. J Hydraul Eng 133(6):649–667
Winter C (2007) Evaluation of sediment transport models. Sediment Geol 202(3):562–571
Winter C, Bartholomä A (2006) Coastal dynamics and human impact in the south-eastern North Sea: an introduction. Geo-Mar Lett 26:121–124
Winterwerp JC, Wang ZB, van Braeckel A et al (2013) Ocean Dyn 63:1293
Wong PP (1998) Coastal tourism development in Southeast Asia: relevance and lessons for coastal zone management. Ocean Coast Manag 38(2):89–109
Wright LD, Thom BG (1977) Coastal depositional landforms: a morphodynamic approach. Prog Phys Geogr 1(3):412–459
Yap WY, Lam JSL (2013) 80 million-twenty-foot-equivalent-unit container port? Sustainability issues in port and coastal development. Ocean Coast Manag 71:13–25

Chapter 8
Offshore Oil and Gas Production and Transportation

Stanislav Patin

Abstract An analysis of sources and factors of environmental risk at the various phases of the offshore oil and gas industry (OOGI) is presented. Practically all operations of the OOGI are shown to be accompanied by physical, chemical and biological disturbances in marine ecosystems. The level of impacts, their scale as well as negative ecological effects vary widely depending on local situations and conditions. Environmental impacts of drilling operations as well as platform and pipeline construction in the sea usually result in local and reversible disturbances in the water columns and benthic communities. The most significant sources and factors of ecological risk associated with the OOGI's activities include accidental oil spills in the coastal zone, operations with tanker ballast waters resulting in introduction of alien species, discharge of produced waters and seismic exploration. Such impacts could produce not only disturbances to local biota but could also lead to ecological catastrophes at a regional level. The most serious economic losses of fisheries result from the restrictions imposed on fishing and mariculture following oil spills in coastal areas.

Keywords Offshore oil and gas industry • Ecological risk • Marine ecosystems • Environmental impact • Seismic surveys • Drilling operations • Produced water • Tanker oil transportation • Offshore pipeline transportation • Ballast water • Invasion of alien species • Oil spills • Impact on fisheries

8.1 Introduction

About 50 years ago, oil and gas production in many regions started moving from land toward the oceans, gradually involving new marine areas. The offshore oil and gas industry (OOGI) has rapidly turned into one of the leading branches of the

S. Patin
Russian Federal Institute of Fisheries and Oceanography, Moscow, Russia
e-mail: patine@rambler.ru

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_8

world economy. At present, the OOGI is developing on the shelf of about 100 countries providing nearly 30% of total hydrocarbon production.

There is a number of reasons to suggest an increase in the offshore hydrocarbon production as well as expansion of the OOGI onto new marine areas in the twenty-first century. First of all we have to note the depletion of many oil and gas fields on land and, second, point to the huge hydrocarbon potential of sedimentary marine deposits. According to known estimates, total geological resources of the World Ocean may exceed 500 billion tons of hydrocarbons and amount to 60–70% of the world reserve. As the scale and geography of the offshore geological exploration expands, these estimates are likely to increase substantially. Thus hydrocarbon potential of the oceans seems to be sufficient to cover the energy needs of humanity in the twenty-first century. In the foreseeable future the energy demand is expected to increase about 2% per year, with oil and natural gas continuing to be the dominant sources of energy.

The most important trends and challenges of the future OOGI's growth include:

- moving of exploration and production activities into the deepwater areas of the oceans;
- increasing interest in the hydrocarbon resources of the Arctic seas, where—as estimated—more than 30% of the world's undiscovered natural gas reserves and 13% of its undiscovered oil reserves are located (Gautier et al. 2009);
- development of new efficient and environmentally friendly technologies, including, for example, compact sub-sea production systems directly on the seabed;
- changes in strategy and geography of the OOGI due to global climate anomalies and ocean warming.

Since the very beginning, the environmental issues of the offshore hydrocarbon production and transportation have been attracting increased attention as compared to some on-land human activities. The list of publications devoted to the environmental impact of the OOGI (especially oil pollution) is unprecedentedly wide and includes thousands of published works. Nevertheless, many aspects of this complex problem remain in the focus of public concern and discussion at the national and international levels.

From an ecological point of view, it is essential to note that virtually everywhere on the continental shelf, hydrocarbon fields *coincide or overlap with the areas of high biological productivity and traditional fishing*. In addition, oil platforms, pipelines and other objects of the OOGI infrastructure are *built into the marine environment* and thus are exposed to all natural elements and impacts (storms, ice field, etc.). On the other hand, the industry itself inevitably impacts marine ecosystems and thus should be subjected to appropriate measures of environmental protection and regulation. The reason is quite evident: the hydrocarbon extraction is finite, while the biological resources are self-renewable and therefore priceless.

This review is devoted to analysis of sources, factors and effects of environmental impact associated with the OOGI activity. The review is based on numerous published works, including recent summary reports (NAS 2003; UNEP 2006; GESAMP 2007; AMAP 2010; IPIECA 2010; OSPAR 2010; RCN 2012) as well as author's publications (Patin 1999, 2001, 2004, 2008).

8.2 General Characteristics of Impacts

Table 8.1 and Fig. 8.1 clearly illustrate that practically all phases of the OOGI activity are accompanied by a number of inevitable impacts on the marine environment.

As old hydrocarbon resources become gradually depleted and new ones start being developed within large fields, the oil production moves to new locations. As a result, the sequence of phases shown in Table 8.1 for an individual location becomes unrecognizable against the background of all other offshore activities in the region. This lead to the situation that just after 10 years of exploitation of a large offshore oil and gas basin, we can see newly installed platforms and pipelines along with abandoned structures, oil tankers along with seismic survey vessels and so on. Thus, local and point impacts become interwoven and combined into vast areas of environmental disturbances. Their nature and intensity may vary widely depending on the combination of a great number of natural and human impacts.

Environmental impacts of the OOGI are very complex by their nature. They result in physical, chemical and biological disturbances in the water column, on the bottom

Table 8.1 Environmental impact at the main phases of the offshore oil and gas industry

Phase	Activity	Type and factor of impact
Geophysical exploration	Seismic surveys	Hydroacoustic anomalies, mortality and behavioural changes of marine organisms, interference with fisheries and other sea users
Drilling exploration	Rig emplacement, exploratory drilling, well testing	Seabed disturbances, discharges of drilling and other wastes, increasing water turbidity, atmospheric emissions, accidents
Field commissioning	Platform installation, pipelaying operations; seafloor excavation; vessel traffic; offshore/onshore support facilities construction	Seabed disturbances, increasing water turbidity, construction and commissioning discharges, interference with fishing; pollution from support vessels
Production	Drilling and other production operations, maintenance and other activities	Discharge of drilling wastes and produced water, increasing water turbidity, accidental oil spills and atmospheric emissions, interference with fishing and other sea uses, physical disturbances of benthic communities
Oil transportation by tankers		Operational atmospheric emissions and discharges of oil wastes, impact on marine biota, oil spills
Decommissioning and abandonment of offshore installations	Platform/structure removal, plugging, abandonment, use of bulk explosive charges	Operational discharges, impact on biota during blasting operations, seabed and water column disturbances

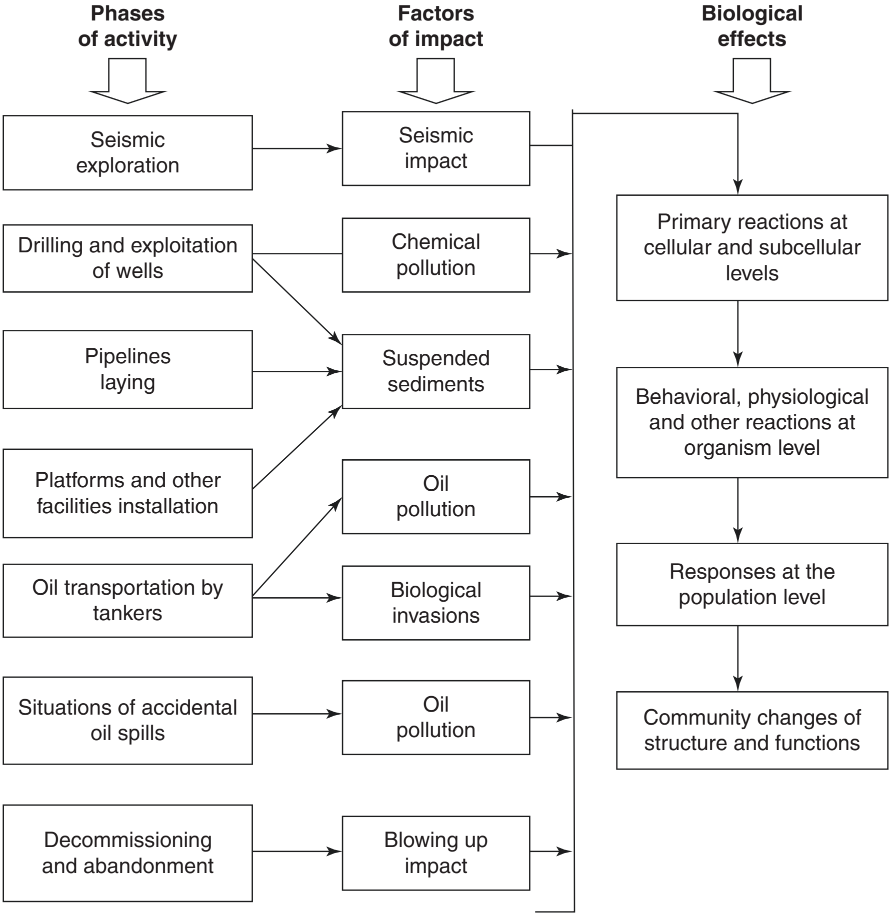


Fig. 8.1 Conceptual scheme of characteristic biological effects and environmental hazards of oil spills in the sea

and, to some extent, in the atmosphere. The assessments of such impacts and their consequences are provided below. They are based on the previously published methodology with a set of ecological and eco-toxicological criteria to rank the degree of environmental risk, including both the likelihood of a particular exposure and severity of its potential effects (spatial and temporal scope, reversibility, etc.) (Patin 2004).

8.3 Seismic Surveys

Seismic exploration is the first phase of any offshore oil and gas development. The tracks of seismic surveys could cover entire regions.

The mechanisms and manifestations of biological effects of seismic impulses on living organisms can vary widely—from effects on primary behavioral reactions (e.g., scattering fish school) to physical tissue damage and, ultimately, to organism death. The nature and degree of these effects depend on many factors, including the type and configuration of seismic source, the depth of the sea, the species of impacted biota, etc. Of course, the distance between the seismic source and the "target" plays a crucial role.

Zooplankton and fish at early stages of their development (larvae, fry and eggs) are particularly vulnerable to physical damage. Their mortality in the zone of direct seismic impact (up to 5 m from the source) could reach 1% of the local population abundance. Low-frequency seismic impulses can easily travel through seawater mass and exceed the acoustic background level at the distance of dozens of kilometers from the source. Many species of marine mammals and fish are capable of sensing and responding to these signals at rather large distance. For example, observations in the Barents Sea revealed changes in the schooling behavior of pelagic fish at the distance up to 50 km from the seismic survey area (Karlsen et al. 2004; Dalen 2007).

Compared to fish, marine mammals (cetaceans in particular) are more sensitive to sound impacts and may respond to low-frequency seismic waves at a distance of more than 100 km from the sound source (IWC 2006; IFAW 2008). The most likely biological consequences of such impacts include disturbance of communication and behavioral changes such as migration of marine organisms, especially whales. In combination with other sources of human impact, seismic explorations could produce cumulative effects in marine ecosystems and populations. An example of such situation is a serious threat to the small population of gray whales on the Sakhalin shelf that has arisen due to seismic surveys and other OOGI's operations. Special mitigation measures had to be implemented for protection of this endangered species (IUCN 2008).

As the first approximation, and in accordance with the adopted methodology (Patin 2004), potential ecological effects of seismic exploration in the sea can be assessed as *moderate* and *reversible*, while the scope of the impact—as *local* and/or *sub-regional* and *short-term*.

It should be noted that low-frequency sound signals can be detected at a distance of over 3000 miles (!) from the source of their generation by airguns (Nieukirk et al. 2004). The biological effects of such phenomenon are still poorly investigated. In spite of gaps in our knowledge, "acoustic pollution" (including seismic surveys) is considered today a serious ecological threat in the sea at the regional and global levels (IFAW 2008) (Boebel, Chap. 24).

8.4 Field Commissioning

Activities at the field commissioning phase include installation of offshore platforms, laying of submarine pipelines, construction of oil terminals, dredging and other operations. At present, there are more than 150,000 km of subsea pipelines and over 8000 offshore facilities installed on the marine shelves world-wide.

The principle factors of environmental risk of such activities are associated with extraction, replacement and resuspension of huge amount of bottom sediments. At the regional level this extraction could amount to millions of tons. For example, laying only 1 km pipeline is accompanied by the resuspension of about 5000 m^3 of bottom sediments. The total area of direct impact on bottom habitats in the North Sea due to construction of platforms and other OOGI's infrastructure exceeds 20,000 km^2 (OSPAR 2010).

The results of these activities inevitably lead to serious disturbances in benthic communities. They occur as a result of:

- physical elimination of benthos in the zone of construction and installation activities;
- mortality of organisms (especially epifauna) beneath the redeposited sediments;
- changes in structure and functions of benthic communities in the damaged bottom habitats.

The recovery time for bottom sediments and communities after field commissioning depends on numerous factors and ranges from several months to several years (sometimes over 10 years). Accordingly, ecological impact assessments vary widely—from *point*, *short-term*, *reversible* and *insignificant* to *local*, *temporary*, *slightly reversible* and *moderate*.

8.5 Drilling Operations

Well drilling and drilling waste removal are among the most common types of the OOGI's activity. The estimated annual scope of these operations at the regional level amounts to hundreds of drilled deep wells and hundreds of thousands of tons of discharged wastes. Drilling wastes include drilling fluids (muds) and drill cuttings (mineral particles generated by drilling). There are three main types of drilling fluids: oil-based fluids (OBF), water-based fluids (WBF) and synthetic-based fluids (SBF). At the end of the last century, most countries imposed a ban on the discharge of the OBF and associated cuttings into the sea. There has been a widespread shift to new technologies of drilling operations with using low toxic WBF and SBF. Some countries implemented a total ban on the disposal of any operational wastes from the offshore platforms ("zero discharge"). However, most countries and regions continue the practice of discharging the WBF and drill cuttings. The volume of such discharges usually amounts to over 1000 m^3 of drilling fluids per a deep well and several times smaller amount of associated cuttings.

Published data demonstrate that environmental impact of the WBF and accompanied cuttings discharged into the open sea is usually limited by *short-term*, *reversible* and *local* changes in plankton and benthos. These effects are mainly caused by the presence of suspended mineral material in drilling wastes. They can be interpreted as an acute stress in the form of temporary disturbances in behavioral, feeding, respiratory and other functions of marine organisms and their distribution.

These effects are similar to those biological changes that occur in the sea as a result of resuspension of bottom sediments during storms and field commissioning operations (see above). The scope of distribution of drilling wastes around platforms is typically limited by few hundred meters from the discharge point. At the same time, numerous well drillings and multiple discharges in the regions of long-term hydrocarbon development can lead to environmental disturbances in bottom habitats and benthos within the vast areas—up to several kilometers from drilling platforms.

8.6 Production Activity

In addition to drilling wastes, the production activity involves yet another, rather specific kind of waste—produced waters extracted along with the hydrocarbons. Quantitatively, these waters by far exceed all other types of the OOGI's wastes. Depending on situations, the amounts of produced waters vary extremely widely—from 10 m^3 per day for a single well to over 10,000 m^3 per day for platforms with numerous productive wells.

A common practice of handling produced waters involves their primary treatment (mainly separation from oil) and subsequent disposal at the sea. Other options involve water reinjection into the wells. This method, however, has not found wide application because of the large volumes of produced water, especially at the last phase of production activity. According to known estimates (IAOGP 2013), over 700 million tons of produced waters are discharged annually into the marine environment world-wide.

Chemical composition of produced waters is characterized by high mineralization (up to 300 g/l) and presence of numerous toxic substances (usually in low concentration), including dispersed oil, monocyclic and polycyclic aromatic hydrocarbons (PAH), alkylphenols, heavy metals, natural radionuclides (mainly radium-226), organic matter, and other trace components.

Field observations and model-based calculations show that the fate of produced waters discharged into the open sea is similar to the WBF distribution. According to different estimates, they are diluted by a factor of hundreds in direct proximity to the point of discharge and by 10^3–10^6 at distances over 100 m from platforms. As a result of this dilution, the actual concentration of produced waters and their components in seawater decreases to levels at which harmful effects are virtually nil or cannot be detected. The most evident ecological disturbances around productive platforms are usually observed in bottom habitats and benthic communities due to sedimentation of mineral fraction of drilling wastes and produced waters. Sometimes the decrease in abundance of the most vulnerable benthic species (especially small forms of crustaceans) could be detected at the distance up to 10 km from platforms.

Generally, the typical impact from production activity should be evaluated as *local* or *sub-regional* and *chronic*, whereas ecological effects can be ranged from *reversible* and *slight* in the seawater to *irreversible* and *moderate* in the bottom sediments.

Extreme negative assessments primarily relate to situations of long-term disposal of oil-containing drilling wastes and produced waters.

It should be recognized that some issues of long-term effect of produced waters discharged into the sea remain open. This applies, in particular, to the possibility of cumulative harmful effects and vulnerability of marine ecosystems in the Arctic (RCN 2012), as well as to the scope of bird mortality due to the oil slicks around the productive platforms (Fraser et al. 2006). It is important to emphasize that ecological risk of any waste disposal into the sea will ultimately depend not only on the amount and composition of the discharges but on location and natural conditions in the area of the disposal (coastal zone, open water, currents, season, etc.).

8.7 Tanker Transportation

Oil tanker fleet currently amounts to over 7000 large tankers of different types, which transport about three billion tons of oil and oil products annually (GESAMP 2007). Transportation routes cover the main areas of the oceans.

Major environmental impacts associated with the routine (accident-free) oil tanker transportation include:

- acoustic, mechanical and light effects on marine mammals, birds and fish;
- oil contamination due to operational and illegal discharges;
- emission of aerosols, volatile organic compounds and other contaminants into the atmosphere followed by their precipitation on the sea surface;
- “biological pollution” as a result of ballast water operations.

Most of these impacts are typical for all large vessels at the sea. Their effects are usually *localized* and *reversible*. But taken together, they can pose a serious and still poorly understood cumulative threat to marine organisms and ecosystems.

In the context of this review, one should pay special attention to operations with tanker ballast waters, which are one of the major cause of “biological pollution”, i.e. invasion of alien species. In the first approximation, the annual discharge of ballast waters from the oil tankers into the world’s oceans amounts to about three billion tons, while the annual world-wide “transportation” of marine biota in ballast waters is estimated to include up to 10,000 species (Raaymakers 2003).

Sometimes harmful bio-invasions lead to ecological disasters at the regional level. One of them occurred in the Black Sea in the 1980s after introduction of *Mnemiopsis leidyi* with ballast waters. This jellyfish is, at first glance, a harmless creature; however it is a very active predator that feeds on zooplankton organisms, including fish eggs and fish larvae. Its biomass in the sea reached ten billion tons and resulted in a dramatic transformation of the entire ecosystem, leading to the drop in fish stock and collapse of commercial fisheries in the region. Later this disastrous invasion spread to the Sea of Azov and the Caspian Sea.

Given the high intensity of the current and projected oil tanker traffic, there is a reason for a serious concern about the ecological risk of such events in many marine regions. Globally, the transfers of ballast waters carrying invasive species are perhaps the biggest environmental challenge facing the shipping industry (especially oil tanker transportation) this century (IPIECA 2010) (Kuhlenkamp and Kind, Chap. 25).

8.8 Transportation by Pipelines

Worldwide, the total length of seabed pipelines for pumping hydrocarbons now exceeds 150,000 km. Environmental impacts during normal (accident-free) functioning of underwater pipelines are usually associated with:

- acoustic, thermal and electromagnetic effects on the bottom fauna;
- changes in topography and bottom structure due to the physical presence of the pipes laid on the sea bottom without burial;
- obstacles to movement and migration of mobile benthic forms, especially invertebrates;
- changes in the composition of benthic communities in the area of the pipeline due to biofouling and reef effect.

Data show that the above factors have a low and localized impacts on the marine environment and biota. At the same time, some issues within the framework of this problem are still poorly understood. This applies, in particular, to the possibility of interference with movement and reproduction of some benthic organisms because large diameter pipelines (over 50–100 cm) could be a barrier to their long-range migration. In general, ecological effects of the offshore pipeline transportation can be assessed as *slight* and *reversible* (*slightly reversible*), while a scope of impact as *sub-regional* (*regional*) and *chronic*.

8.9 Decommissioning

Sooner or later (usually after 30–50 years) hydrocarbon reserves within any oil and gas field are exhausted, and then a number of environmental, technical and economic problems arise. As a rule, these problems remain in the shadow at the early phases of oil and gas projects. We are talking about the fate of disused offshore platforms, underwater pipelines and other facilities of the OOGI's infrastructure. Left at the bottom and under water, they are inevitably exposed to destruction and spreading over large areas, thus threatening marine navigation, fishing and other offshore activities. On the other hand, decommissioning of abandoned facilities involves enormous technical and economic difficulties similar sometimes to the challenges of their installation. Besides, such operations present a very powerful source of harmful impacts on the marine environment, especially due to the use of the explosives.

Over the past several decades, a number of different uses for decommissioned oil and gas platforms has been proposed as alternatives to their complete removal. Among these options, the use of platforms as artificial reefs is especially interesting. Currently, rigs-to-reefs technology has been successfully implemented in some regions, especially in the Gulf of Mexico, where over 200 decommissioned platforms have been converted to artificial reefs (Kaiser and Pulsipher 2005). The results of ecological monitoring around platforms suggest that they not only provide a habitat for fish and other commercial organisms, but also contribute to their reproduction. This phenomenon, as well as an increase in the total biomass around offshore platforms and pipelines can be considered as an evidence of positive impacts of the OOGI on marine ecosystems.

8.10 Oil Spills

Despite a clear decline in the frequency and volume of oil spills in the sea during the recent decades, they still continue to be inevitable events at all phases of the offshore oil and gas development and pose one of the most serious threats to marine ecosystems. By now, a wealth of statistical data on accidental oil spills and oil entering the sea has been accumulated in many countries and regions. Data from one recently published international summary are presented in Table 8.2.

Analysis of presented data and other corresponding materials (e.g., IPIECA 2003; NAS 2003; UNEP 2006; GESAMP 2007; ITOPF 2010; OSPAR 2010) provides the basis for the following conclusions:

- Contrary to the wide-spread opinion, accidental oil spills do not appear to be a major source of oil contamination of the marine environment. They are responsible for about 20% of total anthropogenic input of oil in the World Ocean.
- Most accidental oil losses (about 80%) usually result from spills during oil tanker transportation.

Table 8.2 Worldwide estimates of oil entering the marine environment[a]

Sources of oil input in the sea	Annual release (tons)	
	Total	Accidental spills
Ships (including tankers)	457,000	163,000
Offshore exploration (drilling) and production	20,000	600
Coastal facilities	115,000	2400
Small craft activities	53,000	No data
Natural seeps	600,000	–
Unknown (unidentified) sources	200	No data
Total	1,245,200	166,000

[a]Based on the data covered the 1968–1997 period (GESAMP 2007)

- Small and quickly eliminated oil spills as well as operational and illegal discharges are the most common sources of long-term oil contamination in areas of intense offshore oil production and transportation.
- Particularly large spills releasing thousands tons of oil occur at the rate of zero to several incidents per year.
- Any direct correlation between the amount of spilled oil and the degree of ecological risk does not exist.
- Finally, all effects depend on the type and properties of released oil, current natural situation and specific circumstances of the accident.

The analysis of the worldwide statistics for 1990–2000 (Patin 2008) allowed to estimate that on average a "typical" oil spill releases the following amount of oil per year:

- 100 kg of oil from each productive platform,
- 20 kg of oil from every kilometer of a subsea pipeline and
- 14,000 kg of oil from each oil tanker in action.

In first approximation, the total loss of oil during all operations of the OOGI amounts to about 30 tons per million tons ($3 \times 10^{-3}\%$) produced and/or transported oil.

Over the last decades, there has been a clear trend to a significant reduction in the volume of large oil spills during all operations of the OOGI, including the tanker transportation. However, the dramatic events in the Gulf of Mexico in 2010 clearly demonstrated that the likelihood of oil disasters continues to be the sword of Damocles which is still hanging over the seas.

The conceptual scheme of developing biological effects and consequences of an oil spill under acute and chronic stresses is presented in Fig. 8.2. Depending on numerous specific parameters of an oil spill, a wide range of effects may occur both in the water column and bottom sediments—from behavioral responses of organisms at the initial phases of the spill up to the long-term population disturbances under chronic impact in the coastal zone.

One of the key eco-toxicological characteristics of oil in the sea is the dualism of its biological impact. From one hand, oil includes a combination of dissolved (mainly light aromatic) hydrocarbons and thus it is able to damage physiological and biochemical systems in living organisms. From the other hand, crude oil is a viscous substrate and thus can cause a purely physical damage by covering protective surface layers of an organism. This is especially true in relation to marine birds and mammals which are the most vulnerable species and first victims of oil spills. For example, as a result of the accident with the tanker *Exxon Valdez* in 1989 off the coast of Alaska over 250,000 seabirds were killed (NAS 2003).

From an ecological point of view, there are two main types of oil spills. One of them includes spills that begin and end in the open water, without contact with the shoreline and bottom. Their effects tend to be *temporary*, *local* and *easily reversible* in the form of acute stress. No significant harmful changes or mortality in plankton and nekton (including fish) could be observed due to low oil concentrations in the water column.

The other and the most dangerous type of spills involves situations when oil finds its way into coastal waters and results in long-term ecological consequences. Most

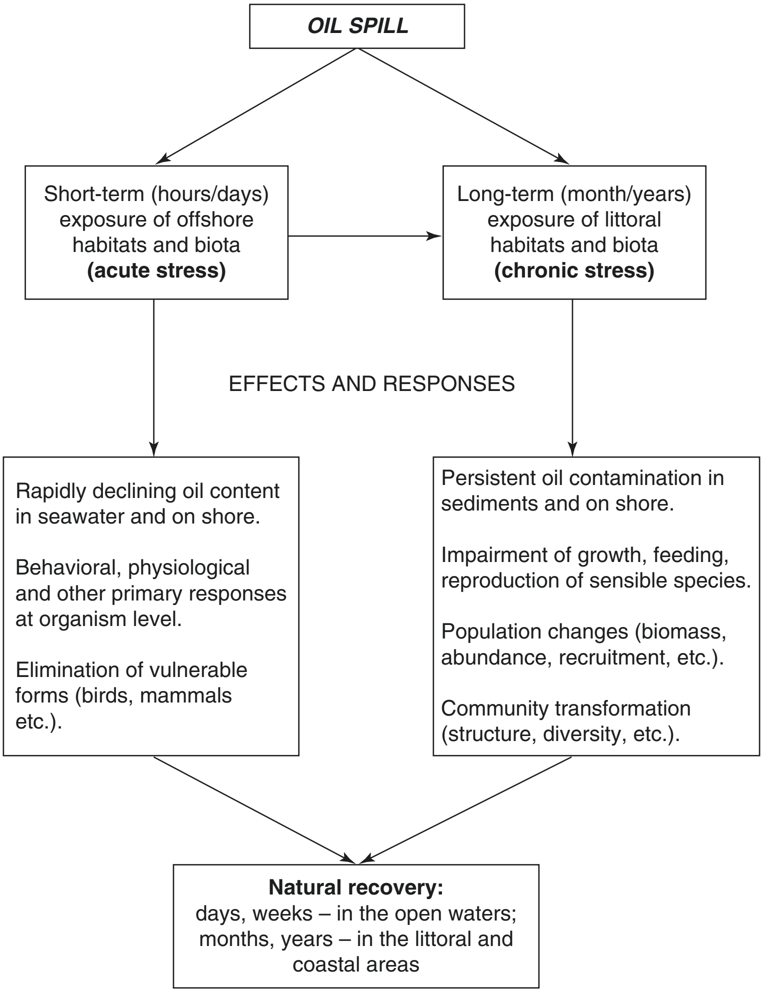


Fig. 8.2 Conceptual scheme of characteristic biological effects and environmental hazards of oil spills in the sea (Patin 2004)

often, these two scenarios (pelagic and coastal spills) develop simultaneously, which is especially likely when an accidental spill occurs close to the shore. Numerous observations in different parts of the world indicate that oil persistence and, consequently, its adverse ecological impact sharply increase from open rocky shores to sheltered wetland (marshes, mangroves), gravel and pebble coasts. Accordingly, the time of recovery of coastline ecology may vary widely—from months to several years, sometimes over 10 years (Patin 2008). The most serious harmful effects are observed in the coastal benthic communities in the form of prolonged and stable changes in their abundance and species composition.

In addition to accidental spills, there are two other sources of oil input in the sea that are considered to pose a serious environmental threat. These sources include operational oil releases and illegal oil discharges, particularly from tankers. These so called "small spills" are responsible for long-term oil contamination of large areas, e.g. European Seas (UNEP 2006).

8.11 Impact on Fisheries

In general, we should consider two main groups of threats from the OOGI activities:

- environmental impact on marine living resources and commercial organisms;
- economic losses, including hindrance to fishing activities.

Until recently, there has been presented no direct evidence of any detectable influence of the OOGI's activities on the abundance and stock of commercial species at the regional level. Most known estimates (summarized by Patin 2008) indicate that mortality of commercial species, even in the most pessimistic scenarios (catastrophic oil spills), usually do not exceed hundreds/thousands tons of biomass and cannot be reliably distinguished against the background of high variability of populations due to environmental changes, natural mortality, and fishing (Fig. 8.3).

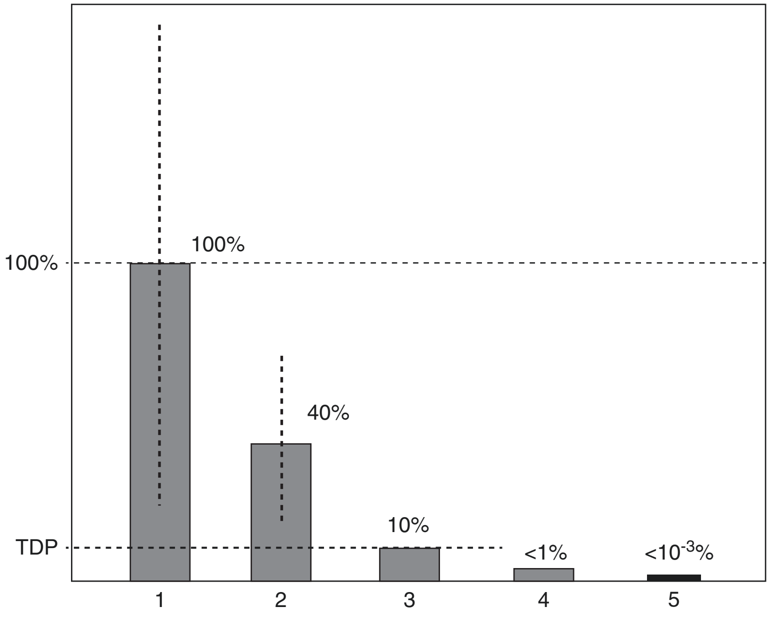


Fig. 8.3 Relative impact of different types of human activities (including oil spills) on commercial fish resources (Patin 2004). *1*, total stock (biomass) of commercial species; *2*, extraction by fisheries; *3*, incidental and discarded catches; *4*, maximum possible loss from pollution; *5*, maximum possible losses due to all offshore oil and gas activities, including oil spills. *TDP* threshold of disturbing population. *Dotted lines* reflect variability of total stock and catch by fisheries

The above conclusion does not mean that the OOGI does not cause any damage to fisheries and mariculture (the cultivation of captive species). Actual economic losses usually occur as a result of:

- temporary restrictions on fishing and mariculture activities after oil spills;
- decrease in value of seafood due to oil contamination of caught and cultivated species;
- limiting the access to fishing grounds and physical interference with trawling operations around platforms, pipelines and other offshore facilities.

The most serious economic losses result from the restrictions (bans, closures) imposed on fishing and mariculture following oil spills in coastal areas. The exact nature and extent of such losses may vary widely depending on a combination of diverse factors, such as the oil spill amount, season, weather situation, etc. In some cases, for example after the catastrophic accidents with tanker *Exxon Valdez* (1989), tanker *Prestige* (2002) and platform *Deepwater Horizon* (2010) economic losses for fisheries and maricultural sector reached billions of dollars.

Nonetheless, the experience of many coastal countries indicates that "peaceful coexistence" of the OOGI and fisheries is possible. The balance of interests of these two offshore industries can be achieved both through national measures and on the basis of a number of international conventions and regulations (Patin 2001; IPIECA 2003; WWF-Norway 2009; ExxonMobil 2015).

8.12 Conclusions

As described above, the OOGI's activities are accompanied by inevitable environmental impacts, which cause physical, chemical and biological disturbances in the sea. The scope and severity of these impacts as well as their ecological effects vary considerably depending on specific local conditions and situations. Impacts from drilling and production operations, platform construction, pipeline installations and other activities to create offshore infrastructure usually result in local and reversible environmental changes in the water column and benthic communities. The seismic explorations cover extensive sea areas but biological effects of this large-scale activity are not well investigated and further research is required.

The major sources of environmental risk from the OOGI's activities include accidental oil spills in the coastal zone and invasion of alien species due to operations with tanker ballast waters. These impacts can lead to regional ecological catastrophes with huge economic and fisheries losses. The main threat to fisheries from oil spills is associated with temporary restrictions on fishing and oil contamination of commercial species.

Considering the OOGI as a whole, it should be taken into account that this industry is only a fragment in the complex network of human activities in the marine environment along with commercial fishing, shipping, disposal and dumping of wastes, extraction of sand and gravel and many others. In many areas (primarily in coastal zones) the cumulative effect of these activities poses a serious long-term threat to marine ecosystems and living resources and therefore should be the focus of appropriate environmental regulation and management.

Numerous scientific investigations have provided the basis for a wide range of national and international measures, approaches and tools that have been implemented in relation to the OOGI. The most common of them include:

- imposing restrictions (norms, standards, criteria, permits, bans) on waste handling and disposal into the sea at all stages and operations of the OOGI;
- implementing environmental monitoring of the marine environment in the regions of oil and gas production and transportation;
- utilizing methodologies (i.e. environmental impact assessment and risk management), which help estimate and mitigate loss of biodiversity and natural resources during the offshore oil and gas activities;
- introducing measures to protect vulnerable environment (e.g. by designation of particularly sensitive sea areas, petroleum-free zones and marine protected areas or via coastal environmental vulnerability mapping);
- implementing oil spill contingency planning.

The proper implementation and further development of such measures should be the most important steps in protecting the marine environment during the offshore oil and gas activities in the twenty-first century (Jessen, Chap. 36).

References

AMAP (Arctic Monitoring and Assessment Programme) (2010) Oil and gas activities in the Arctic. Effects and potential effects. AMAP, Oslo, Norway

Dalen J (2007) Effects of seismic surveys on fish, fish catches and sea mammals. Report for the Cooperation group. Fishery Industry and Petroleum Industry Report no. 2007–0512

ExxonMobil (2015) Coexisting with the fishing industry. Esso Norge as an ExxonMobil Subsidiary. http://www.exxonmobil.no

Fraser GS, Russell J, Von Zharen WM (2006) Produced water from offshore oil and gas installations on the grand banks, Newfoundland and Labrador: are the potential effects to seabirds sufficiently known? Mar Ornithol 34:147–156

Gautier DL, Bird KJ, Charpentier RR et al (2009) Assessment of undiscovered oil and gas in the Arctic. Science 324:1175–1179

GESAMP (UN Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection) (2007) Estimates of oil entering the marine environment from sea-based activities, GESAMP reports and studies, 75

IAOGP (International Association of Oil and Gas Producers) (2013) Environmental performance indicators 2012 data, report 2012

IFAW (International Fund for Animal Welfare) (2008) Ocean noise: turn it down. A report on ocean noise pollution. IFAW

IPIECA (International Petroleum Industry Environmental Conservation Association (2010) Alien invasive species and the oil and gas industry. IPIECA, London

IPIECA (International Petroleum Industry Environmental Conservation Association) (2003) Biological impacts of oil pollution: fisheries. IPIECA, London

ITOPF (International Tanker Owners Pollution Federation) (2010) Oil spill statistics (1970–2009). ITOPF, London

IUCN (International Union for Conservation of Nature) (2008) Western gray whales: status, threats and the potential for recovery. IUCN, Tokyo
IWC (International Whaling Commission) (2006) Features of sound and seismic surveys. Report of the Scientific Committee. Report of the Standing Working Group on Environmental Concerns. IWC, London
Kaiser MJ, Pulsipher AG (2005) Rigs-to-reefs programs in the Gulf of Mexico. Ocean Dev Int rnational Law 36:119–134
Karlsen HE, Piddington RW, Enger PS, Sand O (2004) Infrasound initiates directional fast-start escape responses in juvenile roach Rutilus rutilus. J Exp Biol 207:4185–4193
NAS (National Academy of Sciences) (2003) Oil in the sea: III. Inputs, fates, and effects. National Academies Press, Washington, DC
Nieukirk SL, Stafford KM, Mellinger DK, Dziak RP, Fox CG (2004) Low-frequency whale and seismic airgun sounds recorded in the mid-Atlantic Ocean. J Acoust Soc Am 115:1832–1843
OSPAR (Oslo and Paris Convention) (2010) Quality status report 2010 for the North East Atlantic. OSPAR Commission, London
Patin SA (1999) Environmental impact of the offshore oil and gas industry. EcoMonitor Publ., New York
Patin SA (2001) Oil and continental shelf ecology. VNIRO Publishing, Moscow. (Russian)
Patin SA (2004) Environmental impact of crude oil spills. In: Encyclopedia of energy, vol 1. Elsevier Science, New York, pp 737–750
Patin SA (2008) Oil spills in the sea and their impact on the marine environment and living resources. VNIRO Publishing, Moscow. (Russian)
Raaymakers S (2003) Maritime transport and high seas governance – regulation, risks and the IMO regime. Paper presented at international workshop on governance of high seas biodiversity conservation, Cairns, Australia
RCN (Research Council of Norway) (2012) Long-term effects of discharges to sea from petroleum-related activities. The results of ten years' research. RCN, Oslo
UNEP (United Nations Environment Programme) (2006) Illegal oil discharge in European Seas, Environment Alert Bulletin, 7
WWF-Norway (World Wild Fund, Norway) (2009) Petroleum-free zones in the Norwegian Sea. WWF-Norway, Oslo

Chapter 9
Exploitation of Offshore Wind Energy

Jens Lüdeke

Abstract Offshore wind energy will substantially contribute to future energy generation. However, the use of wind energy in marine areas has implications for marine ecosystems. The results of more than a decade of ecological research concerning offshore wind farms in Germany and abroad have revealed potential negative impacts of offshore wind farms, particularly with regards to seabirds, migrating terrestrial birds, and marine mammals such as harbor porpoises, especially by noise effects during installation of the turbines. Depending on the location of the wind farm, effects on bat populations are also possible. Impact on fish and benthic species are probably less relevant. There are even examples of positive (local) effects on marine biodiversity, for example, due to the introduction of a new hard substrate into ecosystems or the exclusion of fishing from the area of the offshore wind farm. For an overall assessment of the impacts of offshore wind, the effects still have to be investigated on a cumulative and international level over the long term.

A number of measures are necessary to achieve environmentally sound development of the use of offshore wind energy. Marine spatial planning is important for guiding human activities in the marine environment, such as the use of offshore wind energy. Marine protected areas are of high relevance for protecting sensitive habitats and species. State-of-the-art mitigation measures against underwater noise are required to avoid hazards to whales. Finally, marine compensation measures can help to counterbalance adverse impacts of offshore wind farms.

Keywords Offshore wind energy • Offshore wind farms • Underwater noise • Marine spatial planning • Marine compensation measures • Pile driving • Marine mammals • Sea birds protection • Reef effect

---

J. Lüdeke, Dr.-Ing.
Environmental Assessment and Planning Research Group,
Technical University of Berlin, Berlin, Germany
e-mail: Jens.luedeke@ile.tu-berlin.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_9

9.1 Development of Offshore Wind Energy

Offshore wind energy has many advantages over onshore wind production, most prominently in terms of the higher wind speed offshore: the wind speed in the first offshore wind farms (OWFs) has averaged 10 m/s in recent years, whereas, at onshore locations, the average is often not much higher than 6–8 m/s. Moreover, the wind blows much more regularly offshore (offshore more than 4000 full load hours; onshore only 1300–2000 full load hours, depending on the location of the turbines). OWF can supply electricity at almost every hour of the day and any time of the year. Production is highly predictable, with almost no need for backup capacity from conventional energy producers or greater storage volume. In Germany, OWFs are mostly located far off shore, where they do not create acceptance problems among nearby residents (no "Not in My Back Yard" phenomenon). In other countries, OWFs are sometimes built near the shore and therefore can produce conflicts, e.g., with the tourism sector. Offshore wind industries may also create conflicts with fishermen because commercial fishing is prohibited inside the area of OWFs. Nevertheless, the conflicts connected to OWFs are inferior compared with the problems onshore that wind energy regularly has to face, especially with nearby residents.

In Europe, in pioneer countries, such as the UK, Denmark and Germany, offshore wind energy is now becoming increasingly important for energy transition away from fossil fuels towards renewable energy resources. The first OWFs worldwide were built in Denmark in 1991. In 2016, the capacity of offshore wind energy passed 10,000 MW (UK 6000 MW, Germany 3000 MW, and Denmark 1200 MW). More than 3000 turbines are currently installed and grid-connected in more than 80 OWFs in 11 European countries (see Fig. 9.1). This capacity provides sufficient electricity supply to about ten million households in Europe. The European Commission considers offshore wind energy "the energy of the future." Wind energy is supposed to ensure European energy safety and transition to a low carbon economy. The goal for offshore wind in Europe is over 40,000 MW by 2020 (see Table 9.1) and about 150,000 MW in the long run.

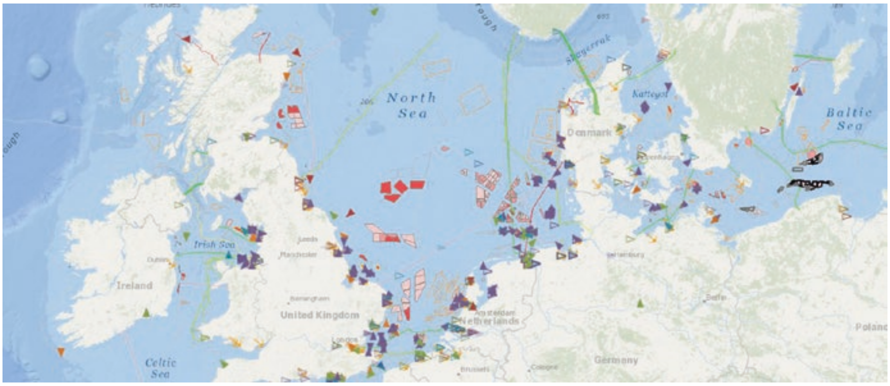


Fig. 9.1 Offshore Wind Projects in selected European Waters (4C Offshore 2016)

Table 9.1 Aims and required marine area for OFW in Europe (Source: adapted from the EU COM 2016, Seaenergy 2020)

Country	2020 Target (MW)	Minimum area for offshore wind farms (≈10 MW per km²) (km²)	Share for offshore wind farms of total EEZ of each country (%)
Belgium	2000	200	5.56
Denmark	1339	140	0.13
Estonia	250	25	0.07
Finland	900	90	0.17
France	6000	600	0.18
Germany	10,000	1000	3.50
Greece	1500	150	0.00
Ireland	550	55	0.01
Italy	680	7	0.00
Latvia	180	18	0.06
Lithuania	100	10	0.16
Netherlands	5978	600	1.02
Poland	500	50	0.15
Portugal	75	7.5	0.00
Spain	3000	300	0.04
Sweden	182	18	0.05
UK	18,000	3300	0.43
Total	≈50,000	≈ 6500 km²	Ø 0.68

The predicted minimum area necessary to achieve the 2020 target is based upon a reference density for offshore wind farms of 10 MW/km² (Seaenergy 2020)

Germany's energy approach—the *Energiewende*—aims to fundamentally restructure the country's energy supply with 80% of electricity renewable by 2050. Offshore wind will play an important role, with the German government having established plans for using 6500 MW offshore wind energy by 2020 and 15,000 MW by 2030 (Federal Ministry for Economic Affairs and Energy 2015).

As required by Article 4 of Directive 2009/28/EC on the promotion of the use of energy from renewable sources (Renewables Directive), EU Member States have defined their legally binding 2020 target for the share of renewable energy in their respective National Renewable Energy Action Plans. The 17 European Coastal States of the North Sea, Baltic Sea, Mediterranean Sea, and Atlantic Coast have announced quantitative objectives for offshore renewable energies by 2020. In order to achieve the goals of the National Renewable Energy Action Plans (EU COM 2016), substantial geographical areas of the Exclusive Economic Zone (EEZ) will be occupied (Table 9.1).

Non-European countries have also started developing OWFs. For example, China already built its first OWF in 2010 and South Korea is preparing to build its first OWF. India is currently working on the legal and policy frameworks to formulate its entrance into the offshore market. There are also plans for OWF in the U.S., although offshore wind is yet in the early stage of development: America's first OWF has been under construction since 2015 and several other projects will be implemented in the next several years (Kota et al. 2015).

9.2 Environmental Impacts of OWF

In the 1990s, prior to the use of offshore wind energy, there was almost no data regarding its potential environmental impacts. Thus, ecological research on the development of OWFs took the highest priority from the outset. Indeed, this is why the Federal Ministry of Environment in Germany provided more than 50 million euros of funding for research. The first German offshore test field—Alpha Ventus—which was completed in the North Sea in 2010, therefore sought to resolve technical and environmental uncertainties. The impact of OWFs on the marine environment has been intensively investigated, as have ways to reduce this impact (Otto et al. 2014). Knowledge concerning the effects of OWFs on the marine environment has been considerably advanced by data gathered in Germany over recent decades. Since the German body of research is comprehensive and unique, this chapter focuses on its research outcomes, evaluated, however, in the context of numerous studies from other countries (Lüdeke 2015).

From the outset, environmental problems presented a major obstacle for the approval of OWFs in Germany, as well as other European countries. One focus of the German research was to compare actual construction and operational effects on the marine environment with the (theoretical) forecasts. Investigations in Germany followed the Before-After-Control-Impact (BACI) design, with comparative investigations in the area of the OWFs (especially in the first OWF Alpha Ventus) and in selected reference areas without turbines, before and during the construction period, as well as in the first years of operation of the wind farm (Beiersdorf 2014).

9.2.1 Impacts of OWFs on Benthos

The impacts of OWFs on benthos (communities of organisms that live in, on or nearby the seabed) are exceptional because they can be assessed as positive in the context of an increase in number of species and biomass. Surveys have demonstrated an increase of endobenthos after OWF construction, although the species composition changed, owing to the new habitats. The results show that OWFs have a substantial effect on the marine benthos. Variations of the benthic in- and epifauna of the sedimentary seafloor indicate an influence on the part of the wind turbines and the associated activities on population dynamics of benthic species. However, the duration of the investigation period still is too short to draw conclusions on the long-term development of the infauna (Gutow et al. 2014). Nevertheless, it was discovered that the cessation of fishing activities in wind farm areas has a positive effect on benthic biodiverstity after several years (Bergman et al. 2015). Even so, according to Gutow et al. (2014), no clear signs of recovery from bottom trawling manifested in the short term. Beyond this, Mesel et al. (2015) note that the community of endobenthos soon became dominated by only a few species, and even non-indigenous, invasive species were found.

The hard bottom associated benthos communities are more likely found around the underground parts of turbines. Although the seafloor changes substantially around the turbine foundations, a great number of species usually inhabiting the original soft bottom fauna is still found in these modified sediments. Turbine foundations serve as artificial reefs, being broadly populated and offering habitats for faunal diversity. This leads to an increase in the number of aquatic animals. At Alpha Ventus, it was not possible to clearly distinguish between the impacts of the turbine foundations (e.g., an increase of biomass caused by the new turbines serving as artificial reefs) and processes associated with their operation (e.g., the recovery of benthic communities after the cessation of bottom trawling).

Five years after the construction of Alpha Ventus and the introduction of new habitats for hard bottom associated mobile demersal megafauna, the fouling assemblage has increased enormously. The new artificial reefs in the marine environment have a substantial influence on nearby sediment and benthic community inhabitants. The species richness and biomass of the fouling assemblage have steadily increased, reaching a biomass of more than 20 kg/m^2 of foundation in the shallow, subtidal mussel accumulation. Shortly after construction, up to 100 times more hard-bottom species were present at the foundations than in the previous soft sediments. Furthermore, the foundation structures have served as nursery grounds, e.g., for the brown crab (*Cancer pagurus*), the Atlantic horse mackerel (*Trachurus trachurus*), and the pouting (*Trisopterus luscus*) (Krone and Krägefsky 2012). Moreover, a large number of mussels (*Mytilus edulis*), which had not formerly been abundant in this location, were observed.

Three years after completion of the OWF, the growth was noticeable: mussels, amphipods, crabs, and sea anemones had all settled within the OWF in large numbers. A cover of mussel shells was established around the foundations. The biomass on the turbine foundation attracted predators and scavengers. The fouling biomass now descends to the seafloor when the organisms die. There, it provides food for scavengers. The change in species composition and increased vegetation has attracted larger animals, which find new food sources around the foundations (Gutow et al. 2014).

Similar results have been obtained in studies outside Germany, in other sea regions. It has been demonstrated that OWFs—including both the wind turbines and associated activities (e.g., cessation of fishing)—have affected the population dynamics of benthic species. Another notable result from investigations at European wind farms is the lack of short-term effects on marine soft-bottom benthos. An increase of benthos is predicted over the long term (Lindeboom et al. 2011).

In conclusion, a number of investigations have proven that OWFs can lead to an increase in abundance and number of hard bottom associated benthic species especially within the wind park area (Andersson et al. 2009; Punt et al. 2009; Wilson et al. 2010; Wilhelmsson et al. 2010; Lindeboom et al. 2011; Coates et al. 2012; van Polanen et al. 2012; Gutow et al. 2013; Krone et al. 2013; Schmidt et al. 2013; Ashley et al. 2014; Bergman et al. 2015; Coates et al. 2014; Dannheim et al. 2014; Hooper and Austen 2014; Krägefsky 2014; Vaissière et al. 2014; Wilding 2014; Lüdeke 2015; Hammar et al. 2016). Thus, the introduction of an artificial substratum allows species which are naturally not occurring at these sites to establish themselves. Consequently, especially the benthos species, which depend on hard substratum, benefits from OWFs. However, an assessment of the implications for the ecosystem in a long-term investigation is still lacking.

9.2.2 Impacts of OFWs on Fish

Fish could be affected by pile driving and other construction activities. Injuries from pile driving sounds have been found to cause injuries to several fish species in a laboratory study. The recovery of the fish occured within 10 days and is unlikely to have affected their survival (Bailey et al. 2014). Beyond this, deleterious effects on fish have been documented. For example, intense construction activities, which involve not only pile driving, but also ship traffic, photo pollution, seafloor disturbance has resulted a 40–50% decrease in the abundance of pelagic fish (primarily mackerel, horse mackerel, herring, and sprats) compared to surrounding areas. Construction activities like pile driving, ship traffic or seafloor turbulence disturb fish (Reichert et al. 2012).

After construction, the abundance of fish species was higher at the wind turbine foundations than in areas outside the wind parks. Overall, there was an increase in the number and biomass of fish. The catches were more than twice as large as those before construction, with larger fish being caught (Reichert et al. 2012). The new artificial reef community included fish such as mackerel, striped dragonets, French cod, and flatfish, as well as predatory fish that are rare on pure sand surfaces. Most experts evaluate this artificial effect as positive, as it increases biodiversity. A recovery of fish populations and benthic communities has been noted to date. Again, two factors are responsible for these occurrences, namely the new artificial reef and the prohibition against trawling within OWFs.

Findings from German studies are supported by those in other sea areas (Leitao et al. 2007; Andersson et al. 2009; Langhamer et al. 2009; Punt et al. 2009; Wilhelmsson et al. 2010; Reubens et al. 2011; De Troch et al. 2013; Reubens et al. 2013a, b; Ashley et al. 2014; Lüdeke 2015; Hammar et al. 2016).

9.2.3 Impacts of OWFs on Birds

Impacts on seabirds and migrating terrestrial birds have been at the center of several studies in Germany and other nations. Seabirds can be affected by OWFs in various ways, including collisions with turbines, barrier effects, habitat loss, and attraction (Dierschke and Garthe 2006). Garthe et al. (2013) published a comprehensive study on resting seabirds, clearly showing that seabird distribution changes substantially as a result of OWFs.

9.2.3.1 Seabirds

A decline in the overall abundance of most seabird species was noted on Germany's first OWF, although bird behaviors varied depending on the species (Mendel et al. 2014). A review of the international research confirmed the data from Germany in showing habitat loss for some seabirds, whereby some seabirds were attracted to OWFs, while others ignored their presence (Dierschke and Garthe 2006; Petersen et al. 2006; Schwemmer et al. 2011; Plonczkier and Simms 2012; Furness et al. 2013; Haelters and Vanermen 2013; Petersen 2013; Bradbury et al. 2014; Mendel et al. 2014; Hammar et al. 2016).

Several species completely avoided the OWF (e.g., red-throated divers (*Gavia stellata*) and black-throated divers (*Gavia arctica*)), whereas others (e.g., long-tailed ducks (*Clangula hyemalis*)) only partly stayed away from the OWF area and its direct vicinity. Furthermore, herring gulls, gannets (*Genus: Morus*), guillemots (*Genus: Cepphus*), razorbills (*Genus: Alca*), and divers (*Genus: Gavia*) more or less avoided the area around the OWF. The two most numerous species occurred in lower numbers after construction, as did the blacklegged kittiwake (*Rissa tridactyla*) and northern gannet (*Morus bassanus*). As a result, it can be noted that these species lost a part of their habitat to the OWF (Mendel et al. 2014). Guillemots and razorbills were only seldom observed in the wind farm; thus, the area surrounding the wind farm no longer seems to be suited as a habitat for these species. The shy divers avoid OWF areas as well; therefore, the area available for these species to rest and feed in the North Sea has decreased (Garthe et al. 2013). Nonetheless, thus far there is no evidence indicating whether habitat loss affects the population of certain species.

For foraging, areas both within and outside the OWF appeared suitable for some species. The proportion of lesser black-backed gulls (*Larus fuscus*) searching for food was relatively similar within and outside the OWF area. Actively feeding birds were observed more often within the OWF. A part of the lesser blackbacked gulls fed within Alpha Ventus. This might be a result of the new hard substrate or small-scale turbulence around the wind turbines providing an increased food supply. In the reference area, only a few actively feeding gulls were observed. Overall, foraging appeared to be more common inside rather than outside the wind farm (Garthe et al. 2013).

Some seabird species were even attracted to OWFs. For example, the number of little gulls (*Hydrocoloeus minutus*) increased after OWF construction, and some species (e.g., gulls and tern species) did not hesitate flying into wind farms to forage. Cormorants even used the structures for resting (Dierschke and Garthe 2006). Also little gulls and herring gulls are numerous inside OWFs. Data have shown that approximately 80% of the seabirds in the wind farm are herring gulls (Mendel et al. 2014). The occurrence of the birds is certainly correlated with an increase in the benthic structural diversity and fish as prey (see Sects. 9.2.1 and 9.2.2).

Flight height measurements suggest some overlap between the flight heights of seabirds and the operational height of Alpha Ventus. The animals exhibited different behaviors, from resting within the OWF to flying through it. They were often observed searching for food inside Alpha Ventus. In most cases, their flight altitude was so low that they could not collide with the rotor blades. Only some of the birds flew in the height range of the rotors. Large gulls were exposed to high collision risks (Mendel et al. 2014). At present, it seems difficult to set thresholds for the impairment of the habitats of seabirds by OWFs. Busch and Garthe (2016) therefore present a new approach for assessing displacement impacts of OWFs on seabirds by making the best use of limited data, which is called potential biological removal assessment (PBR).

9.2.3.2 Migratory Birds (Seabirds and Terrestrial Birds)

Millions of migratory birds pass the North Sea area, especially during the autumn and spring. Research was conducted in Germany on how birds are affected during the daytime and at night, when the OWF is brightly illuminated. Migration mainly occurs over the sea at night and partly at rotor height. Coppack et al. (2013) attempted to quantify the collision risk within the rotor-swept zone in relation to overall migration rates. Some birds were measured at the lowest at 200 m, suggesting that a part of migration over the sea occurred at an altitude that would bring birds within reach of the wind turbines (Hill et al. 2014).

Fijn et al. (2015) showed the magnitude and variation of low-altitude flight activity across the North Sea. More than a million radar echoes, representing individual birds or flocks, were recorded crossing a Dutch wind farm annually at altitudes between 25 and 115 m (the rotor-swept zone). The majority of the birds flying in the daytime consisted of gull species, while at night the mayority were migrating passerines. The results of Fijn et al. (2015) are be useful for assessing the consequences of offshore wind farms for birds.

Although there are very few cases of observed collisions with turbines on OWFs, this does not mean that none have occurred. It was not possible to record collisions or count their number; rather, the probability of collision had to be inferred from the frequency of birds recorded in close proximity to wind turbines. The animals took notice of the turbines and avoided the rotating rotors during the daytime and at night.

Forecast models for possible collisions of migratory birds offshore initially lacked an empirical basis. At the beginning of research conducted on the effects of OWFs, the prognosis models were quite mechanical. The calculation of the probability for collisions was primarily based upon the rotor surface and the existence of birds in the vicinity of moving rotors. At that time, little was known about birds' avoidance behavior of the wind turbines. Consequently, it was not easy to predict the risk of collision. Through extensive research in Germany, it was discovered that in daytime migratory birds have a low risk of collision, given that a large proportion of birds avoid the rotating rotor blades. A number of studies support the observation of (species-specific) avoidance behavior with regards to OWFs, especially in the daytime (Diederichs et al. 2008; Grünkorn et al. 2009; Masden et al. 2009; Aumüller et al. 2011; Kahlert et al. 2011; Reichenbach and Grünkorn 2011; Mateos et al. 2011; Plonczkier and Simms 2012; Cook et al. 2012; Coppack et al. 2013; Furness et al. 2013; Hill et al. 2014; Lüdeke 2015; Schuster et al. 2015).

Nevertheless, OWFs also have an attraction effect, especially when they are illuminated at night. Since a significant proportion of migratory birds fly at night, the research concentrated on this issue. The investigations demonstrated that the risk of collision is strongly related to weather conditions, whereby the highest danger exists during times of fog, and poor and abruptly changing weather conditions. This is a result of the fact that migratory birds tend to fly especially low when weather conditions are poor (and therefore at the height of the rotors), while they are simultaneously attracted to the brightly illuminated wind turbines (Hill et al. 2014).

Radar and night-vision cameras proved that the illuminated OWF attracted nocturnal migrating birds, leading to a greater risk of collision. However, such attraction effects might be offset by micro-avoidance in response to rotor movements at some OWFs (Coppack et al. 2013). Birds that migrate nocturnally might be more affected by OWFs. Nocturnal migration is dominated by passerine species (e.g., such as thrushes). Circling flights around illuminated OWFs were observed by radar, thermal imaging, and video cameras. Several technical methods for monitoring were employed, although collisions were only very occasionally detected.

Studies from other sea areas also indicated that the construction of OWFs led to changes in the number and composition of species, as well as migration volumes and flight altitudes (Wendeln et al. 2013). Some studies found that OWFs are barriers in the daytime and that lethal collisions predominately occur at night or during poor weather, while some observed that collisions were more common when good migration weather changed to fog, drizzle or tailwinds. Namely, at night and during poor weather, birds are attracted to lit structures (Hüppop et al. 2006, 2016; Ballasus et al. 2009). Hüppop et al. (2016) estimated that the mortality rate at more than 1000 human structures in the North Sea could reach hundreds of thousands of birds that had collided with turbines. Nevertheless, Schuster et al. (2015) concluded that the fatality rate of migrating birds offshore is lower than expected, due to species-specific avoidance behavior. However, with the current state of knowledge, an exact quantification of the mortality rate of migrating birds colliding with OWFs seems to be not yet possible.

9.2.4 Impacts of OWFs on Bats

Bats are primarily species that inhabit terrestrial environments. Thus, only lately has attention been drawn to the potential effects of OWFs on bats. Only a few species are known to forage and migrate offshore. The investigation of Ahlén et al. (2009) observed the migration behavior of bats offshore, up to 14 km off the coastline, reporting that not only migrants, but also residents had been foraging in the offshore area. Most bats migrate lower than 10 m above the water surface (Ahlén et al. 2009), which is below the rotor swept area. But some bats increased their flight elevation because of an accumulation of insects at the level of the turbines.

Hatch et al. (2013) observed bats flying more than 40 km off the coastline and at relatively high altitudes of over 100 m and sometimes even higher than 200 m above sea level. Migration behavior took place during daylight as well. Bat activity peaked in the month of September and when there were strong tailwinds (Hatch et al. 2013). Sjollema et al. (2014) recorded bats at up to 22 km off the coastline with a mean distance of about 8 km. In two Dutch OWFs, bats of the species *Nathusius pipistrelle* and *Noctule spec* have been detected on autumn nights when there were low wind speeds (Jonge Poerink et al. 2013).

Ahlén et al. (2009) concluded that the risk of collision during migration offshore is likely to be low. During foraging, the risk increased for migrating and resident species, especially close to departure points near the coast and under weather conditions that attract insects. By contrast, Sjollema et al. (2014) declare that OWFs might produce similar collision rates as onshore wind farms. Since 2014, in the German Baltic Sea, which is known for its bat migrating routes (Rydell et al. 2014), bats have been taken into consideration as part of the environmental impact assessment (BSH 2013).

9.2.5 Impacts of OWFs on Harbor Porpoises

In addition to birds, the discussion concerning the environmental impact of OWFs in Germany (in the North Sea) has particularly focused on harbor porpoises (*Phocoena phocoena*). Other mammals, like seals, (at least in Germany) do not yet seem susceptible to the risk of injury or disturbances by OWFs.

The current practice for constructing OWF foundations is pile driving, which is associated with strong impulse noise emissions. Given the sensitive hearing of harbor porpoises, they are at the center of research related to the ecological effects of OWFs and possible mitigation measures (see Sect. 9.3.2).

In German investigations, a greater number of harbor porpoises were detected at distances >10 km from the OWFs than at shorter distances from the installations. Porpoises were displaced by construction at least in the zone of 8–10 km from the wind farms (Gilles et al. 2014). Wahl et al. (2013) also observed that harbor porpoises left the vicinity of winds farm during pile driving. The porpoises' acoustic activity was reduced by almost 100%. After construction, their acoustic activity remained below normal levels for up to 20 h. The displacement time widely varied, from <1.5 h to more than 140 h, with an average of approximately 17 h (Gilles et al. 2014).

An aerial survey by Dähne et al. (2014) showed that ramming without mitigation had effects at up to 20 km from OWF sites. Data from Horns Rev 2 in Denmark revealed the existence of spatial displacement effects up to 18 km from the construction site (without noise mitigation). Using technical mitigation measures, Nehls et al. (2016) studied the effects of OWF construction on harbor porpoises in an area up to 10 km from the sites.

Operation of OWFs has no proven effect on harbor porpoises. Noise effects were validated, although they did not prove to have an effect on the number of harbor porpoises in the vicinity of the OWFs (Gilles et al. 2014). A study by van Radecke and Benesch (2012) describes the operational noise of the OWF as akin to "background noise" at a distance of 100 m from the site. No effect was observed on animals at that distance.

Furthermore, it seems that the operation of OWFs does not appear to affect harbor porpoise density in the long term. Harbor porpoise density in the southern German Bight—with more ten OWFs already installed—increased from 3000 in 2004, when the first OWF was constructed, to 15,000 (Gilles et al. 2009; Gilles et al. 2011; Dähne et al. 2013). Similar increases were observed in neighboring countries (Scheidat et al. 2012; Hammond et al. 2013). The population of harbor porpoises in the entire North Sea is estimated to be >200,000.

Studies have shown that animals return to area around the wind farm within hours or days after pile driving has ceased. The impacts of OWF operation on marine mammals indicated by international research have varied. Increased porpoise detection rates were observed at the first OWF in the Netherlands, probably due to the artificial reef effect (Scheidat et al. 2012) and the absence of ship traffic and fishing (Dähne et al. 2014). Moreover, other studies have shown that operational wind farms are regularly frequented by porpoises, presumably attracted by the increased number of fish around the structures (Reichert et al. 2012). Data from another OWF in the Dutch North Sea, however, did not indicate increased rates of porpoises after the wind farm was built (van Polanen et al. 2012).

Overall, the noise of pile driving has a strong displacement effect on harbor porpoises. This displacement effect was temporary and no long-term impacts on the numbers of porpoises around OWFs could be found (Brandt et al. 2011; Nehls and Betke 2011; Scheidat et al. 2011; Haelters et al. 2012; Haelters and Vanermen 2013; Wahl et al. 2013; Lüdeke 2015; Schuster et al. 2015). Around operating OWFs, the abundance of harbor porpoises was similar to or higher than it was prior to construction of the wind parks (Diederichs et al. 2008; Scheidat et al. 2011; Scheidat et al. 2012; Dähne et al. 2014).

9.3 Strategies for an Environmentally Sound Development of Offshore Wind Energy

Marine Protected Areas (MPA) and marine spatial planning are important management instruments for protecting ecological sensitive sea areas from the construction of OWFs. The abundance of species under special protection (such as rare seabirds and marine mammals) should thus be monitored and special sensitive sea areas need to be identified. Another possibility for protecting marine biodiversity from the construction of OWFs is through alternative foundation methods (like gravity foundations) or technical mitigation measures against underwater noise (like bubble curtains). A measure for minimizing collision risk could be a requirement that lighting is used only when necessary. At present, this seems compatible with existing shipping and aviation security requirements (Hill et al. 2014). Finally, potential impairments or injuries to species that cannot be avoided or mitigated can be offset by marine compensation measures.

9.3.1 Exclusion of OWFs in Areas of High Ecological Priority

The environmentally sound development of offshore wind power should start already in the planning stage of the installations. Inappropriate sites from the ecological perspective should be excluded. One must define the area of the potential effects, as well as the scale and significance of the impacts of construction on population levels (Bailey et al. 2014; Federal Ministry of Environment, Nature Protection and Nuclear Safety 2014). In Germany, large parts of marine areas are already protected. Approximately 30% of the German EEZ is under special protection (see von Nordheim Chap. 46). No feed in tariffs for renewable electricity production are paid for OWFs in these marine protected areas (MPAs). Since 2011 the installations of OWFs is excluded in these MPAs (BSH 2011a, b). Moreover, nature conservation, species protection laws, and legally protected biotopes (after § 30 Federal Nature Conservation Act) outside the marine protected areas should be taken into account. Bearing in mind the main results of German ecological research with regards to OWFs, this should be particularly concentrated on the most relevant impacts of OWFs, namely habitat loss for seabirds and marine mammals caused by construction noise and the potential collision risks for migratory birds. Research and monitoring are important for gaining a better understanding of the ways in which this use of the sea affects the marine ecosystem.

Construction of future OWFs should thus be planned outside important seabird habitats (e.g., of loons) to avoid high collision rates and habitat loss. In accordance with the precautionary principle, corridors between seabird habitats should be left free of wind farms so that birds can safely move between sites. At the spatial planning stage, it seems crucial to avoid dead-end corridors between wind farms. Beyond this, the primary migrating routes of seabirds (e.g., through the Baltic Sea) should be kept free of OWFs.

This is also true for sea areas with a high density of whales, such as harbor porpoises. To this end, a sound abatement against ramming noise was established in Germany to protect these animals. The highest abundance of harbor porpoises has been detected in the early summer months at the Sylt Outer Reef, northeast of the German EEZ (Gilles et al. 2009). Thus, this area has special protection status and the construction of OWFs is strictly regulated (Federal Ministry of Environment, Nature Protection and Nuclear Safety 2014).

9.3.2 Technical Mitigation Measures against Ramming Noise

A number of investigations proofed that marine mammals can be injured or disturbed during the period, when turbines are rammed into the seabed. Most OWFs are constructed by impact pile driving, causing highly relevant underwater noise, which can cause harm, particularly to whales such as harbor porpoises (*Phocoena phocoena*) (Gilles et al. 2014).

Pingers can be used to scare porpoises away from the dangerous area around the pile sites. Seal scarers have been used to displace harbor porpoises up to 7.5 km in the North Sea (Brandt et al. 2013). Another possibility is to start pile driving at a low energy level (a so-called soft start) that gradually increases.

Unless alternative foundations without ramming noise are not state-of-the-art, there is a need for mitigation measures to avoid sound injuries or disturbances that could affect marine mammals (e.g., their fecundity) (Gilles et al. 2014). In Germany, the Federal Ministry of Environment has provided more than €25 million to investigate the possibilities of minimizing the impacts of pile driving, with several technical mitigation measures against noise emissions having been developed.

The hydraulic ramming of the OWF leads to dangerous sound pressure. To avoid direct damage to whales, a threshold of 160 dB SEL at 750 m distance from the OWF was established in Germany. Furthermore, noise mitigation measures were implemented to ensure maximum safeguards for harbor porpoises. These set a limit such that at most 10% of the area of the German North Sea may under sound pressure at one time. Moreover, special protection of the species during particularly sensitive months is foreseen. The application of best available practices and techniques is required to avoid underwater noise (Federal Ministry of Environment, Nature Protection and Nuclear Safety 2014). To date, other countries such as the UK and Denmark have not restricted the employment and in particular the sound emissions of offshore ramming in the same way as Germany has (Lüdeke 2012).

According to precautionary principles for environmental conservation, noise mitigation should be obligatory for pile driving. Noise mitigation techniques like bubble curtains depend on an air barrier or sound-dampening obstacles placed between the pile and the water. The available methods for noise reduction and alternative foundations are as follows (after Lüdeke 2012; Verfuss 2014; Bellmann et al. 2015):

- *Bubble curtains* are the most developed noise mitigation technique, whereby air bubbles are produced over the entire height of the water column by pumping compressed air through a perforated hose (see Fig. 9.2).
- *Large bubble curtains enclose* an entire construction site. Large bubble curtains have proven their efficacy in more than 150 cases, reducing noise by approximately 15 dB up to 750 m. In this way, the sensitive area for a potential injury can be reduced by approximately 98% and the area of disturbance (>145 ΔSEL [dB]) by 90% (Nehls et al. 2016).
- *Small bubble curtains* are used in direct vicinity of a pile. Initial tests of SBCs have shown reductions of up to 14 ΔSEL [dB].
- *Hydro sound damper* is a bubble curtain placed in the vicinity of a pile (within a few meters); air bubbles are replaced by air-filled balloons of different sizes, enabling a possible reduction of up to 13 ΔSEL [dB].
- *Casings* can be made for pile sleeves out of different materials or from hollow steel tubes around the pile. The latter are particularly suited for monopiles. The IHC noise mitigation system is a double-walled steel cylinder with sound-insulated

Fig. 9.2 Bubble curtain against underwater ramming noise at OWF Godewind (© DONG Energy)

connections and an air-filled cavity, allowing a possible reduction of up to 15 ΔSEL [dB].

- *Cofferdams* are based upon the idea of driving the piling in the air rather than in the water (dewatered casing), enabling a possible reduction of up to 20 ΔSEL [dB].
- *Vibratory piling* is a low-noise foundation installation technology limited to the first several meters of the foundation.
- *Offshore foundation drilling* is particularly suited to difficult soil conditions (e.g., rocky seabed) and up to 80 m of water depth. However, in relation to other methods, it is more expensive and requires more time. Several approaches are under development to make offshore foundation drilling more practical.
- *Suction buckets and suction cans* provide an alternative to piles for securing OWFs. The technique is already used by the oil and gas industry. Initial experiences with the erection of wind turbines on bucket foundations already occurred a decade ago. However, the approach has not yet been tested on a full scale and potential risks to the stability of wind turbine substructures have not yet been assessed.

9.3.3 Application of Marine Compensation Measures

9.3.3.1 The Need for Marine Compensation

The Federal Law on Nature Protection in Germany requires that, in cases in which nature is impaired, impact should first and foremost be avoided. If that is not possible, impact to the environment should be reduced or minimized, and lastly compensated measures should be taken. Only if real compensation is not possible, in-lieu fee mitigation in the form of monetary compensation can be granted. However, no compensation is required for offshore wind power until 2017. The model for onshore compensation needs be similarly adopted for marine areas (Lüdeke et al. 2014).

It seems obvious that even with the use of avoidance and mitigation measures, the risk of impact—especially on birds and mammals—will remain. A portion of the remaining impact could be reduced with compensation measures. According to Jacobs et al. (2016), only 7% of the proposed measures in French environmental impact assessments of the effects of OFWs on marine life have the goal of offsetting the predicted degradation of sites containing remarkable biodiversity. The other 93% of proposed measures consist of avoidance, reduction, and monitoring measures.

Compensation measures could perhaps also serve to avoid prohibition pursuant to the European species protection law, for example. For instance, compensation could serve as CEF measures (Measures of Ecological Functionality), thereby functioning as a special form of avoidance. Up until the present, there has been a lack of experiences with marine compensation measures. As compensation measures for OWFs are not yet obligatory, according to national conservation laws, actual marine compensation for OWFs does not yet exist. Nevertheless, many investigations concerning the possibilities for practical implementation of compensation measures have been completed nationally and internationally, with several international agreements (e.g., the Convention on the Protection of the Marine Environment of the Baltic Sea Area (HELCOM), the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) and the EU-Habitat Directive) requiring such measures.

9.3.3.2 Real Marine Compensation Measures

Possible approaches to marine compensation exist, which make manifest that marine compensatory mitigation measures are a prerequisite for offshore renewable energy development. In the international context, numerous studies already have been conducted on the creation of marine habitats that have been quite effective. For example, the restoration of sea grass meadows and the creation of artificial reefs have been successfully implemented (Levrel et al. 2012; Hudson et al., 2008; Kilbane et al. 2008; Van Dover et al. 2014). Artificial reefs can be easily created using stones found in the ocean. The turbines of the OWF themselves serve as artificial reefs, thus the OWF represents an in-situ compensation. Experiments with marine compensation measures have therefore already been performed, though most have been realized very close the coast, whereas experiments in deeper water are thus far lacking (Van Dover et al. 2014).

As habitat loss for seabirds and for harbor porpoises are of particular relevance, focus should be concentrated upon compensation measures for these species. A genuine compensation measure was implemented in the German OWF Riffgat with the reintegration of the population of lobsters (Homarus gammarus) on that OWF.

9.3.3.3 Alternative forms of Offshore Compensation: Onshore Compensation of Offshore Impacts or Minimization of Other Marine Impacts

Another approach would be to fulfill compensation measures onshore, as these efforts could support affected species through establishing compensation measures for specific species, for example, in the onshore breeding areas of affected birds. Furthermore, species-specific risks, such as collision risks with grid connections or hunting, could be reduced as a form of compensation. For the harbor porpoises the incidental bycatch, prey depletion or the pollution of oceans, could be decreased as compensation from possible OWF impacts (Lüdeke et al. 2014).

To minimize intensive marine use as a form of compensation could, for example, entail fisheries and shipping companies receiving payment not to use specific sensitive areas. However, because of the competency of the EU with regards to fishing grounds, and because of the status of the International Maritime Organization with regards to shipping, there are legal restrictions to compensation payments for less intensive fishing.

9.3.3.4 Monetary Payment as a form of Marine Compensation

As ultima ratio, marine compensation measures could also take the form of monetary payment. Especially in cases where compensation is disproportionate to impairment, in-lieu fees could replace other compensation measures (Lüdeke et al. 2014). Kyriazi et al. (2015) describe how to coordinate a net gain compensation agreement from the OWF developer to the manager of the marine protected area.

However, the methods for assessing amounts of monetary compensation are still underdeveloped, as they have rarely been applied in Germany or in other countries.

9.3.3.5 Compensation Models

To quantify the necessity for marine compensation, Levrel et al. (2012) attempted to assess impacts according to the loss of ecosystem services. Sylvain (2015) suggests assessing the level of marine compensation payment (e.g., for the impact on fish of the creation of new reefs) using the Visual Habitat Equivalency Analysis. Scemama and Levrel (2016), by contrast, use the Habitat Equivalency Analysis to assess the rehabilitation of marshes as a form of marine compensation to mitigate the effects of nitrate loading on the sea.

Marine compensation measures for certain marine biotopes and onshore compensation measures already exist and should be required as part of the approval procedure for new construction of OWFs. Only in cases where compensation is disproportionate to impact could in-lieu fees replace these compensation measures. There is a need for a consistent, international marine compensation model for offshore wind energy (Lüdeke et al. 2014).

9.3.3.6 Disadvantages and Weaknesses of Marine Compensation Measures

Marine compensation measures alone of course cannot fully offset the impairments of the marine environment by offshore wind farms. Ecologic compensation measures (onshore and offshore) currently have some weaknesses, e.g. of the lack of species-specific real compensation measures and of a consistent compensation model, the frequently occurring problem of inadequate implementation of compensation measures or the time lag effect until the compensatory measure reach its ecological effectiveness. Moreover, if compensation is accomplished by monetary payment, it cannot be guaranteed that the current state of the species will be maintained. This is particularly true if payments are not used to implement for species-specific measures. Marine compensation therefore should only be the last step of the mitigation hierarchy.

Aware of the huge plans for offshore wind energy, the possibility for compensation measures could soon reach its spatial boundaries anyway. Next, before a large-scale use of marine compensation measures can be accomplished, further research on the environmental effectiveness of marine compensation measures is needed (including a long term monitoring).

9.3.4 Conclusions and Future Tasks

Data gathered in Germany and other nations over the last decade has significantly advanced knowledge regarding the impacts of OWFs on the marine environment. Sufficient data exists that assesses certain impacts caused by OWFs, such as the change in habitats for benthic organisms and fish close to OWF foundations, the impact on birds caused by rotating and illuminated wind turbines, as well as the impact on the behaviors of harbor porpoises. Although research is ongoing, some conclusions are fairly clear; for instance, negative impacts mainly affect resting birds, migrating birds, and harbor porpoises during the time of construction. However, there is still a lack of data on the longer-term impacts of OWFs, especially with regards to population levels.

The current challenge is to integrate these findings into future planning processes, licensing conditions, and construction processes, as well as to share this knowledge internationally. The Environmental Impact Assessment approval procedure first has to be updated to include more recently acquired knowledge. Thresholds should be established, especially for the relevant negative impacts on birds and harbor porpoises; otherwise, comprehensive environmental assessments cannot be reflected in approval decisions to erect new OWFs. Unless standardized methods and thresholds are established in Europe and internationally, it will remain impossible for agencies to effectively assess and compare impacts.

Marine spatial planning methods are crucial to ecologically steering the development of the use of offshore wind (Schubert, Chap. 54). Areas with a high abundance of rare or sensitive marine organisms, such as divers or harbor porpoises, should be kept free from the installation of OWFs.

Technical mitigation measures are capable of keeping piling noise beneath the level of sound exposure that causes injuries. These measures should continue to be integrated in construction processes, as has already been undertaken in Germany.

In summary, the adverse impacts of OWFs on marine life can be reduced or, at least partially, avoided by careful and well coordinated planning of the times of year and locations chosen for wind farm installation.

Given that the impacts of OWFs cannot always completely be avoided or properly mitigated by spatial planning and technical mitigation measures, compensation measures (offshore and onshore) provide another option.

The review of offshore data from the last decade shows that environmentally sound development of offshore wind energy and even synergies between offshore wind energy and nature protection seem to be possible, e.g., through the localized cessation of fishing and shipping to develop de facto marine reserves or the creation of artificial reefs.

Acknowledgement I would like to thank Dr. Lars Gutow and Dr. Ommo Hüppop whose suggestions helped to improve and clarify this book chapter.

References

4C Offshore (2016) Global Offshore Wind Farm Database. Accessed on 21 June, 2016. http://www.4coffshore.com/offshorewind/

Ahlén I, Baagøe HJ, Bach L (2009) Behavior of Scandinavian bats during migration and foraging at sea. Journal of Mammalogy 90(6):1318–1323. doi:10.1644/09-MAMM-S-223R.1

Andersson MH, Berggren M, Wilhelmsson D, Öhman MC (2009) Epibenthic colonization of concrete and steel pilings in a cold-temperate embayment: a field experiment. Helgoland Marine Research 2009 63(3):249–260

Ashley MC, Mangi SC, Rodwell LD (2014) The potential of offshore windfarms to act as marine protected areas – A systematic review of current evidence. Marine Policy 45:301–309

Aumüller R, Boos K, Freienstein S, Hill K, Hill R (2011) Beschreibung eines Vogelschlagereignisses und seiner Ursachen an einer Forschungsplattform in der Deutschen Bucht. Vogelwarte 49:9–16

Bailey H, Brookes KL, Thompson PM (2014) Assessing environmental impacts of offshore wind farms: lessons learned and recommendations for the future. Aquatic Biosystems 10:8. doi:10.1186/2046-9063-10-8

Ballasus H, Hill K, Hüppop O (2009) Artificial light as a threat for birds and bats. Berichte zum Vogelschutz 46:127–157

Beiersdorf A (2014) Accompanying ecological research at alpha ventus. The stuk-plus research project. In: Federal Maritime and Hydrographic Agency/Federal Ministry of Environment, Nature Conservation and Nuclear Safety (eds) Ecological research at the offshore windfarm alpha ventus – challenges, results and perspectives, pp 31–37

Bellmann MA, Remmers P, Gündert S, Müller M, Holst H, Schultz-von Glahn M (2015) Is there a state-of-the-art regarding noise mitigation systems to reduce pile-driving noise? Presentation at the Conference on Wind Energy and Wildlife Impacts, Berlin

Bergman MJN, Ubels SM, Duineveld GCA, Meesters EWG (2015) Effects of a 5-year trawling ban on the local benthic community in a wind farm in the Dutch coastal zone. ICES J Mar Sci 72(3):962–972. doi:10.1093/icesjms/fsu193

Bradbury G, Trinder M, Furness B, Banks AN, Caldow RW, Hume D (2014) Mapping seabird sensitivity to offshore wind farms. PloS One 9(9):e106366. doi:10.1371/journal.pone.0106366
Brandt MJ, Diederichs A, Betke K, Nehls G (2011) Responses of harbor porpoises to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea. Marine Ecology Progress Series 421:205–216. doi:10.3354/meps08888
Brandt MJ, Höschle C, Diederichs A, Betke K, Matuschek R, Nehls G (2013) Seal scarers as a tool to deter harbour porpoises from offshore construction sites. Marine Ecology Progress Series 475:291–302. doi:10.3354/meps10100
BSH (Federal Maritime and Hydrographic Agency) (2011a) Spatial Plan for the German Exclusive Economic Zone in the North Sea. Accessed on 21 June 2016. http://www.bsh.de/en/Marine_uses/Spatial_Planning_in_the_German_EEZ/documents2/Spatial_Plan_North_Sea.pdf
BSH (Federal Maritime and Hydrographic Agency) (2011b) Spatial Plan for the German Exclusive Economic Zone in the Baltic Sea. Accessed on 21 June 2016. http://www.bsh.de/en/Marine_uses/Spatial_Planning_in_the_German_EEZ/documents2/Spatial_Plan_Baltic_Sea.pdf
BSH (Federal Maritime and Hydrographic Agency) (2013) Standards for the environmental assessment (stuk 4). http://www.bsh.de/en/Products/Books/Standard/index.jsp
Busch M, Garthe S (2016) Approaching population thresholds in presence of uncertainty: assessing displacement of seabirds from offshore wind farms. Environmental Impact Assessment Review 56:31–42
Coates D, Vanaverbeke J, Vincx M (2012) Enrichment of the soft sediment macrobenthos around a gravity based foundation on the Thorntonbank. In: Degraer S, Rabant R, Rumes B (eds) Offshore windfarms in the Belgian part of the North Sea: heading for an understanding of environmental impacts. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, Marine Ecosystem Management Unit, Brussels, pp 41–54
Coates DA, Deschutter Y, Vincx M, Vanaverbeke J (2014) Enrichment and shifts in macrobenthic assemblages in an offshore wind farm area in the Belgian part of the North Sea. Marine Environmental Research 95:1–12
Cook ASCP, Johnston A, Wright LJ, Burton NHK (2012) A review of flight heights and avoidance rates of birds in relation to offshore windfarms. BTO Research Report 618
Coppack T, Dittmann T, Schulz A (2013) Avian migration over offshore wind farms: How many birds will get stuck plus the tools you need to find out. Presentation at the StUKplus Conference, Berlin, 30–31 October 2013
Dähne M, Gilles A, Lucke K, Peschko V, Adler S, Krügel K, Sundermeyer J, Siebert U (2013) Effects of pile-driving on harbor porpoises (Phocoena phocoena) at the first offshore wind farm in Germany. Environmental Research Letters. 8:025002. doi:10.1088/1748-9326/8/2/025002
Dähne M, Peschko V, Gilles A, Lucke K, Adler S, Ronnenberg K, Siebert U (2014) Marine mammals and windfarms: effects of alpha ventus on harbor porpoises. In: Federal Maritime and Hydrographic Agency/Federal Ministry of Environment, Nature Conservation and Nuclear Safety (eds) Ecological research at the offshore windfarm alpha ventus – challenges, results and perspectives, pp 133–149
Dannheim J, Brey T, Schröder A, Mintenbeck K, Knus R, Arntz WE (2014) Trophic look at soft-bottom communities—short-term effects of trawling cessation on benthos. Journal of Sea Research 85:18–28
De Troch M, Reubens JT, Heirmann E, Degraer S, Vincx M (2013) Energy profiling of demersal fish: a case-study in wind farm artificial reefs. Marine Environmental Research 92:224–233
Diederichs A, Hennig V, Nehls G (2008) Investigations of the bird collision risk and the responses of harbor porpoises in the offshore windfarms Horns Rev, North Sea, and Nysted, Baltic Sea, in Denmark. Part II: Harbor porpoises. Final Report. Universität Hamburg
Dierschke V, Garthe S (2006) Literature review of offshore wind farms with regards to seabirds. In: Zuccho C, Wende W, Merck T, Köchling I, Köppel J (eds) Ecological research on offshore wind farms: international exchange of experience. Part B: Literature review of ecological impacts. Bundesamt für Naturschutz (BfN), Bonn, pp 131–198
Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing

Directives 2001/77/EC and 2003/30/EC. Accessed on 21 June 2016. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF
EU COM 2016 National action plans. Accessed on 21 June 2016. https://ec.europa.eu/energy/en/topics/renewable-energy/national-action-plans
Federal Ministry for Economic Affairs and Energy (Bundesministerium für Wirtschaft und Energie - BMWi) (2015) Die Energiewende – ein gutes Stück Arbeit Offshore-Windenergie. Ein Überblick über die Aktivitäten in Deutschland. Accessed on 21 June 2016. https://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/bmwi_de/offshore-windenergie.pdf?__blob=publicationFile&v=2
Federal Ministry of Environment, Nature Protection and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit) (2014) Konzept für den Schutz der Schweinswale vor Schallbelastungen bei der Errichtung von Offshore-Windparks in der deutschen Nordsee (Schallschutzkonzept/conception against underwater noise). Accessed on 21 June 2016. https://www.bfn.de/fileadmin/BfN/awz/Dokumente/schallschutzkonzept_BMU.pdf
Fijn RC, Krijgsveld KL, Poot MJM, Dirksen S (2015) Bird movements at rotor heights measured continuously with vertical radar at a Dutch offshore wind farm. IBIS 157(3):558–566
Furness RW, Wade HM, Masden EA (2013) Assessing vulnerability of marine bird populations to offshore wind farms. Journal of Environmental Management 119:56–66
Garthe S, Mendel B, Kotzerka J, Sommerfeld J (2013) Effects of alpha ventus on distribution patterns, behavior and flight heights of seabirds. Presentation at StUKplus Conference, Berlin
Gilles A, Scheidat M, Siebert U (2009) Seasonal distribution of harbor porpoises and possible interference of offshore wind farms in the German North Sea. Marine Ecology Progress Series 383:295–307. doi:10.3354/meps08020
Gilles A, Adler S, Kaschner K, Scheidat M, Siebert U (2011) Modelling harbor porpoise seasonal density as a function of the German Bight environment: implications for management. Endangered Species Research 14:157–169. doi:10.3354/esr00344
Gilles A, Dähne M, Ronnenberg K, Viquerat S, Adler S, Meyer-Klaeden O, Peschko V, Siebert U (2014) Ergänzende Untersuchungen zum Effekt der Bau- und Betriebsphase im Offshore-Testfeld alpha ventus auf marine Säugetiere. In: Beiersdorf A, Boethling M, Binder A, Nolte N (eds) Ökologische Begleitforschung am Offshore-Testfeldvorhaben alpha ventus zur Evaluierung des Standarduntersuchungskonzeptes des BSH (StUKplus). 116. Accessed on 21 June 2016. www.bsh.de/de/Meeresnutzung/Wirtschaft/Windparks/StUKplus/Berichte/Abschlussberichte/SB_2014-10-06_StUKplus-Teilprojekt-TiHo1_StUKplus_BSH_0327689A_adobe.pdf
Grünkorn T, Diederichs A, Poszig D, Diederichs B, Nehls G (2009) Wie viele Vögel kollidieren mit Windenergieanlagen? How many birds collide with wind turbines. Naturschutz und Landschaftsplanung 84(7):309–314
Gutow L, Teschke K, Gusky M, Schmidt A, Krone R (2013) The turbine focus: benthic fauna on and around offshore wind farm constructions. Presentation at the StUKplus Conference, Berlin
Gutow L, Teschke K, Schmidt A, Dannheim J, Krone R, Gusky M (2014) Rapid increase of benthic structural and functional diversity at the alpha ventus offshore test site. In: Federal Maritime and Hydrographic Agency/Federal Ministry of Environment, Nature Conservation and Nuclear Safety (eds) Ecological research at the offshore windfarm alpha ventus—challenges, results and perspectives, pp 67–81
Haelters J, van Roy W, Vigin L, Degraer S (2012) The effect of pile driving on harbor porpoises in Belgian waters. In: Degraer S, Brabant R, Rumes B (eds) Offshore wind farms in the Belgian part of the North Sea. Heading for an understanding of environmental impacts. Royal Belgian Institute of Natural Sciences, Brussels, pp 127–143
Haelters J, Vanermen N (2013) Top predators at presentation. Presentation at the WINMON.BE conference, Brussels, Belgium
Hammar L, Perry D, Gullström M (2016) Offshore wind power for marine conservation. Open Journal of Marine Science 6:66–78. doi:10.4236/ojms.2016.61007
Hammond PS, Macleod K, Berggren P, Borchers DL, Burt L, Cañadas A, Desportes G, Donovan GP, Gilles A, Gillespie D, Gordon J, Hiby L, Kuklik I, Leaper R, Lehnert K, Leopold M, Lovell

P, Øien N, Paxton CGM, Ridoux V, Rogan E, Samarra F, Scheidat M, Sequeira M, Siebert U, Skov H, Swift R, Tasker ML, Teilmann J, Van Canneyt O, Vázquez JA (2013) Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. Biological Conservation 164:107–122. doi:10.1016/j.biocon.2013.04.010

Hatch SK, Connelly EE, Divoll TJ, Stenhouse IJ, Williams KA, Brown JD (2013) Offshore observations of eastern red bats (Lasiurus borealis) in the mid-atlantic united states using multiple survey methods. Plos One 8(12):e83803. doi:10.1371/journal.pone.0083803

Hill R, Aumüller R, Boos K, Freienstein S, Hill K (2014) Results, conclusions and perspectives from 10 years of offshore bird migration research in the German Bight. In: Federal Maritime and Hydrographic Agency/Federal Ministry of Environment, Nature Conservation and Nuclear Safety (eds) Ecological research at the offshore windfarm alpha ventus—challenges, results and perspectives, pp 111–131

Hooper T, Austen M (2014) The co-location of offshore windfarms and decapod fisheries in the UK: constraints and opportunities. Marine Policy 43:295–300

Hudson JH, Schittone, J., Anderson, J., Franklin, E. C. & Stratton, A. (2008). Coral reef restoration monitoring report. Monitoring events 2004–2007. Florida Keys National Marine Sanctuary Monroe County, Key West, Accessed on 21 June 2016. http://sanctuaries.noaa.gov/science/conservation/pdfs/wellwood2.pdf

Hüppop O, Dierschke J, Exo K, Fredrich E, Hill R (2006) Bird migration studies and potential collision risk with offshore wind turbines. IBIS 148:90–109

Hüppop O, Hüppop K, Dierschke J, Hill R (2016) Bird collisions at an offshore platform in the North Sea. Bird Study 63:73–82. Accessed on 21 June 2016 http://dx.doi.org/10.1080/00063657.2015.1134440

Jacobs C, Pioch S, Thori S (2016) The effectiveness of the mitigation hierarchy in environmental impact studies on marine ecosystems: a case study in France. Environmental Impact Assessment Review 60:83–98

Jonge Poerink B, Lagerveld S, Verdaat JP (2013) Pilot study bat activity in the Dutch offshore wind farm OWEZ and PAWP (Report/IMARESC026/13). IMARES, Den Helder. Accessed on 21 June 2016 https://www.researchgate.net/publication/263124387_Pilot_study_Bat_activity_in_the_dutch_offshore_wind_farm_OWEZ_and_PAWP

Kahlert JA, Laubek B, Aan K, Waagner S, Groom G, Andersen PN (2011) Rødsand 2 offshore wind farm – post-construction studies on migrating land birds, Autumn 2010. Accessed on 21 June 2016. http://www.ens.dk/sites/ens.dk/files/undergrund-forsyning/vedvarende-energi/vindkraft-vindmoeller/havvindmoeller/miljoepaavirkninger/Roedsand/eon_roedsand2_land_bird_migration_post_construction_2010.pdf

Kilbane D, Graham B, Mulcah R, Onder A, Pratt M (2008) Coral relocation for impact mitigation in Northern Qatar. Paper presented at the 11th International Coral Reef Symposium, Ft. Lauderdale, FL

Kota S, Bayne SB, Nimmagadda S (2015) Offshore wind energy: a comparative analysis of UK, USA and India. Renewable and Sustainable Energy Review 41:685–694

Krägefsky S (2014) Effects of the alpha ventus offshore test site on pelagic fish. In: Federal Maritime and Hydrographic Agency/Federal Ministry of Environment, Nature Conservation and Nuclear Safety (eds) Ecological research at the offshore windfarm alpha ventus—challenges, results and perspectives, pp 83–94

Krone R, Krägefsky S (2012) Untersuchung der Effekte von Windenergieanlagen auf Fische und vagile Megafauna im Testfeld “alpha ventus” Arbeitspaket B: Untersuchungen der Auswirkungen auf demersale Fische und Megazoobenthos

Krone R, Gutow L, Joschko TJ, Schröder A (2013) Epifauna dynamics at an offshore foundation—implications of future wind power farming in the North Sea. Marine Environmental Research 85:1–12

Kyriazi Z, Lejano R, Maes F, Degraer S (2015) Bargaining a net gain compensation agreement between a marine renewable energy developer and a marine protected area manager. Marine Policy 60:40–48

Langhamer O, Wilhelmsson D, Engstrom J (2009) Artificial reef effect and fouling impacts on offshore wave power foundations and buoys—a pilot study. Estuarine, Coastal and Shelf Science 82:426–432

Leitao F, Santos MN, Monteiro CC (2007) Contribution of artificial reefs to the diet of the white sea bream (Diplodus sargus). ICES Journal of Marine Science 64:473–478

Levrel H, Pioch S, Spieler R (2012) Compensatory mitigation in marine ecosystems: which indicators for assessing the "no net loss" goal of ecosystem services and ecological functions? Marine Policy 36:1202–1210

Lindeboom HJ, Kouwenhoven HJ, Bergman MJN, Bouma S, Brasseur S, Daan R, Fijn RC, de Haan D, Dirksen S, van Hal R, Lambers RHR, Ter Hofstede R, Krijgsveld KL, Leopold M, Scheidat M (2011) Short-term ecological effects of an offshore wind farm in the Dutch coastal zone; a compilation. Environ. Res. Lett. 6(3):035101. doi:10.1088/1748-9326/6/3/035101

Lüdeke J (2012) Is a German Harbour Porpoise much more sensitive than a British One? Comparative analyses of mandatory measures for the protection of harbour porpoises (Phocoena phocoena) During offshore wind farm ramming in Germany, Denmark and the UK. Paper Presented at the 11th European Conference on Underwater Acoustics, 2012, Edinburgh, Scotland. Published by Acoustical Society of America

Lüdeke J (2015) Review of 10 years of research of offshore wind farms in Germany: the state of knowledge of ecological impacts. Conference Proceedings of Advances in Environmental and Geological Science and Engineering, June 27–29, Salerno, pp 26–37

Lüdeke J, Köppel J, Nagel PB (2014) Marine Kompensation als Voraussetzung für eine umweltverträgliche Energiewende im Meer, in Naturschutz und Landschaftsplanung. NuL 46:283–289

Masden EA, Haydon DT, Fox AD, Furness RW, Bullman R, Desholm M (2009) Barriers to movement: impacts of wind farms on migrating birds. ICES Journal of Marine Science 66:746–753. doi:10.1093/icesjms/fsp031

Mateos M, Muñoz AG, del Rosario JJ (2011) Modelling seabird collision risk with offshore windfarms. In: May R, Bevanger K (eds) Proceedings. Conference on Wind energy and Wildlife impacts. NINA Report 693. Conference on Wind energy and Wildlife impacts, 2–5 May 2011, vol 39. Norwegian Institute for Nature Research, Trondheim

Mendel B, Kotzerka J, Sommerfeld J, Schwemmer H, Sonntag N, Garthe S (2014) Effects of the alpha ventus offshore test site on distribution patterns, behavior and flight heights of seabirds. In: Federal Maritime and Hydrographic Agency/Federal Ministry of Environment, Nature Conservation and Nuclear Safety (eds) Ecological research at the offshore windfarm alpha ventus – challenges, results and perspectives, pp 95–110

Mesel ID, Kerckhof F, Norro A, Rumes B, Degraer S (2015) Succession and seasonal dynamics of the epifauna community on offshore wind farm foundations and their role as stepping stones for non-indigenous species. Hydrobiologia 756(1):37–50

Nehls G, Betke K (2011) Darstellung und Bewertung der Auswirkungen von Schallemissionen durch offshore-Rammarbeiten auf Meeressäugetiere. Accessed on 21 June 2016. http://www.bioconsultsh.de/pdf/Nehls%20&%20Bethke%202011%20Schallbericht%20OFW20111215.pdf

Nehls G, Rose A, Diederichs A, Bellmann M, Pehlke H (2016) Noise mitigation during pile driving efficiently reduces disturbance of marine mammals. The effects of noise on aquatic life II. Advances in Experimental Medicine and Biology 875:755–762

Otto E, Durstewitz M, Lange B (2014) The RAVE research initiative: a successful collaborative research, development and demonstration programme. In: Federal Maritime and Hydrographic Agency/Federal Ministry of Environment, Nature Conservation and Nuclear Safety (eds) Ecological research at the offshore windfarm alpha ventus – challenges, results and perspectives, pp 25–29

Petersen IK (2013) Is the distribution and abundance of waterbirds altered in and around offshore windfarms? Presentation on StUKplus Conference, Berlin

Petersen IK, Christensen TK, Kahlert J, Desholm M, Fox AD (2006) Final results of bird studies at the offshore wind farms at Nysted and Horns Rev, Denmark: Report request. Commissioned by DONG Energy and Vattenfall A/S. National Environmental Research Institute

Plonczkier P, Simms IC (2012) Radar monitoring of migrating pink-footed geese: behavioral responses to offshore wind farm development. Journal of Applied Ecology 49(5):1187–1194. doi:10.1111/j.1365-2664.2012.02181.x

Punt MJ, Greoneveld RA, van Ierland EC, Stel JH (2009) Spatial planning of offshore wind farms: a windfall to marine environmental protection? Ecological Economics 69:93–103

Reichenbach M, Grünkorn T (2011) A multimethod approach to determine the impact of existing wind power plants on bird and bat migration on the island of Fehmarn, Germany. In: May R, Bevanger K (eds) Proceedings. Conference on Wind energy and Wildlife impacts. NINA Report 693. Conference on Wind energy and Wildlife impacts, 2–5 May 2011, vol 118. Norwegian Institute for Nature Research, Trondheim

Reichert K, Dannheim J, Gusky M, Krägefsky S, Krone R, Gutow L (2012) Fish and benthos at alpha ventus. Presentation at International RAVE Conference 2012, Bremerhaven, Germany

Reubens J, Degraer S, Vincx M (2011) Aggregation and feeding behavior of pouting (Trisopterus luscus) at wind turbines in the Belgian part of the North Sea. Fisheries Research 108:223–227

Reubens JT, De Rijcke M, Degraer S, Vinc M (2013b) Diel variation in feeding and movement patterns of juvenile Atlantic cod at offshore wind farms. Journal of Sea Research 85:214–221

Reubens JT, Braeckman U, Vanaverbeke J, Van Colen C, Degraer S, Vincx M (2013a) Aggregation at windmill artificial reefs: CPUE of Atlantic cod (Gadus morhua) and pouting (Trisopterus luscus) at different habitats in the Belgian part of the North Sea. Fisheries Research 139:28–34

Rydell J, Bach L, Bach P, Diaz LG, Furmankiewicz J, Hagner-Wahlsten N, Kyheröinen E-M, Lilley T, Masing M, Meyer MM, Pētersons G, Šuba J, Vasko V, Vintulis V, Hedenström A (2014) Phenology of migratory bat activity across the. Baltic Sea and the south-eastern North Sea Acta Chiropterologica 16(1):139–147

Scheidat M, Tougaard J, Brasseur S, Carstensen J, van Polanen-Petel T, Teilmann J, Reijnders PJH (2011) Harbor porpoises (Phocoena phocoena) and wind farms: a case study in the Dutch North Sea. Environment Research Letters 6:025102. doi:10.1088/1748-9326/6/2/025102

Scheidat M, Verdaat H, Aarts G (2012) Using aerial surveys to estimate density and distribution of harbor porpoises in Dutch waters. Journal of Sea Research 69:1–7. doi:10.1016/j.seares.2011.12.004

Scemama P, Levrel H (2016) Using habitat equivalency analysis to assess the cost effectiveness of restoration outcomes in four institutional contexts. Environmental Management 57(1):109–122

Schmidt A, Gutow L, Teschke K, Preuß S, Gusky M, Breyer S, Fürst R, Bönsch R (2013) Development of a soft bottom community within an offshore wind farm. Presentation on StUKplus Conference, Berlin, 30–31 October 2013

Schuster E, Bulling L, Köppel J (2015) Consolidating the state of knowledge: a synoptical review of wind energy's wildlife effects. Environmental Management 56(2):300–331. doi:10.1007/s00267-015-0501-5

Schwemmer P, Mendel B, Sonntag N, Dierschke V, Garthe S (2011) Effects of ship traffic on seabirds in offshore waters: implications for marine conservation and spatial planning. Ecological Applications 21:1851–1860

Seaenergy 2020 Offshore renewable energy and maritime spatial planning recommendations for adaptation and development of existing and potentially new international marine spatial planning instruments. Accessed on 21 June 2016. http://www.seanergy2020.eu/wp-content/uploads/2011/11/111020_Seanergy2020_Deliverable3.2_Final.pdf

Sjollema AL, Gates JE, Hilderbrand RH, Sherwell J (2014) Offshore activity of bats along the mid-atlantic coast. Northeastern Naturalist 21(2):154–163. doi:10.1656/045.021.0201

Sylvain P (2015) How to size "Fair" compensatory mitigation due to coastal area destruction for fisheries resources: visual habitat equivalency analysis software, a scoring method to sizing compensatory mitigations applied in offshore windmill renewable energy project case study. In: Ceccaldi HJ, Hénocque Y, Koike Y, Komatsu T, Stora G, Tusseau-Vuillemin MH (eds) Marine productivity: perturbations and resilience of socio-ecosystems. Springer, Cham, pp 223–234

Vaissière AC, Levrel H, Pioch S, Carlier A (2014) Biodiversity offsets for offshore wind farm projects: the current situation in Europe. Marine Policy 48:172–183

van Dover CL, Aronson J, Pendleton L, Smith S, Arnoud-Haond S, Moreno-Mateos D, Barbier E, Billett D, Bowers K, Danovaro R, Edwars A, Kellert S, Morato T, Pollard E, Rogers A, Warne R (2014) Ecological restoration in the deep sea: Desiderata. Marine Policy 44:98–106
van Polanen PT, Geelhoed SCV, Meesters HWG (2012) Harbor porpoise occurrence in relation to the Prinses Amalia windpark. Report Number C177/10. IMARES, Wageningen, p 34
van Radecke H, Benesch M (2012) Operational underwater noise at alpha ventus. Presentation at International RAVE Conference, Bremerhaven, Germany
Verfuss T (2014) Noise mitigation systems and low-noise installation technologies. In: Federal Maritime and Hydrographic Agency, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (eds) Ecological research at the offshore windfarm alpha ventus, pp 181–191
Wahl V, Braasch A, Joost M, Ketzer C, Michalik A, Todeskino D (2013) Behavioral responses of harbor porpoises to pile driving on a temporal and spatial scale at the BARD Offshore 1 windfarm. Presentation at StuKplus – Five Years of Ecological Research at alpha ventus – Challenges, Results and Perspectives, Berlin
Wendeln H, Walter G, Todeskino D (2013) Comparing baseline and construction studies in the BARD Offshore 1 wind farm: aspects of bird migration. Presentation at Five years of Ecological Research at alpha ventus – Challenges, Results and Perspectives, Berlin
Wilding TA (2014) Effects of man-made structures on sedimentary oxygenation: extent, seasonality and implications for offshore renewables. Marine Environmental Research 97:39–47
Wilhelmsson D, Malm T, Thompson R, Tchou J, Sarantakos G, McCormick N, Luitjens S, Gullström M, Patterson EJK, Amir O, Dubi A (2010) Greening blue energy: identifying and managing the biodiversity risks and opportunities of off shore renewable energy. IUCN, Gland, p 102
Wilson JC, Elliott M, Cutts ND, Mander L, Mendao V, Perez-Dominguez R, Phelps A (2010) Coastal and offshore wind energy generation: is it environmentally benign? Energies 3:1383–1422

Chapter 10
Dredging for Navigation, for Environmental Cleanup, and for Sand/Aggregates

Craig Vogt, Eugene Peck, and Gregory Hartman

Abstract Underwater excavation is called dredging. While essential to maintain ports and channels and to meet other needs, such as fighting the impacts of climate change by building sand dunes, such operations can cause severe environmental impacts in the marine environment. This chapter overviews the dredging process and equipment, followed by a presentation of the environmental concerns associated with dredging and disposal or placement for beneficial uses. The chapter concludes with a brief discussion of the international regulatory regime and remarks on future trends.

Keywords Climate change • Dredging • Dredged material • Beneficial use • Environmental effects • Navigation • Sand and gravel mining • Cleanup dredging • Contaminated dredged material • Confined disposal • Facilities • CDF • Confined aquatic disposal • CAD • Turbidity • Sediments • London convention • Sediment management • Sustainable dredging

10.1 Introduction

Underwater excavation is called dredging. Dredging is the term given to removal by digging, gathering, or pulling out materials from the bed to deepen waterways and to create harbors, channels, and berths. Dredging is also conducted for construction

C. Vogt (✉)
Craig Vogt Inc., Ocean & Coastal Environmental Consulting, Hacks Neck, VA, USA
e-mail: Craig@CraigVogt.com

E. Peck
Viridian Alliance Inc., Hamden, CT, USA
e-mail: gene.peck@viridianalliance.com

G. Hartman
Hartman Associates Inc., Redmond, OR, USA
e-mail: HartmanAssociates@gmail.com

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_10

purposes, for mining, and for environmental cleanup and enhancement. The complete dredging activity includes three elements:

1. *Excavation*: the dislodgement and removal of sediments (clay, silt, sand, gravel, and rock) from the bed of the water body by a dredge, either mechanically, hydraulically, or by combination of the two dredging methods.
2. *Transport*: the transport of excavated material from the point of dredging to the final disposal site. This can be accomplished by haul barges separate from the dredge equipment, or by a dredge equipped with hoppers, or by pipeline from the dredge to the disposal or placement site. In many cases, the dredged material may be off-loaded from the haul barge and sent by rail or truck to the final disposal site.
3. *Disposal or placement*: the final disposal or placement of dredged material. Whether dredged material is disposed or placed (i.e., reused for another purpose, such as creation of a wetland or beach nourishment) is determined by a range of factors, including the objectives of the dredging project. Decision-making typically considers the sediment type to be dredged (e.g., grain size), the volume of dredged material, location of the dredging project versus the disposal site or beneficial use site, future disposal site utilization, physical and chemical characteristics of the sediment (e.g., is it contaminated?), regulatory requirements, and available funding.

Operations that cause potential environmental impacts associated with the dredging process include (1) the sediment removal process from submerged excavation at the point of dredging and (2) the placement for disposal or use of the dredged material. Environmental concerns relate to the location of the sediment removal by dredging and the disposal or placement site. General environmental considerations include:

- Physical and ecological impacts due to turbidity and sedimentation.
- Ecological and human health impacts: acute and chronic toxicity due to chemical contamination; e.g., PCBs, PAHs, dioxin, metals—such as lead, cadmium, and mercury.
- Loss of habitat—due to dredging or placement of dredged material on beaches/dunes.
- Impacts to endangered species (e.g., turtles) due to dredging.
- Emissions of air pollutants

Increasingly considered a resource, dredged material has a wide number of beneficial use applications that must be considered in dredged material management. Such beneficial uses can include beach nourishment, shoreline fill, habitat creation or restoration, manufactured soil, construction aggregate, use as capping material, and coastal reinforcement to combat sea level rise.

This chapter initially provides an overview of the dredging process and equipment followed by presentation of the environmental concerns associated with dredging and disposal or placement for beneficial use. This is followed by a brief discussion of the international regulatory regime with concluding remarks on future trends and sustainable dredging.

10.2 Dredging: Purposes, Equipment, and Material Transport

10.2.1 Purposes

Dredges of various designs have been used for many years to create and maintain navigable waterways to move people, goods, and materials. It is theorized that thousands of years ago blocks of stone that make up the Pyramids in Egypt were barged from a distant quarry through a dredged canal. At that time, the canals were likely dredged using a barge with people using long-handled dipper shovels to raise solids out of a waterway and then place those solids on a haul barge deck for disposal elsewhere. Productivity gains likely came about when animal power was used to increase the digging power of early dredges. The late 1800s saw the development of electric and steam power units which enabled the construction of huge mechanical dredges with bucket ladders, back hoe dredges and pipeline dredges with centrifugal pumps (Fig. 10.1). Hydraulic technology made great advancements in the 1960s with the result that hydraulic winches and hydraulic rotary cutter drives became a welcome replacement facilitating the removal of finer grain sediment (compared to clunky and inefficient mechanical drives) (Willard 2009).

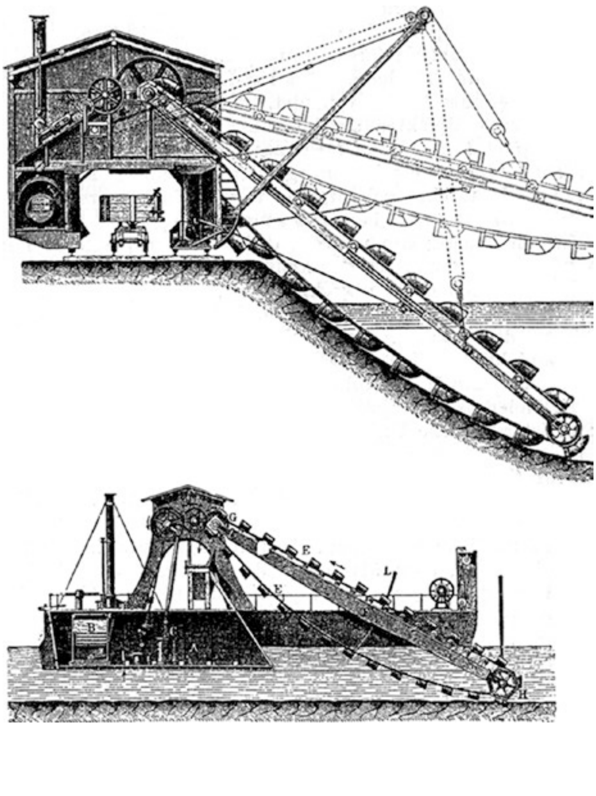


Fig. 10.1 Early bucket dredge. *Photo Courtesy of Wikimedia*

Today, the dredge type can be hydraulic or mechanical, and can be used for a multitude of purposes and projects. The primary purposes are navigation, environmental enhancement, and mining/construction (Cohen 2010).

10.2.1.1 Navigation Dredging

Most coastal and river ports, harbors and navigation channels are not naturally deep enough or wide enough to support safe passage of vessels. Navigation channels need to be dredged to create waterway channels with adequate channel area, depth, and access to port and harbor facilities. Nearly all the major ports in the world have at some time required dredging to deepen and widen the access channels, to provide turning basins, and to achieve appropriate water depths to and from waterside facilities.

Virtually all of the navigation channels created in rivers and harbors have had and continue to require maintenance dredging, i.e. the removal of sediments which naturally accumulate on the bottom of the dredged channel. Navigation channel dredging can be categorized as two types. (1) New work dredging is the initial dredging conducted to excavate a channel with navigable depths greater than naturally exist. (2) Maintenance dredging is the dredging after new work that removes accumulated sediments and ensures that the channel continues to provide adequate dimensions for vessels engaged in domestic and international commerce, as well as for other types of vessels, such as recreational boating and commercial fishing.

10.2.1.2 Environmental Enhancement Dredging

In the last three decades, dredging has been successfully used to remove contaminated sediments from waterways, with the intention of improving water quality and restoring the health of aquatic ecosystems. Clean-up dredging for removal of contaminants is used in waterways, lakes, ports and harbors, usually in highly industrialized or urbanized areas that are suffering from past toxic waste and waste water disposal practices. After removal from the bed, the contaminated sediments are usually transported and disposed under strict environmental controls (e.g., lined upland confined disposal facilities). In some cases, the contaminated sediments may be treated and some or all of the sediments used for beneficial objectives. Under proper conditions, a viable alternative to removal is in-situ isolation, i.e. the placement of a cap (i.e., a cover of clean material) over the contaminated sediments in their original location (Otten and Hartman 2002).

Environmental enhancement and restoration projects also include dredging for the purpose of beach nourishment (e.g., replacing lost sand to widen beaches) and providing sediments to enhance marshes and wetlands often as a climate adaptation strategy (USACE 2015). Approaches that utilize dredged materials and natural processes to reduce costs and impacts are favorable to hard structure armoring in many circumstances (Van Slobbe et al. 2013; Fredette 2012).

10.2.1.3 Dredging for Reclamation, Extraction of Sand and Gravel, and Construction

Dredging is an integral tool in many types of water-related construction projects, such as emplacement of pipelines or immersed tunnels, underwater foundations, and maintaining storage capacity in water supply and recreational reservoirs. In addition, off shore dredging is important in mining activities, with an increasing quantity of aggregate mined from marine and fresh water borrow sites used in concrete production, fill, and land reclamation projects. A coming trend is the use of dredged sand for coastal reinforcement including beach nourishment (UNEP 2014; Hanson et al. 2002; USACE 2015).

10.2.2 Dredging Equipment

While specialized dredging equipment varies widely in many sizes and types, dredging is actually accomplished basically by only two dredge types. They are mechanical dredges and hydraulic dredges. The type of dredge is derived from the method of sediment capture and removal from the bed.

Selection of dredging equipment and the methods used to perform the dredging depends on the following factors (USACE 2004a):

- Physical characteristics of material to be dredged,
- Quantities of material to be dredged,
- Depth of material to be dredged,
- Method of disposal or placement,
- Distance to disposal or placement site,
- Physical environment of the dredging area(s),
- Physical environment of the disposal area(s),
- Level of contamination of the material to be dredged,
- Dredge production capability,
- Type of dredges available, and
- Time, environmental, and economic limits of the project.

10.2.2.1 Mechanical Dredges

Mechanical dredges remove bottom sediment through the direct application of mechanical force to dislodge and excavate the material at almost in situ densities. The mechanical dredges (Fig. 10.2) are well-suited to removing hard-packed material or debris and to working in confined areas, such as in environmental clean-up dredging. Cohesive sediments that are mechanically dredged usually remain intact, with large pieces retaining their in-situ density and structure through the dredging and placement process. Sediments excavated with a mechanical dredge are generally placed into a haul barge or scow for transportation from the dredging site to the disposal or placement site.

Fig. 10.2 Mechanical backhoe with articulated arm on dredge *New York*. *Courtesy of Great Lakes Dredge & Dock Company*

Fig. 10.3 Mechanical Dredges: Environmental Closed Buckets *Courtesy of Cable Arm Company*

Dredging for environmental cleanup requires much greater precision than navigation dredging and can be accomplished using articulated fixed-arm mechanical dredges, which are similar to conventional upland excavators placed on a barge. The rigid arm, as compared to the cable connected bucket, provides greater positioning control in placing the bucket on the bottom. Bucket dredges that are designed for a level cut and equipped to be enclosed after the cut are also effective in environmental dredging. These buckets (Fig. 10.3) minimize the leakage of water and contaminants during the excavation and placement of the contaminated material on the barge for transport.

10.2.2.2 Hydraulic Dredges

Hydraulic dredges are identified by two primary types. They are the pipeline cutterhead dredge and the trailing suction hopper dredge. The hydraulic dredge works by dislodging bed sediment and hydraulic removal of the sediment from the bed of the waterway by suction pipe.

Fig. 10.4 Typical hydraulic cutterhead dredge. *Courtesy of Ellicott Dredges Company*

The hydraulic pipeline dredge has an active cutterhead (Fig. 10.4) that rotates and dislodges the sediment from the bed. This allows the suction, created at the cutterhead by the suction pipe and pump, to capture the sediment, pull it up the suction pipe, and then be pumped through the discharge pipeline to the disposal or placement site. A booster pump is used for long distances to the disposal site (Fig. 10.5). The pipeline dredge (Fig. 10.6) is not self-powered. It moves through the cut using the "walking" spud and then the working spud for dredging, thereby allowing the dredge to move forward as it swings the cutterhead from left to right and return.

Hopper dredges are ships designed for dredging (Figs. 10.7 and 10.8). The trailing suction hopper dredge is a self-propelled seagoing ship equipped with a suction pipe, which trails over the side of the vessel or through a well in the hull. The sediment and water slurry is transported through the pumps just as the pipeline dredge, but when the sediment and water slurry passes through the pump to the discharge pipeline, it is discharged immediately into the hoppers of the dredge. When the hoppers are full, the sediment and water slurry is transported by the ship to the disposal site.

10.2.2.3 Environmental Cleanup Dredges

Dredging of contaminated sediments is potentially very harmful to the local environment during dredging and disposal. Contaminants can be re-mobilized and/or released into the water column where they can detrimentally affect aquatic life and

Fig. 10.5 Pipeline booster pump. *Courtesy of Great Lakes Dredge & Dock*

Fig. 10.6 Cutterhead pipeline dredge *CSD Texas. Courtesy of Great Lakes Dredge & Dock*

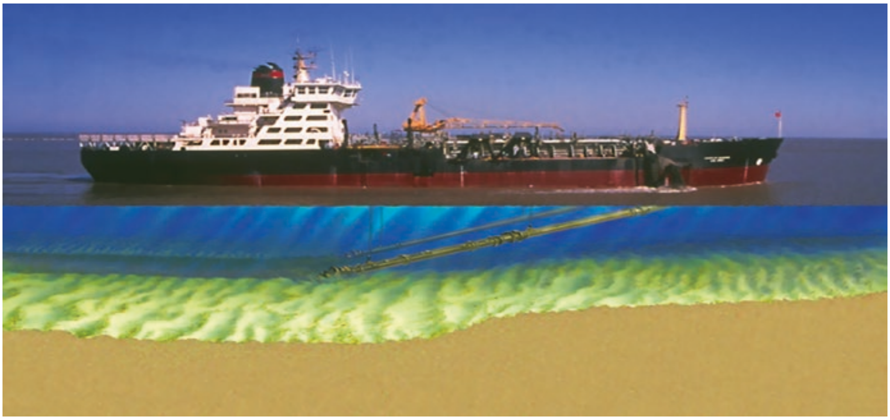


Fig. 10.7 Typical hopper dredge. *Photo Courtesy of Corps of Engineers*

Fig. 10.8 Hopper dredge *Liberty Island. Photo Courtesy of Great Lakes Dredge & Dock Company*

pose a risk to human health. Technological advances have fostered modification of existing dredge equipment and the creation of new dredging equipment to address the environmental issues. Contaminated sediment dredging focuses on minimizing suspension and release of problem sediments in the water column while increasing the precision of dredging to reduce overdredging. Sheet pile or caisson enclosures of the dredging area may be employed. Examples of contaminated sediment dredges include the following:

- Encapsulated bucket lines for bucket chain dredges,
- Closed buckets for backhoes,

- Closed clamshells for grab dredges,
- Auger dredges, disc cutter, scoop dredges, and sweep dredges (all modified cutter dredges), and
- Diver-assisted suction dredges (Bray 2008).

10.2.3 Transportation of Dredged Material

Transportation methods generally used to move clean and contaminated dredged materials are included in the three basic dredge types: pipelines, barges or scows, and hopper dredges.

- Pipeline transport is the method most commonly associated with cutterhead, dustpan, auger head, and other hydraulic dredges. Dredged material may be directly transported by hydraulic dredges through pipelines for distances of up to several miles, depending on a number of conditions. Longer pipeline pumping distances are feasible with the addition of booster pumps, but the cost of transport greatly increases proportionally with each booster pump added to the discharge line.
- Barges and scows, used in conjunction with mechanical dredges, have been one of the most widely applied methods of transporting large quantities of dredged material over long distances.
- Hopper dredges are capable of transporting the material for long distances in a self-contained hopper. Hopper dredges normally discharge the material from the bottom of the vessel hull by opening the hopper doors; however, most hopper dredges are equipped to pump out the material from the hopper and deliver the sediment much like a hydraulic pipeline dredge.

10.3 Dredged Material Disposal and Beneficial Use

Evaluation and design of a proposed dredging project involves comprehensive assessment of alternatives for disposal or placement of the dredged material. Identification of the specific disposal site or beneficial use involves a number of different considerations, including environmental, technical, and economic factors (USACE 2004a).

Three major disposal/placement/use alternatives are available:

- Open-water disposal in deep waters or along banks of a river outside the navigation channel,
- Confined disposal in open water (confined aquatic disposal (CAD)), and on land (confined disposal facility (CDF)), and
- Placement for beneficial use.

In the case of very contaminated sediments and clean-up dredging, treatment of the dredged material after temporary storage and before final disposal may be necessary.

10.3.1 Open-Water Disposal

Open-water disposal means that dredged material is placed at designated sites in oceans, estuaries, rivers, and lakes such that it is not isolated from the adjacent water. Clean dredged materials are the only acceptable dredged materials for disposal at open-water disposal sites. The determination that dredged material is "clean" is based upon a series of chemical and biological tests, the results of which must meet national and local environmental regulations. Regulatory requirements for disposal vary among countries; the overall international guidelines from which national dredged material disposal regulations are based are the Waste Assessment Guidelines for Dredged Material established by the parties to the international treaties, London Convention and Protocol (IMO 2003). The disposal of contaminated material can be considered for open-water disposal, but only with appropriate control measures, such as capping the contaminated sediments by the use of clean capping materials.

The objective of capped in-water disposal is to isolate contaminated materials from the environment by covering the contaminated materials with clean materials, such as fine to coarse sand. The contaminated material is placed on a level bottom, in engineered deep constructed pits, or in bottom depressions. The cap of clean sediment that is placed on top must be designed to withstand erosion over time from bottom currents, waves, vessel movement and propwash, and burrowing bottom creatures (Fig. 10.9). Caps should be monitored over time to ensure their integrity (Otten and Hartman 2002).

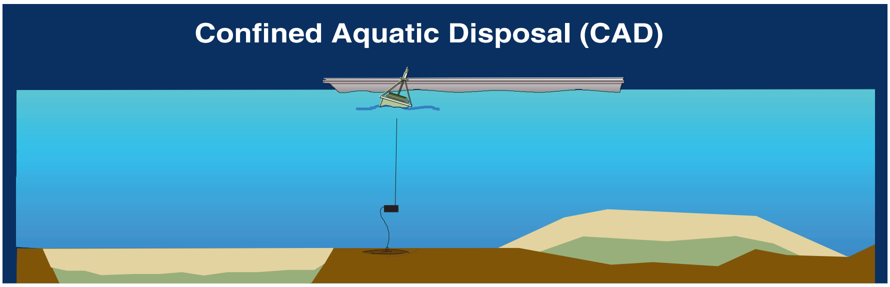


Fig. 10.9 Confined aquatic disposal (CAD). *Courtesy of Corps of Engineers*

10.3.2 *Confined Disposal Facilities*

Confined disposal is placement of dredged material within engineered diked nearshore or upland confined disposal facilities (CDFs) via pipeline or barge delivery of sediments. CDFs may be constructed as upland sites, nearshore sites with one or more sides in water (sometimes called intertidal sites), as island containment areas, or as subaqueous contained capped cells (Figs. 10.10, 10.11, and 10.12).

The two objectives inherent in design and operation of CDFs are to provide for adequate storage capacity to meet dredged volume requirements and to maximize

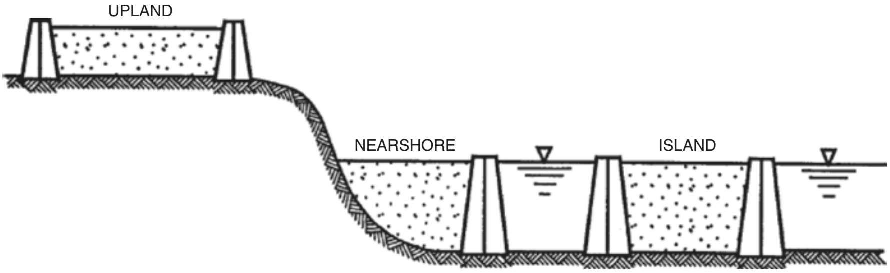


Fig. 10.10 Types of confined disposal facilities *Courtesy of Corps of Engineers*

Fig. 10.11 Nearshore CDF Huelva Estuary Spain. *Courtesy of Spain government*

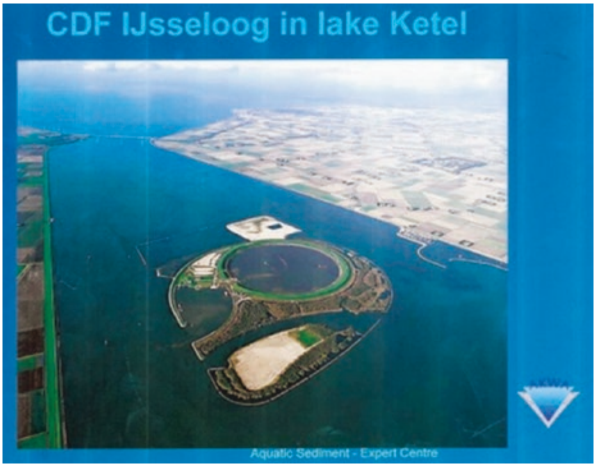


Fig. 10.12 Island CDF at IJsseloog, Netherlands. *Courtesy of Dutch government*

efficiency in retaining the solids. For facilities receiving contaminated material, an additional objective is to provide the efficient isolation of contaminants from the surrounding area. To achieve these objectives, depending on the degree of intended isolation, CDFs may be equipped with a complex system of control measures, such as surface covers and bottom liners, treatment of effluent, surface runoff and leachate monitoring, and management controls.

10.3.3 Beneficial Use of Dredged Material

Dredged material is increasingly regarded as a resource rather than as a waste Depending upon the physical and chemical characteristics, dredged material can be acceptable for a wide range of environmentally and economically beneficial uses. The first step in examining dredged material management options is to consider possible beneficial uses of dredged material. Recent decades have seen the increasing use of dredged materials for habitat creation, habitat restoration, beach nourishment, and coastal reinforcement (USEPA 2007; USACE beneficial uses website).

Beneficial use is defined as "*Utilizing dredged sediments as resource materials in productive ways, which provide environmental, economic, or social benefits*" (USEPA 2007). Broad categories of beneficial uses of dredged material, based on the functional use of the dredged material or site, include:

- Habitat development and restoration
- Parks and recreation
- Coastal protection and reinforcement
  - Beach and dunes nourishment
  - Riverbank and lakeshore protection

- Nearshore placement/littoral zone sediment management
- Construction and agricultural
  - Construction and industrial/commercial development (roads, dikes, levees, parking lots), concrete production
  - Land reclamation/remediation (brownfield restoration, strip mine reclamation)
  - Agriculture, forestry, horticulture, and aquaculture

10.4 Environmental Considerations and Protection of the Marine Environment

10.4.1 Physical Impacts of Dredging and Disposal of Dredged Material

The potential environmental effects of dredging are the result of the actual dredging activity in the water and a result of the disposal or use of the dredged material (Figs. 10.13 and 10.14).

During dredging, effects may arise due to the excavation of sediments causing resuspension in the water column, loss of material during transfer to the barge, overflow from the dredge while loading and loss of material from the hopper dredge and/or pipelines during transport to disposal. Potential effects during disposal arise depend upon the physical and chemical characteristics of the dredged material and the selected disposal site (i.e., open-water, nearshore, or upland).

During all dredging operations, the removal of material from the seabed also removes the surface-based (benthic) animals living on and in the sediments (benthic animals). With the exception of deep burrowing animals or mobile surface animals that may survive a dredging event through avoidance, dredging can initially result in the complete removal of surface dwelling biota from the dredging site. Where the channel or berth has been subjected to regular maintenance dredging over many years, it is very unlikely that well-developed benthic communities will occur in or around the dredged area. The recovery of disturbed habitats following dredging ultimately depends upon the nature of the new sediment at the dredge site, sources and types of re-colonizing benthos, river width and bankline, and the extent of the disturbance (ICES 1992). Benthic recovery rates at offshore borrow sites mostly range from 1 to 3 years (SAIC 2012).

When dredging and disposing of non-contaminated fine materials (e.g., silts, clays) in estuaries and coastal waters, the main environmental effects are associated with suspended sediments and increases in turbidity. All methods of dredging release suspended sediments into the water column, during the excavation itself and during the overflow of dredging water from hoppers and barges. In many cases, the locally increased suspended sediments and turbidity associated with dredging and

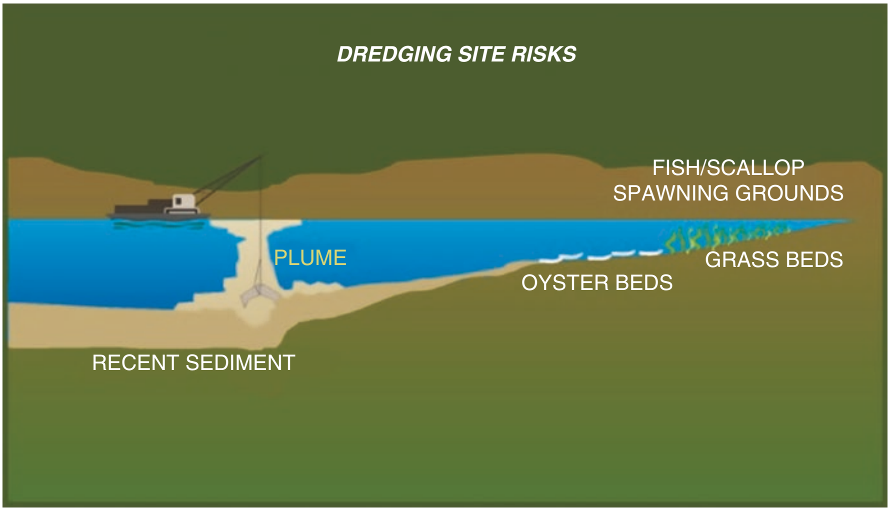


Fig. 10.13 Environmental risks: at the dredging sites. *Courtesy of Corps of Engineers*

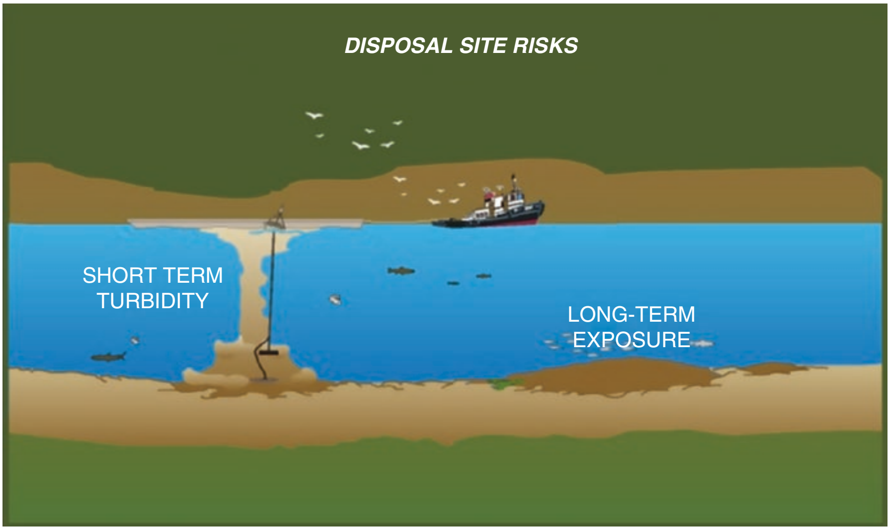


Fig. 10.14 Environmental risks: at the disposal sites. *Courtesy of Corps of Engineers*

disposal is obvious from the turbidity ‘plumes’ which may be seen trailing behind dredges and disposal sites (UK 2001).

The degree of resuspension of sediments and turbidity from dredging and disposal depends on four main variables:

- The sediments being dredged (size, density and quality of the material),
- Method of dredging (and disposal),

- Hydrodynamic regime in the dredging and disposal area (current direction and speed, mixing rate, tidal state), and
- The existing water quality and characteristics (background suspended sediment and turbidity levels).

Increases in suspended sediments and turbidity levels from dredging and disposal operations may under certain conditions have adverse effects on marine animals and plants by reducing light penetration into the water column, burial and by physical disturbance. Increased turbidity can impact filter-feeding organisms, such as shellfish, through clogging and damaging feeding and breathing equipment (Bray 2008; ICES 1992).

Similarly, young fish can be damaged if suspended sediments become trapped in their gills, and increased fatalities of young fish have been observed in heavily turbid waters. Adult fish are likely to move away from or avoid areas of short-term high suspended solids, such as dredging sites, unless food supplies are increased as a result of increases in organic material. In important spawning or nursery areas for fish and other marine animals, dredging can result in smothering eggs and larvae. Shellfish are particularly susceptible during the Spring when spatfall occurs. Increases in turbidity results in a decrease in the depth that light is able to penetrate the water column, which may affect submerged seaweeds and plants, such as eelgrass *Zostera* species, and coral by temporarily reducing productivity and growth rates (Jones et al. 2015).

The resuspension of sediments during dredging and disposal may also result in an increase in the levels of organic matter and nutrients available to marine organisms. In certain cases, nutrient enrichment can lead to the formation of algal blooms (eutrophication). These blooms can reduce the surrounding water quality by causing the removal of oxygen as the blooms break down, or occasionally, by the release of toxins which may disturb marine wildlife (Howarth 2008).

Sediments dispersed during dredging and disposal may resettle over the seabed and the animals and plants that live on and within it. This blanketing can cause smothering of benthic animals and plants, may cause stress, reduced rates of growth or reproduction and, in the worse cases, the effects may be fatal. Generally, sediments settle within the vicinity of the dredged area where they are likely to have little effect on the recently disturbed communities, particularly in areas where dredging is a well-established activity (Fig. 10.15). However, in some cases sediments are distributed more widely within the estuary or coastal area and may settle over adjacent subtidal or intertidal habitats possibly some distance from the dredged area.

Dredging can cause direct threats to endangered species such as sea turtles and their nearshore marine habitats (Sea Turtle Conservancy 2016 website). Hopper dredges have been directly responsible for the incidental capture and the death of hundreds, if not thousands, of sea turtles in the United States. Development of specially designed hopper dredge dragheads and institution of best management practices in areas of turtle populations has helped alleviate the majority of the takings of turtles during dredging operations.

When dredged materials are placed in open-water disposal sites, they will have a blanketing and smothering effect on benthic organisms in the immediate disposal site. The continual disposal of maintenance dredging at disposal sites may prevent the development of stable benthic communities, and the partial or complete loss of

Fig. 10.15 A hopper dredge disposing dredged material. *Courtesy of Cairns Post*

benthic production and habitat. Recolonization is expected when disposal operations have been completed, depending on the characteristics of the dredged material and the changes to the hydrodynamic conditions at the disposal site (USACE 2004a). In general, naturally stressed environments, such as beaches, are less impacted and faster to recover than deeper, more stable habitats (Bolam and Rees 2003).

Dredging and disposal activities may impact adjacent communities through noise, work area lighting and construction traffic, particularly if material is transported by truck for disposal. Emissions from vessels and machinery, as well as odors and hydrogen sulfide released from dredged sediment, can impact local air quality and require management or mitigation.

10.4.2 Potential Impacts of Contaminated Dredged Material

A variety of harmful substances, including heavy metals, tributyltin, polychlorinated biphenyls (PCBs), and pesticides, are in the sediments in certain ports, harbors, and waterways. These contaminants are often of historic origin and from local or upstream sources. The highest levels of contaminants generally occur in industrialized estuaries. Dredging and disposal can release these contaminants into the water column, making them available to be taken up by animals and plants, with the potential to cause adverse acute and chronic toxicity. The risk of this occurring depends upon factors such as the type and degree of sediment contamination, pore water chemistry and the sediment organic content. If contaminants are released into the water column or are in the sediments at the open-water disposal site, they may bioaccumulate in marine animals and plants and transfer up the food chain to fish and sea mammals, with associated risks to human health (Moore et al. 1998).

The environmental issues associated with dredging and dredged material disposal include:

- Removal of the surface based (benthic) animals living on and in the sediments (benthic animals) being dredged.
- Physical and ecological impacts due to turbidity, sedimentation, noise, and disturbance.
- Ecological and human health impacts: acute and chronic toxicity due to chemical contamination; e.g., PCBs, PAHs, dioxin, metals—such as lead, cadmium, and mercury.
- Disturbance to habitat—due to dredging or the placement of dredged material on beaches/dunes or in open water.
- Impacts to endangered species (e.g., turtles) due to dredging activities.
- Impacts to fish behavior, migration and spawning due to turbidity and exposure to toxic chemicals from dredging and disposal, noise and disturbance.
- Others: emissions of air pollutants; quality of life issues (e.g., noise, lights).

10.4.3 Disposal of Contaminated Dredged Material

Nearshore or upland CDFs are the most commonly used disposal technique for contaminated dredged material. Pathways for potential exposure to animals/plants and humans are similar for these two types of disposal sites. Comparison to open water sites is not necessarily appropriate since open-water sites should be receiving clean dredged material while nearshore and upland sites isolate contaminated dredged material from the surrounding environment. Potential pathways include the discharge into receiving waters (e.g., estuary or river) of the excess water from the dredged material, leakage through the CDF barrier, contamination of ground water, and exposure of birds and animals to the dredged material in the CDF. Depending upon the level of contamination, controls can be used to minimize negative environmental impacts, such as using of impervious liners for disposal sites receiving dredged material from cleanup dredging.

10.4.4 Using Dredged Material for Beneficial Purposes

When dredged materials are used for beach nourishment or coastal reinforcement (Fig. 10.16), impacts include (1) a short-term disturbance of the indigenous biota of the beach or dunes (e.g., by smothering with new sand or with incompatible

Fig. 10.16 Coastal reinforcement dredging project in the Netherlands. *Courtesy Van Oord–Boskalis*

material) with attendant temporary reduction in the invertebrate forage base for fish and shorebirds, (2) the potential to alter habitats or used by species for nesting, nursing, and breeding, and (3) short term increases in turbidity along the shoreline. The recovery of the beach and dunes is generally in a year or less, especially when sand is placed on sand-starved beaches with limited habitat functions. In California, USA, the fish, California grunion, may use the new beaches and habitat right away for spawning and birds can use it for resting. Over relatively short periods, many marine species are able to adapt with increased levels of turbidity and suspended sediments, similar to natural events caused by storms. Longer term exposures can be problematic to fish and benthos (SAIC 2012).

10.5 Environmental Regulation of Dredging and Disposal/Placement

In addition to national and regional legislation and policies, the most widely applicable international regulatory instrument for management of environmental issues associated with dredging is the London Convention and Protocol, which is part of the International Maritime Organization, an organization of the United Nations. The London Convention and Protocol regulates disposal of wastes into ocean waters, world-wide (IMO 2003). The London Convention and Protocol is an international regulatory regime, which includes 99 country signatories. Member countries are required to implement the conditions of the treaty including the waste assessment, disposal, monitoring, and permitting procedures noted below.

The London Convention and Protocol Waste Assessment Guidelines for Dredged Material allow disposal of dredged material into ocean waters, provided that strict environmentally protective criteria are met. A step-by-step process to evaluate a dredging project, the alternatives for disposal or placement for beneficial use, an action list for judging environmental acceptability of open water disposal, criteria for location of disposal sites, monitoring, and permitting requirements are specified in the Guidelines (London Convention 2014).

After an assessment of the need for dredging, major dredging or disposal projects should have studies carried out in order to ensure that any potential adverse effects are identified in advance and dealt with in an appropriate manner. Such investigations include characterization of the dredged material (physical, chemical, and toxicity), an examination of any sources of contamination and the potential to control those sources, an assessment of the biological communities, an assessment of disposal or beneficial use placement alternatives including identification and characteristics of the disposal site, and design of monitoring studies to determine whether any potential impacts are correctly predicted.

The environmental impact assessment should highlight the positive and negative, and the short- and long-term impacts. Appropriate testing may be required to determine the physical behavior of the material at the disposal site. Also, testing of the material proposed to be dredged and assessments of the potential contaminants of concern may be required, depending upon existing knowledge of the dredging site and any potential contaminant pathways. Where potentially adverse effects are anticipated, management techniques should be implemented to reduce risks to acceptable levels. Possible controls for open-water alternatives include operational modifications, use of submerged discharges of dredged material, treatment, lateral containment, and capping or contained aquatic disposal. Possible controls for confined disposal facilities include operational modifications, treatment, and various site controls (e.g., covers and liners) (PIANC 2002). Temporal constraints on dredging and disposal operations or “environmental windows”, are a possible control to protect biological resources by avoiding such activities during times when biological resources are present or most sensitive to disturbance (USACE 2015).

An important component in development of the environmental impact assessment and in identifying potential impacts and implementing acceptable measures is the involvement of interested groups and organizations, consulting with them, and reaching a consensus in the early in the process of determining the alternatives. It is in the best interests of the project sponsors and stakeholders that the decision-making process is transparent, stakeholders are involved, and that the reasons for the selection of the preferred dredging and disposal or placement options are clearly understood.

While an international regulatory regime is in place for disposal of dredged material, a major gap exists in the dredging of sand and gravel from offshore sources. The mining by dredging of about 40 billion tonnes per year of sand and gravel is essentially unregulated in the vast majority of cases (UNEP 2014).

United Nations Environmental Programme statement on mining of sand and gravel:

> Despite the colossal quantities of sand and gravel being used, our increasing dependency on them and the significant impact that their extraction has on the environment, this issue has been mostly ignored by policy makers and remains largely unknown by the general public. (UNEP 2014).

10.6 Future Directions: Sustainable Dredging and Dredged Material Management

The global economy and the dependence upon food and commodities via international trade require that vessels have sufficiently deep channels in ports, harbors, and waterways for safe passage. Other interests include national security and water resources, as well as recreational opportunities.

While upstream sediment management controls will help, the natural erosion process in rivers and estuaries will continue. Thus, navigation dredging will continue to be needed over the very long term. Environmental cleanup dredging will be needed for decades to come, even as improved controls are placed upon waste and wastewater sources. Legacy contaminants already in the sediments will continue to pose aquatic and human health risks until they are removed or isolated from the surrounding aquatic environment. The environmental considerations relate to the quality and quantity of the sediment to be dredged, the potential environmental risks from the dredging itself, and what to do with the dredged material.

Over time, dredging and dredged material management practices will move towards approaches that reduce impacts and the consumption of resources. Sustainability in dredging can be achieved by efficiently investing the resources needed to support the desired social, environmental and economic services generated by the dredging project for the benefit of current and future generations. Improved technical approaches and governance relate directly to commitments of the international community in major documents, such as the Millennium Development Goals, the Rio Declaration of Sustainable Development, the World Water Assessment Programme, and the World Organization of Dredging Association Statement on Mitigating and Adapting to Climate Change, among others (UNESCO, IRTCES 2011; WODA 2016). The likely trends include: sediment management, beneficial use, climate adaptation, technological innovations and nature-based engineering to reduce impacts and costs, and a tightened regulatory environment.

10.6.1 Sediment Management

Dredging projects will be managed as part of the overall sediment system (USACE 2004b) at the basin-level and along the coastlines. Regional sediment management and integrated basin management programs that recognize interconnections and ecosystem services provided by sediment systems are gradually redefining sediment issues as regional, rather than local concerns (European Union Sediment Network 2014).

10.6.2 Beneficial Use of Dredged Material

Dredged material is increasingly being considered a resource with a multitude of potential uses, such as serving as a feedstock for the manufacture of beneficial use products (e.g., manufactured soil products that can replace the mining and transport of raw materials). Opportunities for beneficial use of dredged material will increase as potential beneficial use projects (e.g., habitat restoration or creation, beach nourishment and coastal protection, and construction purposes) and their sponsors are identified early in the dredging project planning process (USACE 2015).

10.6.3 Climate Adaptation

Climate change and sea level rise can cause more erosion in some places and less in others, with associated changes in the quantities of sediment needed to be removed by dredging for navigation purposes. Continued focus upon balanced management of local and upstream sources of sediment and the control of contaminant sources will begin to pay dividends by reducing the frequency and cost of navigation dredging. Improved chemical and toxicological quality of those sediments will occur as additional environmental controls are put in place to control municipal and industrial discharges and storm water runoff from urban and rural areas, including farmlands. Instituting environmental controls on the disposal of hazardous waste will help reduce the need for environmental cleanup dredging.

Tremendous pressures are foreseen to protect coastlines against sea level rise; extraction of offshore sources of sand and gravel by dredging will play a major role in coastal reinforcement. Increased focus by regulatory authorities is essential to acknowledge and manage the potential environmental impacts of removal of sand and gravel from those offshore areas.

10.6.4 Sustainability: Technological Innovations

Driven by concerns about the potential impacts to aquatic life and human health, technology will continue to evolve in dredging hardware, treatment of contaminated dredged material, and use of dredged material in beneficial use applications.

Innovations in dredging technology are focused upon reduction in the disbursement of suspended solids and associated contaminants into the water column during dredging and disposal operations.

Further technological innovations in the types and efficiencies of treatment technologies will likely identify potential reuse opportunities for certain dredged materials, such as use as soil, fill, or aggregates.

Other areas of dredging and disposal are likely to see significant changes:

- Electric powered dredges will contribute fewer greenhouse gas emissions and fewer diesel emissions and NO_x in locations where compliance with air pollution standards is an issue or regulation.
- Changes in navigation channel design to accommodate larger ships (deeper channels) will impact dredging projects, and improved channel design will be necessary due to limited project funding (e.g., narrower channels and institution of vessel operational controls and fewer deep water ports with attendant increases in the use shallower draft vessels to move cargo between coastal ports).
- Increased emphasis on science and engineering to ensure that contaminated dredged material remains isolated from the aquatic environment over the long-term, given the trend for increased use of confined aquatic disposal cells.
- A renewed emphasis on beneficial use of dredged material will be necessary as disposal options become more restricted and confined disposal facilities reach their capacity.
- Approaches to the design and implementation of dredging projects will align natural forces and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaborative processes.

10.6.5 Nature-Based Engineering

Increasingly, designs of navigation coastal protection and restoration projects are seeking to meet project objectives through an ecosystem context that intentionally aligns natural and engineering processes. By using natural forces and processes to advantage, rather than engineering to counter them, reduced disturbance, environmental impact and maintenance costs can be realized. This trend is likely to continue based on opportunities for cost-sharing and the potential to achieve multiple objectives (Fredette 2012).

10.6.6 Application and Implementation of International Regulations

International guidelines (i.e., London Convention/London Protocol) are in place for protection of the environment from dredged material disposal in ocean waters. National and local regulations are in place in many countries that implement the London Convention/London Protocol guidelines as well as for protection of internal country waters. These regulations are in various stages of implementation worldwide. Technical cooperation and assistance programs are on-going to assist developing countries in their application (London Convention website).

One key aspect of the national and local regulations is the characterization of the dredged material prior to disposal. Updated procedures for testing dredged material will provide better techniques to assess its acceptability for open water disposal or for specific beneficial uses; these include improved bioassays, interpretive guidance, and the application of risk assessment in cases where high uncertainties exist (More et al. 1998). Moreover, the poorly understood interactions and effects of new compounds, such as nanomaterials, released in industrial discharges will likely pose toxicological risks stimulating future regulation and characterization challenges (Schierz et al. 2014).

The final trend in the regulatory arena is the use of mitigation for unavoidable adverse impacts due to dredging and disposal. This will become more widespread as one of the tools for regulatory authorities.

References

Bolam SG, HL Rees (2003) Minimizing impacts of maintenance dredged material disposal in the coastal environment: A habitat approach. Environ. Mgmt 32(2):171–188

Bray RN (2008) Environmental aspects of dredging. Taylor and Francis, London

Cohen M (2010) Dredging: the environmental facts. ISBN 90-75254-11-3

European Union Sediment Network (2014) Moving sediment management forward – the four sednet messages. http://sednet.org/download/Moving-Sediment-Management-Forward.pdf

Fredette T (2012) Analysis and overview of existing navigation and coastal engineering with nature projects. Paper presented at Dredging 2012 Conference, San Diego, CA

Hanson H, Brampton A, Capobianco M, Dette HH, Hamm L, Laustrup C, Spanhoff R (2002) Beach nourishment projects, practices, and objectives—a European overview. Coast Eng 47:81–111

Howarth RW (2008) Coastal nitrogen pollution: a review of sources and trends globally and regionally. Harmful Algae 8:14–20

IMO (2003) London convention 1972 and the 1996 protocol, 2nd edn. International Maritime Organization, London

International Council for the Exploration of the Sea (ICES) (1992) Report of the ICES working group on the effects of extraction of marine sediments on fisheries. Copenhagen (Denmark): ICES Cooperative Research Report # 182

Jones R, Ricardo GF, Negri AP (2015) Effects of sediments on the reproductive cycle of corals. Mar Pollut Bull 100:13–33

London Convention (2014) Specific guidelines for assessment of dredged material. http://www.imo.org/en/OurWork/Environment/LCLP/Publications/wag/Pages/default.aspx

London Convention website. http://www.imo.org/en/OurWork/Environment/LCLP/TC/Pages/default.aspx

Moore DW, Bridges TS, Ruiz C Cura J, Driscoll SK, Vorhees D, Peddicord D (1998) Environmental risk assessment and dredged material management: issues and application. Proceedings of Workshop

Otten MT, Hartman G (2002) Placing and capping fine-grained dredged material. Paper presented at Third Specialty Conference on Dredging and Dredged Material Disposal

PIANC (2002) Environmental guidelines for aquatic, nearshore and upland confined disposal facilities for contaminated dredged material. Report of EnviCom Working Group 5

Sea Turtle Conservancy (2016) Sea turtle threats: beach nourishment & dredging. Accessed on 1 Sept 2016. http://www.conserveturtles.org/seaturtleinformation.php?page=nourishment
Schierz A, Espinasse B, Wiesner MR, Bisesi JH, Sabo-Attwood T, Ferguson PL (2014) Fate of single walled carbon nanotubes in wetland ecosystems. Environ Sci Nano 1:574–583
Science Applications International Corporation (SAIC) (2012) Review of sediment management impacts and issues relevant to protection of California Coastal Biota; Volume 2: User's guide and resource protection guidelines. California Sediment Management Master Plan, 2012
UK Marine Protected Areas Centre (2001) UK Marine SACs project; Dredging and disposal. http://www.ukmarinesac.org.uk/activities/ports/ph5.htm
UNESCO, IRTCES (2011) Sediment issues and sediment management in Large River basins. International Sediment Initiative, Technical Documents in Hydrology, CN/2011/SC/IHP/PI/2
United Nations Environmental Programme (2014) Sand, rarer than one thinks; UNEP Global Environmental Alert Service. Taking the pulse of the planet. Connecting science with policy. www.unep.org/glea
U.S. Army Corps of Engineers and U.S. Environmental Protection Agency (2004a) Evaluating environmental effects of dredged material management alternatives---a technical framework, EPA842-B-92-008
U.S. Army Corps of Engineers (2004b) Regional sediment management--primer
U.S. Army Corps of Engineers (2015) Dredging and dredged material management. Engineer manual, EM 1110-2-5025
U.S. Army Corps of Engineers Beneficial use of dredged material website. https://budm.el.erdc.dren.mil
U.S. Environmental Protection Agency and U.S. Army Corps of Engineers (2007) Identifying, planning, and financing beneficial use projects using dredged material beneficial use planning manual
Van Slobbe E, De Vriend HJ, Aarninkhof S, Lulofs K, De Vries M, Dircke P (2013) Building with Nature: in search of resilient storm surge protection strategies. Nat Hazards 65:947–966
Willard (2009) Willardsays … Dredge history done lite. Accessed on 25 May. http://1123 www.willardsays.com/dredge_history.pdf
World Organization of Dredging Associations (WODA) (2016) Statement on mitigation and adapting to climate change. https://westerndredging.org

Chapter 11
Environmental Risks of Deep-sea Mining

Philip P.E. Weaver, David S.M. Billett, and Cindy L. Van Dover

Abstract The mining of the deep-sea for minerals has been on the horizon for many years with interest increasing rapidly since 2010 following the application for, and approval of, many new contracts for exploration in international waters. Some contracts for exploitation have been granted in national waters with mining expected in the next few years. These activities will impact ecosystems that have not been affected by man's influence before, and many of them are poorly understood due to their remoteness and complexity. This paper describes the likely impacts for mining the three main deep-sea minerals—manganese nodules, cobalt crusts and polymetallic sulphides and briefly looks at possible mitigation measures.

Keywords Deep-sea mining • Environmental impact • Polymetallic nodules Seafloor sulphides • Cobalt crusts

11.1 Introduction

Deep-sea mining is a term used to describe the extraction of metals from the deep ocean. There are three common resource types—manganese, or polymetallic, nodules that occur in surface sediments in abyssal plain muds, mainly in the Pacific and Indian Oceans; cobalt crusts that occur as a surface crust on seamounts and rock outcrops in all oceans but with highest known grades in the western Pacific; and seafloor massive sulphides that are formed at seafloor hot springs along ocean plate boundaries. In addition, a contract has been granted to explore for metal-rich muds

P.P.E. Weaver (✉)
Seascape Consultants, Romsey, UK
e-mail: phil.weaver@seascapeconsultants.co.uk

D.S.M. Billett
Deep Seas Environmental Solutions, Ashurst, Southampton, UK

C.L. Van Dover
Duke University, Durham, NC, USA

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_11

under dense brines in the Red Sea (Bertram et al. 2011), and the possibility of mining ocean sediments to recover Rare Earth Elements (REEs or technology metals) has been suggested in the last few years (Kato et al. 2011). The mining of phosphate along continental margins is sometimes also included under the term deep-sea mining, but that topic is not addressed here.

Interest in mining metals in the deep sea began in the 1960s, focussed initially on the extraction of manganese nodules. The first pilot mining activities were carried out by the Ocean Minerals Company (OMCO) in 1976 and 1979 (see Chung 2009) and were located in the central Pacific in water depths in excess of 5000 m. These early steps and further activities by other nations did not lead to any commercial mining, though soon after the discovery of deep-sea hydrothermal vents, the US Minerals Management Service considered lease blocks for the Gorda Ridge hydrothermal areas off the coast of Oregon (McMurray 1987). Interest in mining the deep sea remained at a relatively low level for many years due to a combination of factors, including relatively low metal prices, the engineering challenges and the lack of a legal framework in the High Seas. In 1994 the International Seabed Authority (ISA) was established under the United Nations Convention on the Law of the Sea to organize and regulate all mineral-related activities in the international seabed area beyond the limits of national jurisdiction (the 'Area'). The ISA had granted seven contracts for exploration for manganese nodules by the end of 2002. Interest in deep-sea mining however, remained low and by the end of the decade only one further manganese nodule exploration contract had been awarded. Since 2010, however, a sea change has occurred. This was stimulated in part by the creation of new Regulations for the exploration of seafloor massive sulphides and for cobalt rich crusts and, possibly, by spatial management measures introduced to preserve and protect the marine environment. By June 2017 the number of exploration contracts had increased to 27, (Fig. 11.1). Exploration contracts now cover all three major resource types (International Seabed Authority 2015). However, until exploitation regulations are approved and published, there can be no active mineral extraction in the Area.

In parallel with the recent increase in interest in deep-sea minerals in international waters, there have also been rapid developments in deep-sea mining within

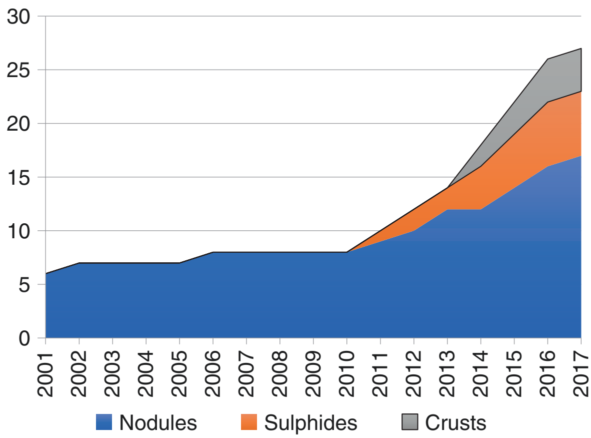


Fig. 11.1 Cumulative number of contractors who have approved contracts for exploration by the International Seabed Authority

the Exclusive Economic Zones (EEZs) of Pacific Island States (Secretariat of the Pacific Community 2014). For many these island states, minerals in their EEZs and continental shelf extensions are their only exploitable natural resource, apart from fish. All three major mineral types are found in this region.

The first metal mining to take place in the ocean is likely to be by Nautilus Minerals Inc. licensed within its EEZ by the State of Papua New Guinea (Secretariat of the Pacific Commission Community 2014). A massive sulphide deposit is targeted to be mined as earlier as 2018, at a water depth of around 1500 m (Lipton 2012). Nautilus Minerals has commissioned the design and build of mining equipment and a mining support vessel (Fig. 11.2). In addition to the Nautilus mining effort at Solwara 1, the Natural Resources and Energy Agency of Japan plans to carry out test

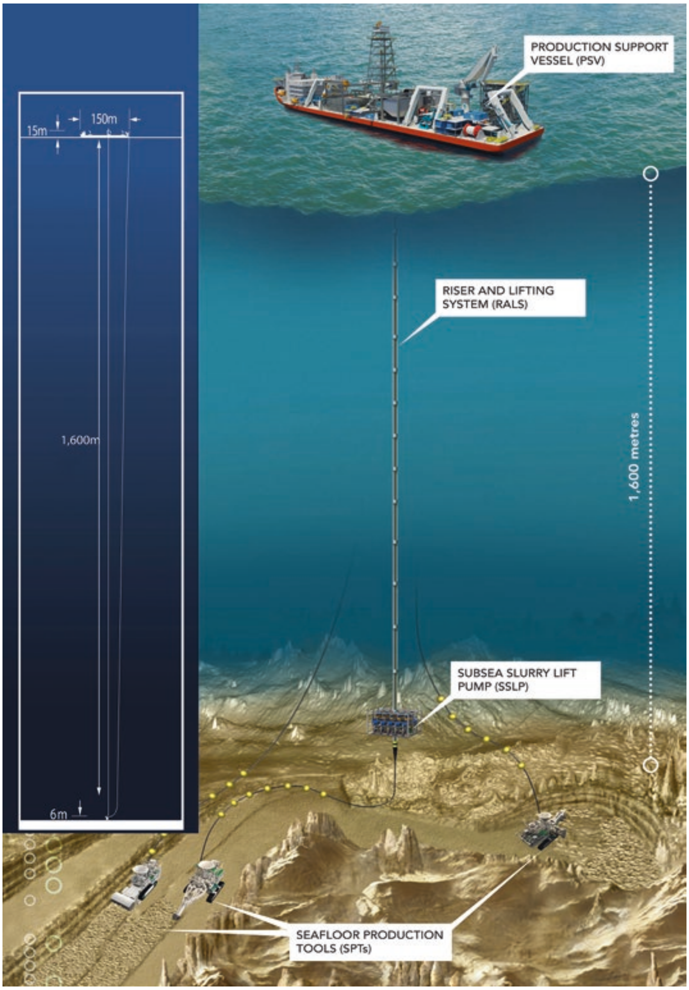


Fig. 11.2 Schematic representation of deep-sea mining for seafloor massive sulphides at Solwara 1 offshore Papua New Guinea. *Courtesy Nautilus Minerals*

mining in the Okinawa Trough at depths greater than 800 m in 2017 (http://www.rscmme.com/all-news/2015/6/29/govt-set-to-mine-mineral-resources-off-okinawa accessed August 3rd 2015). Thus deep-sea mining has moved from little more than a concept at the end of the twentieth century to a likely reality before 2020.

The potential environmental impacts of deep-sea mining were recognised at an early stage (McMurray 1987; Thiel et al. 1991). There are many concerns relating to physical impacts of the mining systems on the seafloor, the creation of sediment plumes through seabed operations, the integrity of the riser pipes and the release of wastes following pre-processing of the minerals at the sea surface. A wide variety of environmental issues need to be resolved, including (1) the very large areas that will be impacted by mining for nodules and, to a lesser extent, for crusts, (2) impacts on chemosynthetic ecosystems on ocean plate boundaries, (3) effects on very stable ecosystems with long lived individuals, and organisms in the water column and on the seabed in areas that are adjacent to the mined areas due to plumes of sediment laden and potentially toxic water, and (4) the effects of noise pollution. In all cases, predictions of impacts are hampered by a lack of knowledge because many areas of interest for deep-sea minerals are remote, research is logistically challenging and time consuming, and in the case of nodules, the scale of the impacts will cover an exceptionally large area.

Impacts on the deep-sea environment need to be weighed against those caused by on-land mining. All mining causes negative environmental impacts, and a balance needs to be achieved between social needs for a healthy environment, wealth creation, and minerals vital for our everyday lives. In this regard, Nautilus Minerals commissioned a report in 2015 (Batker and Schmidt 2015) that concluded mining sulphide deposits in the deep sea off Papua New Guinea would have less environmental impact than land mining. A number of reasons were given for the advantages of ocean sulphide mining, including that no people live at the mine site, there are no historic or cultural claims to the seabed where the minerals lie, freshwater surface and groundwater resources will not be used and contaminated, little waste rock overburden will be removed, there is no need for infrastructure such as roads, the ore quality is of a higher grade, and the site is in an active volcanic region where seabed destruction and renewal is commonplace. However, the Batker and Schmidt report has been challenged for not comparing like with like (Rosenbaum and Grey 2015) and omitting many of the negative factors of deep-sea mining. Working in a fluid and dynamic environment will have wider impacts than just at the mine site, monitoring of effects on the environment will be difficult in terms of both geography and depth, and the duration of some mines for seafloor massive sulphides (SMS) will be short. All factors must be considered carefully to arrive at the right balance.

In this contribution we examine the main environmental risks of deep-sea mining, which in many cases depend on the particular mineral type to be mined. While the main impact of mining is the same for each of the three main mineral resources (i.e., modification of or removal of habitat), there will be major differences in the effects on biological communities, their ecosystem structure and functioning, and their resilience. We have dealt with each of the three resource types independently, dealing with the environmental concerns for each followed by potential mitigation measures that could be employed. The main risks and their impacts are listed in Table 11.1 at the end of this chapter.

Table 11.1 Summary of main risks and impacts of deep-sea mining for manganese nodules, seafloor massive sulphides and cobalt crusts (modified from ECORYS 2014).

Nodule mining impacts				
Area of each mine site: Mined area—~170 km² per operator per year. Exploration contract area for each operator—up to 75,000 km²				
Impact	*Length of impact*	*Potential impacted area*	*Nature of impact*	*Potential for recovery*
Removal of nodules, complete disturbance of seabed and its compaction	Long term. Probably hundreds to thousands of years for a non-compacted surface layer to reform	About 170 km² per year per operator. ISA consider 3–10 operators at any one time. Therefore 510–1700 km² per year	Destruction of habitat and associated organisms	Extremely slow. Hundreds of years for sediments. Millions of years for nodules
Sediment laden plumes near seabed containing particle load	During mining activity	Spread will depend on mining process and local currents. Could be kilometres beyond contract area boundaries	Smothering of seabed animals. Effects on benthopelagic organisms	Likely to be very slow especially in areas heavily impacted
Sediment laden plumes in water column	During mining activity	Spread will depend on local currents and volume of material released plus length of time of release. The depth at which the plume is released may also determine its spread. Potential areas affected could be very large—thousands of square kilometres	Plumes released in the photic zone (down to c200 m) may reduce light penetration and reduce plankton growth or release deep-water nutrients increasing productivity with food chain effects. Plumes released below 200 m depth must be negatively buoyant. Effects on pelagic ecosystems	Recovery will be rapid once activity ceases
Noise	During mining activity	Low frequency noise could travel up to 600 km and have strong impacts on marine mammals within 15 km	Masking effects on marine mammals	Recovery will be immediate once activity ceases

(continued)

Table 11.1 (continued)

Nodule mining impacts				
Area of each mine site: Mined area—~170 km² per operator per year. Exploration contract area for each operator—up to 75,000 km²				
Impact	*Length of impact*	*Potential impacted area*	*Nature of impact*	*Potential for recovery*
Size and ecosystem function fractionated impact on life	Shifts in sediment grain size distribution	Depending on position relative to mining and/or sediment plume impacts, sediments may change in their grain size towards sandier or finer composition	This changes the habitat in terms of the sizes of life that will either be benefited or be impacted negatively	These effects may be long lasting as background sedimentation rates are low
SMS mining impacts				
Area of each mine site: May include a series of areas each at least 300 m diameter based on the Solwara 1 location				
Potential Impact (if unmitigated)	*Length of impact*	*Potential impacted area*	*Nature of impact*	*Potential for recovery*
Mining of seabed, with removal of habitat	On active vent sites may be some years beyond the mining phase. On inactive vent sites may be hundreds of years due toxic metal surfaces and long generation times of faunal	Area of each mine maybe c300 m diameter (based on proposed Solwara 1 mine, Papua New Guinea). However, there may be multiples of these within a contractor's contract area	Destruction of habitat and associated organisms by initial mining and pollution of the environment by toxic metals and metal compounds. This will have a greater impact in inactive sites	On active vent sites, maybe relatively short term (years?). On inactive vent sites likely to be of longer term—probably tens to hundreds of years
Sediment laden plumes near seabed containing particle load and toxic metals and metal compounds	During mining activity and for many years beyond due to toxic metals and metal compounds	Spread will depend on mining process and local currents. Could be kilometres beyond mined area boundaries affecting other depths up and down slope	Smothering of seabed animals by particulates, especially proximal to the mined area. Toxicity to animals in areas affected by the plume. Effects on benthopelagic fauna	Recovery from the particulates will probably take a few years. In the inactive vents recovery from chemical pollution may take longer

Sediment laden plumes in water column containing particle load and chemical toxins	During mining activity	Spread will depend on local currents and volume of material released plus length of time of release. Potential areas affected could be very large—thousands of square kilometres	If Plumes released in the photic zone (down to c200 m) may reduce light penetration and reduce plankton growth or release deep-water nutrients increasing productivity with food chain effects. Toxins in the plumes could cause loss of organisms at all levels in the food chain	Recovery will be rapid once activity ceases
Noise	During mining activity	Low frequency noise could travel up to 600 km and have strong impacts on marine mammals within 15 km (Steiner 2009)	Masking effects on marine mammals	Recovery will be immediate once activity ceases; mammals may move away temporarily?
Cobalt crust mining impacts				
Area of each mine site: Mined area—around 100 km² per operator per year				
Impact	*Length of impact*	*Potential impacted area*	*Nature of impact*	*Potential for recovery*
Removal of crusts,	Long term. Probably hundreds to thousands of years		Destruction of habitat of attached epifauna	Likely to be very slow (tens to hundreds of years)
Sediment laden plumes near seabed containing particle load	During mining activity	Spread will depend on mining process and local currents. Plumes are likely to flow down the seamount flanks	Smothering of seabed animals	Likely to be very slow (tens to hundreds of years) if epifaunal organisms are impacted on bare rock surfaces

(continued)

Table 11.1 (continued)

Nodule mining impacts				
Area of each mine site: Mined area—~170 km² per operator per year. Exploration contract area for each operator—up to 75,000 km²				
Impact	*Length of impact*	*Potential impacted area*	*Nature of impact*	*Potential for recovery*
Sediment laden plumes in water column	During mining activity	Spread will depend on local currents and volume of material released plus length of time of release. Potential areas affected could be very large—thousands of square kilometres	Plumes released in the photic zone (down to c200 m) may reduce light penetration and reduce plankton growth or release deep-water nutrients increasing productivity with food chain effects. Plumes released below 200 m depth must be negatively buoyant. Effects on pelagic ecosystems	Recovery will be rapid once activity ceases
Noise	During mining activity	Low frequency noise could travel up to 600 km and have strong impacts on marine mammals within 15 km	Masking effects on marine mammals	Recovery will be immediate once activity ceases
Size and ecosystem function fractionated impact on life	Shifts in sediment grain size distribution	Depending on position relative to mining and/or sediment plume impacts, sediments may change in their grain size towards sandier or finer composition	This changes the habitat in terms of the sizes of life that will either be benefited or be impacted negatively	These effects may be long lasting as background sedimentation rates are low
	May also include changes in fine scale (biologically relevant) bathymetry	Shifts at crust sites likely larger than nodule mining sites		

11.2 Manganese Nodules

Manganese nodules are concretions formed by concentric layers of iron and manganese hydroxides around a core. They vary in size from microscopic to some tens of centimetres across, although most are between 5 and 10 cm in diameter (Fig. 11.3), and they grow extremely slowly—at rates of 5–10 mm/million years. Commonly, they sit on the seabed, half buried in sediment, although they can also be found buried in the upper sediment layers. Nodules vary in abundance and distribution, being limited to areas with very low sedimentation—typically deep seafloors between 4000 and 6500 m water depth, and they are more common in the Pacific than in other oceans. Exceptionally, they can cover up to 70% of the seabed. To be economically viable, nodules need to occur with an abundance greater than 15 kg/m^2 over areas of more than several tenths of a square kilometre (https://www.isa.org.jm/files/documents/EN/Brochures/ENG7.pdf accessed 11th February 2016). Three areas with commercial potential have been identified in the Pacific: the Clarion Clipperton Zone (CCZ), a vast area in the equatorial eastern Pacific lying between Hawaii and Mexico; the Penrhyn Basin near the Cook Islands; and the Peru Basin. By the close of 2015, the ISA had approved 14 contractors to explore for nodules, with 2 further contracts under negotiation. Thirteen of the agreed contracts are for exploration within the CCZ (Fig. 11.4) and one in the Indian Ocean. The Cook Islands have also carried out a licensing round for exploration of some of its offshore areas.

Nodules are easy to extract by a collector that sifts the upper few centimetres of the seabed and passes them back to a separator where the sediment is removed and redeposited behind the collector. Nodules may then be crushed at the seabed and passed to the riser pipe or they may be passed to the riser pipe intact. Once in the riser pipe they will be pumped to the surface ship where they need to be dewatered and transferred to an adjacent barge for transport to shore. The recovered water needs to be filtered to remove the largest particles and returned to the ocean. Figure 11.5 shows a typical mining process.

The main environmental concerns with mining manganese nodules are:

Fig. 11.3 Manganese nodules. Specimen on left from the CCZ and three nodules on the right from the North Atlantic

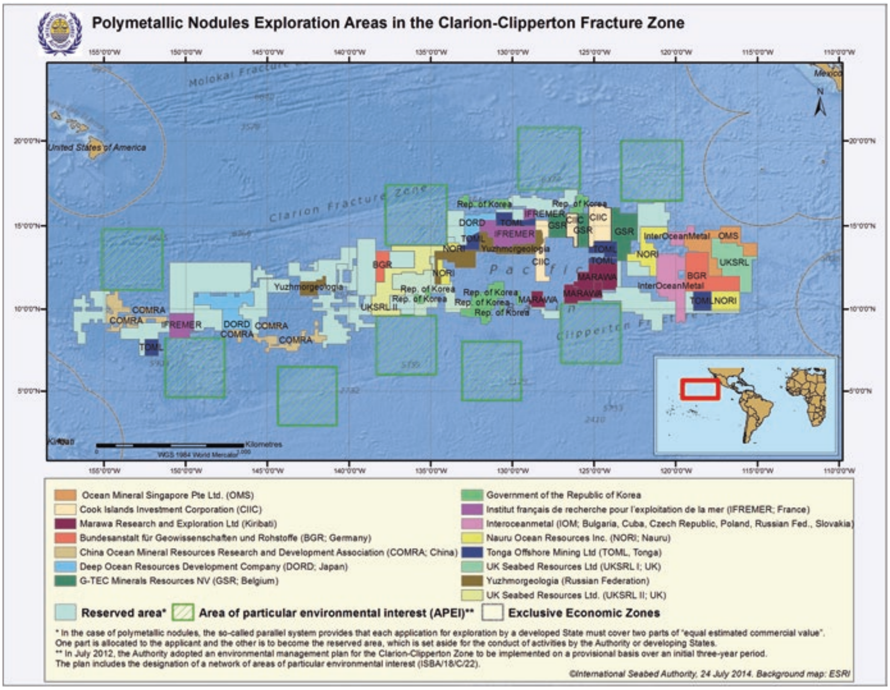


Fig. 11.4 Polymetallic nodule exploration areas in the Clarion Clipperton Fracture Zone of the Pacific Ocean as of 2014 (ISA www.isa.org.jm/contractors/exploration-area#maps-page_1-0)

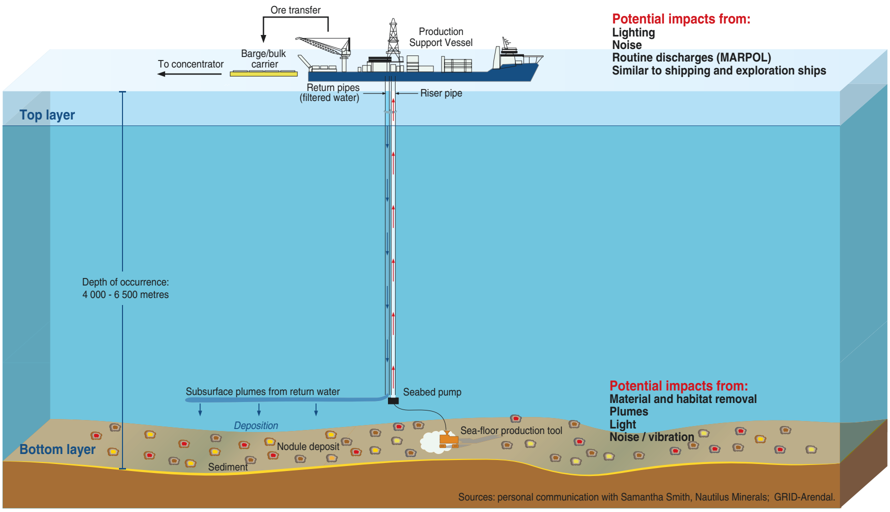


Fig. 11.5 Example of a sea-floor manganese nodule mining system and related sources of potential environmental impact. *Courtesy GRID-Arendal*

11.2.1 Potential Widespread Habitat Destruction in Areas with Fragile and Poorly Understood Ecosystems

Contracts to explore for manganese nodules are typically for areas up to 75,000 km^2. In total the area approved for exploration for nodules in the CCZ to date is 1,258,000 km^2. It is estimated that about 30% of each contract area will be suitable for mining, although the area affected by sediment plumes from mining will be much greater. The 'Blue Mining Consortium' estimates that an area of 177 km^2 has to be mined each year to satisfy an annual production of two million dry tonnes (https://www.isa.org.jm/sites/default/files/bbk1.pdf accessed 11 November 2015). Several mining systems may work in a claim, so the area of seabed physically disturbed each year in one mine contract area may be between 200 and 600 km^2, the size of a large town or Pacific island. Mining in one contract area may last 20–30 years. The number of different mining licence operations at any one time is unknown, but will depend to a large extent on the economics of mining and on demand for metals. In comparison, the Goro laterite mine on New Caledonia covers an area of less than 80 km^2 and is expected to produce over 120 million tons of ore over a 29 year period from this one site (http://www.mining-technology.com/projects/goro-nickel/accessed 5th February 2015). The difference in the areal extent of mining is due to the fact that land based mines are 3-dimensional, with ores extending into the ground for many tens of metres, as opposed to those in the deep sea where the ore layer is just a few centimetres thick. There are no significant gains in ore quality with the deep-sea nodules, which contain about 28.4% manganese, 1.1% copper, 1.3% nickel and 0.21% cobalt.

The area of seabed that will be impacted by sediment plumes is likely to be at least as large as the area altered physically, although new technologies may reduce plume effects. Good physical oceanographic modelling can predict the extent of plumes and the thickness of resedimentation, which will decrease with increasing distance from the mine site. However, the scales of ecosystem effects in relation to the thickness of resedimentation are unknown. What is known is that the abyssal ecosystems in areas with nodules are adapted to exceptionally low sedimentation rates. This is why the nodules occur on the seabed in the first place. So, it may be surmised that even low levels of resedimentation will have significant biological effects, and that these may extend for a considerable distance from the mine site, depending on the mining technology used. Better data are required on the effects of resedimentation thickness on abyssal benthic ecosystems. These data should be coupled with oceanographic models in order to predict ecosystem risk.

While the area affected by mining operations can be estimated over a variety of timescales, it is also important, when comparing land and marine mining, to consider the proportion of a particular habitat that is being impacted and whether regional biodiversity, ecosystem function, ecosystem services and human populations will be affected to a significant degree. On land there are many competing demands for space. On the remote abyssal plains other direct and competing human users are negligible. However, all of humankind depends on the ecosystem services

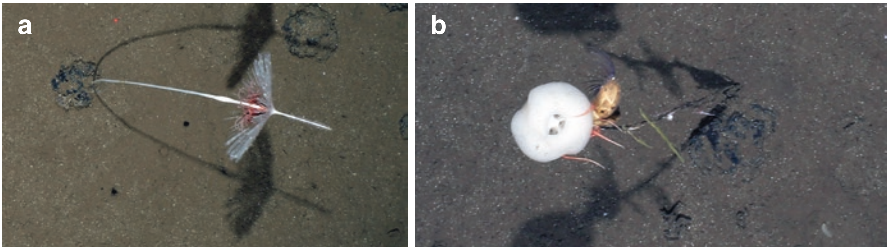


Fig. 11.6 Fauna living attached to nodules in the CCZ (**a**) stalked hydrozoan with anemone inside (*pink*). (**b**) Sponge with stalked barnacles, ophiuroid and amphipods *Images courtesy AWI-Launcher OFOS, DISCOL SO242-2, 2015, Alfred Wegener Institute, Germany*

provided by the oceans, such as the production of life-giving oxygen and the long-term sequestration of carbon dioxide. Might deep-sea nodule mining have a deleterious effect on these indirect benefits to society?

The area of prime interest in manganese nodules, the Clarion Clipperton Zone, is vast (Fig. 11.4). It is important to appreciate its scale, extending, as it does, across an area the size of the United States of America. If one third of this area is mined (including areas affected by resedimentation from plumes) over a period of 200 years, will ecosystem services be affected significantly? It may be argued that as faunal biomass is so low on abyssal plains, there will be little impact on our lives, as far as man is concerned. Alternatively, biological diversity is great on abyssal plains, including the CCZ (ISA 2008a), and especially in areas where nodules occur (Vanreusel et al. 2016) (Fig. 11.6). These biological resources may have as yet untapped value for biotechnologies and medicines. A case can be made that all forms of life are worth preserving.

The distances over which species occur in the abyss are, for the most part, unknown. It is uncertain what proportion of the seabed can be impacted without making species extinct. To address this one has to imagine the USA covered uniformly by a landscape of many mud-covered ridges and troughs, about 200–300 m in relief, mostly oriented north-south and interspersed occasionally by large (sub-sea) mountains. Some might view this as a rather uniform landscape, with little physical variety, and therefore with little faunal change. However, it is known that major faunal changes occur depending for instance on distance from land, increasing depth and surface water productivity. The latter two drivers, in particular, have a profound effect on how food reaches the seafloor, controlling deep-sea food chains and species assemblages. An apparently uniform landscape therefore can have considerable biological variety.

One of the first studies of biodiversity across the expanse of the CCZ was reported to the ISA in 2007 (ISA 2008a). This study stressed the need for much better spatial sampling and coordination of science in the CCZ, in particular in relation to biodiversity, heterogeneity of habitats, geographic ranges of species and connectivity between populations. Smith et al. (2008) found that there was not a single deep-sea biological assemblage across the entire CCZ, but that species distributions varied on scales of 1000 km or less. It was proposed that strong gradients of sea surface primary productivity both from east to west and from north to south were a major driver of change in species. These gradients, and their effect on the downward flux of organic matter in the water column to the seafloor, had a strong influence on biomass, biodiversity, species composition and reproduction. Following the precautionary principle Smith et al. (2008) recommended that nine large areas of seabed should be set aside to preserve regional biodiversity. Discussions at the International Seabed Authority used the recommendations to create an Environmental Management Plan (EMP) for the CCZ including nine Areas of Particular Environmental Interest (APEI) (see Fig. 11.4).

Major design constraints of the APEIs were that each area should be large enough to sustain naturally reproducing populations and be unaffected by any sediment plumes caused by mining operations. While the primary aim of the APEIs is to conserve regional biodiversity (i.e. to ensure no species would be made extinct), the areas might also sustain populations from which recolonisation of impacted areas might occur once mining had ceased.

Each APEI is 200 × 200 km in size, an area large enough to preserve regional biodiversity and allow for reproductively viable populations. In addition, protection from sediment plumes was provided by adding a buffer zone of 100 km. It was estimated that 99% of the particles would likely to deposit from plumes within 1 month within 100 km of the mining activity (Rolinski et al. 2001). Each area set aside therefore was 400 × 400 km. Considerable developments in numerical oceanographic models have occurred in recent years. In reviewing the EMP for the CCZ, therefore, new physical oceanographic numerical modelling of plume behaviour might be employed to verify the size of the buffer zones.

In addition contractors to the ISA have been gathering environmental baseline information in the CCZ as part of their contractual commitments. Gradually environmental data are being submitted to the Authority, but very few data have been published (Lodge et al. 2014). This makes the creation of regional strategic environmental management plans very difficult. There is a great need of many more data, standardised to common formats to be submitted and made available to society at large.

11.2.2 The Impact of Sediment-Laden Plumes in Mid-Water

In addition to plumes created by mining activities at the seabed, discharge plumes will be created by the return of excess water following initial processing of the ore slurries and dewatering on board the surface vessel, and by return of excess water when the ore slurries are transported from the mother ship to the transport barges. ISA regulation ISBA-16/LTC/7 (ISA 2010) suggests that the discharge plumes should be injected below the thermocline and oxygen-minimum-zone, which could be as deep at 1500 m in the CCZ. These plumes may contain much less particulate material than the seabed plumes but the particles are likely to be very small (<8 μm), and thus they will deposit more slowly and be capable of travelling greater distances perhaps even 1000s km depending on their release depth and the temperature differences between the released water and the ambient conditions. They may have an impact on local mid water ecosystems—many gelatinous zooplankton in the mesopelagic and bathypelagic zones filter feed and their feeding may be affected by the increased particle content. Good control of operations at the sea surface will be required to restrict the introduction of cold, nutrient rich water at the sea surface which has the potential to change phytoplankton production and hence surface water ecosystems (ECORYS 2014).

11.2.3 Slow Recovery Potential of Seabed Ecosystems

One of the major concerns about nodule mining is the potential for recovery of ecosystems once mining ceases. A number of experiments have been carried out where the seabed has been disturbed in areas containing nodules. The experiments removed the nodules, fauna attached to the nodules, and organisms in the sediment, partially compacting the seabed and covering adjacent areas with re-sedimented deposits. The DISCOL experiment was carried out in 1989 in the Peru Basin in the Pacific following a pre-disturbance baseline study (Thiel et al. 1992). The site was revisited four times up to 1976 to assess recovery (Bluhm 2001). Results show limited recovery of the sessile (nodule attached) megafauna in terms of both taxa and individuals. However a reduced number of mobile megafauna taxa did return over the 7-year period. In a recent study Vanreusel et al. (2016) have shown that epifaunal abundance is at least 250% higher in areas covered by dense nodule fields compared to areas where nodules are absent or in low density. Some taxa (such as alcyonaceans and antipatharian corals) are virtually absent from nodule-free areas. Furthermore, surveys along tracks from experimental mining simulations conducted up to 37 years previously, suggest that the recovery of epifauna is exceptionally slow within the mined areas.

11.2.4 Noise and Light

Many marine animals use sound as their primary mode of communication and since sound travels more than four times faster underwater than in air, and absorption is less compared to air, human-generated sound can be a major issue (WODA 2013; Chap. 24). Noise and vibration together can affect the auditory senses and systems of some animals. There can be direct damage to animals, discomfort that might cause avoidance reactions, or an increase in background noise that can interfere with communication between animals or limit their ability to detect prey (Popper and Hastings 2009). Deep-sea mining will introduce noise and vibration from (1) seabed production tools, (2) midwater pumps used to transfer ores to the surface ship and (3) from the surface ship itself. At the seabed the noise introduced by the nodule harvester could impact invertebrates and fish as well as noise generated by nodule crushers, if these are used. In midwater invertebrates and fish could be impacted by noise and vibration from the vertical transport system and the pumps placed different depths along the pipe. Such a line source of noise can increase the potential for propagation to greater distances. In depths shallower than about 1000–2000 m marine mammals could also be affected.

The surface vessel may become a major source of sound, which is generated from a variety of sources including propellers for dynamic positioning of the ship, engines and generators, and hydraulic pumps plus noise related to transfer of nodules to barges. In addition to propeller and machinery noise, the ship is likely to have several sources of high-intensity sound, such as echo sounders, ADCPs, Doppler log and acoustic pingers to assist in dynamic positioning of the ship and collector system. The fact that the ship will operate almost continuously for many years may also be a factor that needs to be assessed.

Light can attract or repel some animals depending on species and bright lights can even blind some species. Strong light can have an effect on birds as well as near surface marine animals.

The effects of light and noise on deep-sea animals is not well known and will need to be monitored. However, the location of nodule-rich areas in oligotrophic regions distant from ocean margins, and the low abundances of fauna typical of these low productivity zones, means that impacts from noise and light are likely to be less important than in other regions.

11.2.5 Mitigation of Impacts

In land-based mining restoration of ecosystems in impacted areas is common practice. It is unlikely that restoration could be considered in nodule areas, such as the CCZ, owing to the lack of comprehensive species inventories and knowledge of food webs. However, a number of possible engineering solutions have been suggested to at least reduce the impact or improve recovery. One possibility is to reduce compaction caused by the weight of the mining vehicle on the seabed, or at least to lightly decompact the sediment at the rear of the vehicle. This may enhance the potential of infaunal organisms to recolonise. However if deeper sediments with lower organic content are entrained into surface sediments this may still affect the potential of recovery by the microbiota and meiofauna.

A significant proportion of the animals are dependent on the nodules, which create a hard substrate. They will not return for millions of years until the nodules are formed. Mitigation options could include leaving some tracks of unmined nodules or not harvesting the small or very large nodules—though it would be necessary to ascertain that these remained on the seabed and did not become buried. Spreading manufactured replacement nodules or briquettes is an option that would provide hard substrate. These could even contain a significant proportion of manganese, since much of the recovered manganese will be a waste product.

Reducing the volume of the seabed plume and its spread would probably have the greatest beneficial mitigation effect because plumes have the potential to impact habitats at considerable distances from the nodule harvesting sites. For the returned water plume—returning this as deep as possible in the water column would reduce midwater impacts, though potentially increase the impact on benthic and bentho-pelagic communities. Reducing the particle size in the plume and total volume of particles would reduce potential impacts.

Other measures that might be used include spatial management measures such as set aside Marine Protected Areas (e.g. Areas of Particular Environmental Interest) (see Lodge et al. 2014). These should be as close to the harvesting areas as possible, to allow for recolonisation potential, but need to remain unaffected by mining activities e.g. the plumes. Attention should be given to the representativeness, adequacy, resilience, and connectivity of a network of areas (UNEP-WCMC 2008). Due to the very long term over which recovery is expected to take place such areas of protection will also need to be in place for the very long term (Clark and Smith 2013).

11.3 Cobalt Crusts

Cobalt crusts are formed on bare rock surfaces in the ocean by the precipitation of minerals from seawater. Crusts form layers up to 25 cm thick on rock surfaces and can extend for many square kilometres in water depths ranging from 400 to 4000 m. The thickest and most economically interesting crusts form on the outer rims and saddles of seamount summits in water depths ranging from 800 to 2500 m (Hein and Koschinsky 2014). It is estimated that in the Pacific Ocean, there are more than 11,000 seamounts (57% of the global total) and 41,000 knolls (Yesson et al. 2011, estimated from the latest global bathymetry) (Fig. 11.7).

The main minerals of interest are cobalt, copper and nickel. Rare Earth Elements may also be recovered. The first exploration contracts for crusts in international waters were allocated by the ISA in 2014. There are now 4 contracts awarded or pending. Each contract for exploration of crusts can include up to 150 blocks, each block no greater than 20 km^2, and set within a rectangular or square area no more than 3000 km^2.

Cobalt crust mining machines present a technological challenge since the ore is bound to the underlying rock surface, which may be very irregular. Thus the mining machine needs to determine the crust thickness just ahead of the cutters and adjust the depth of cut continuously to match this thickness. Any inclusion of underlying rock will diminish the grade of the ore. This presents a major technological challenge (Hein et al. 2013). The ore will then be passed to the riser pipe and transported to the overlying ship as a slurry. At this point it will be dewatered and transferred to barges to be transported to shore. The recovered water will be filtered to remove the larger particles and then returned to the ocean. Figure 11.8 shows an idealised concept for cobalt crust mining.

The main environmental concerns with mining cobalt crusts on seamounts are:

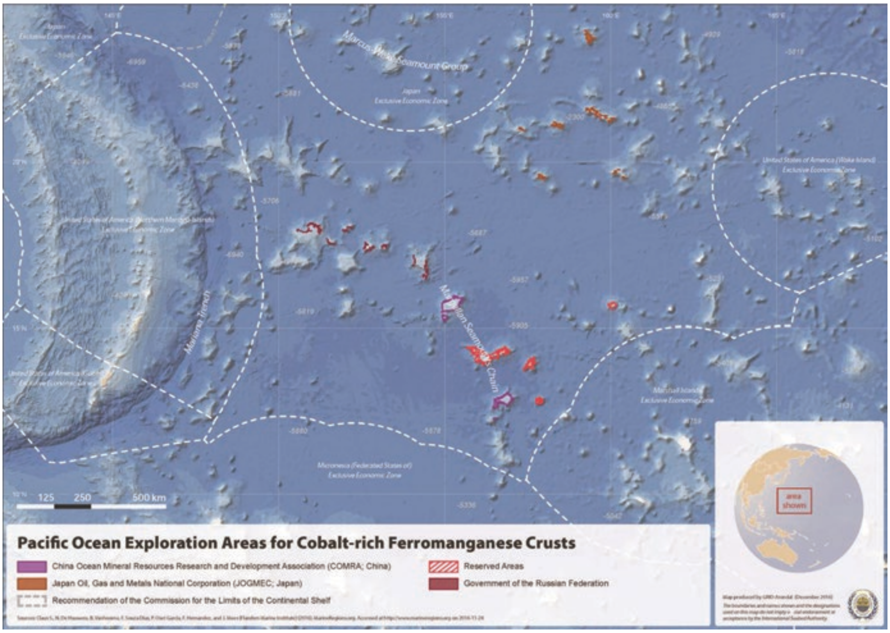


Fig. 11.7 Pacific Ocean exploration areas for cobalt-rich crusts on seamounts and guyots in the Pacific Ocean. (ISA www.isa.org.jm/sites/default/files/maps/pacocean-all-area.jpg)

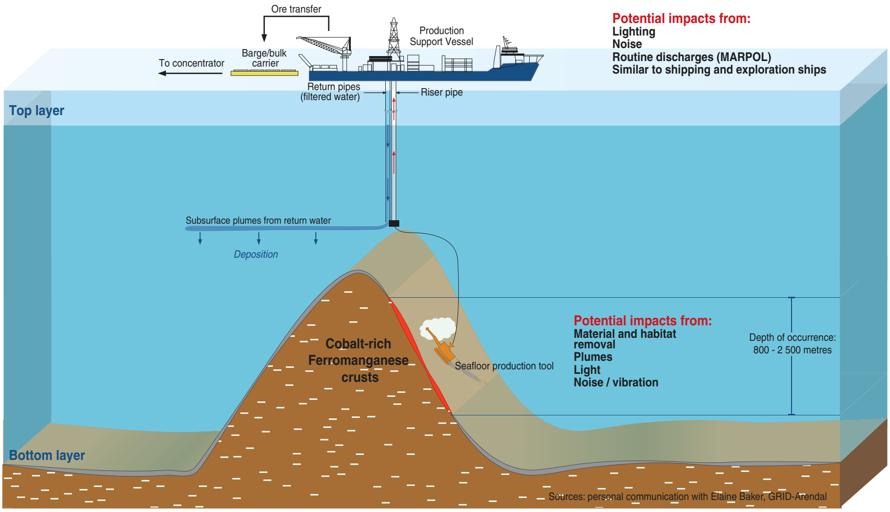


Fig. 11.8 Sea-floor cobalt crust mining system and related sources of potential environmental impact. *Courtesy GRID-Arendal*

11.3.1 Potential Widespread Habitat Destruction in Areas with Fragile and Poorly Understood Ecosystems

Cobalt crusts are essentially a two-dimensional deposit, the same as for manganese nodules. It has been estimated that for each operation, mining 2 million tons of ore per year, an area of 26–77 km^2 would be needed per annum for the operation to be cost effective (ISA 2008b).

The ecosystems that would be affected by mining cobalt crusts are quite different to those that exist in the nodule areas. They consist of seamount faunas comprised of many species most of which are attached to the hard substrate (Fig. 11.9), as well as species that live in adjacent sedimented areas. Species composition will vary with water depth down the flanks of a seamount. Some seamounts are known to be areas of high species richness (Taranto et al. 2012). They can attract fish aggregations (Morato et al. 2010; Litvinov 2007) and depending on the summit depth and the biogeographical setting might attract marine mammals (Kaschner (2007) and turtles (Santos et al. 2007). As with nodule areas knowledge of seamount ecosystems remains extremely limited (Clark et al. 2012).

The isolated nature of many seamounts, although often occurring in groups or chains, led to various hypotheses that seamounts were hotspots of diversity, abundance, biomass and endemism. In many ways these views were built on what was known about island biogeography (McClain 2007). Subsequent sampling, however, has challenged these initial thoughts, and today the 'distinctness' of assemblages on seamounts is unproven (McClain 2007; Rowden et al. 2010). Other sources claim that while many species are shared with other deep-sea habitats such as continental slopes and banks, seamount assemblages may have a different community structure (Clark et al. 2012). Seamounts are very poorly sampled and genetic studies of connectivity show a variety of patterns depending on the taxon studied (Shank 2010; Baco and Cairns 2012; Bors et al. 2012; O'Hara et al. 2014).

The lack of comprehensive data has led to generalisations about seamounts as a whole, which probably apply only to a subset, depending in part on the biogeographical province in which they occur (McClain 2007; Clark et al. 2012). A major step forward has been made, however, in compiling a relational database of geomorphological, physical oceanographic and biological characteristics of seamounts, with strict quality control and a measure of confidence in the data (Kvile et al. 2013). These data have highlighted that the degree of knowledge decreases very markedly with increasing depth of and on the seamount. The level of knowledge of seamount ecosystems at depths at which cobalt crusts may be mined is extremely limited.

Cobalt crusts may also occur on large ridge like features on the seafloor, such as the Rio Grande Rise off Brazil (Perez et al. 2012). Recent research on non-hydrothermal vent fauna on seamounts along the Mid Atlantic Ridge (MAR) in the North Atlantic has shown large-scale similarity of fauna between the MAR and fauna found on the European and North American continental margins at bathyal depths (200–3000 m) (Priede et al. 2013). It is likely therefore that benthic fauna are widely distributed within any one particular ocean basin, although there may be differences between ocean basins.

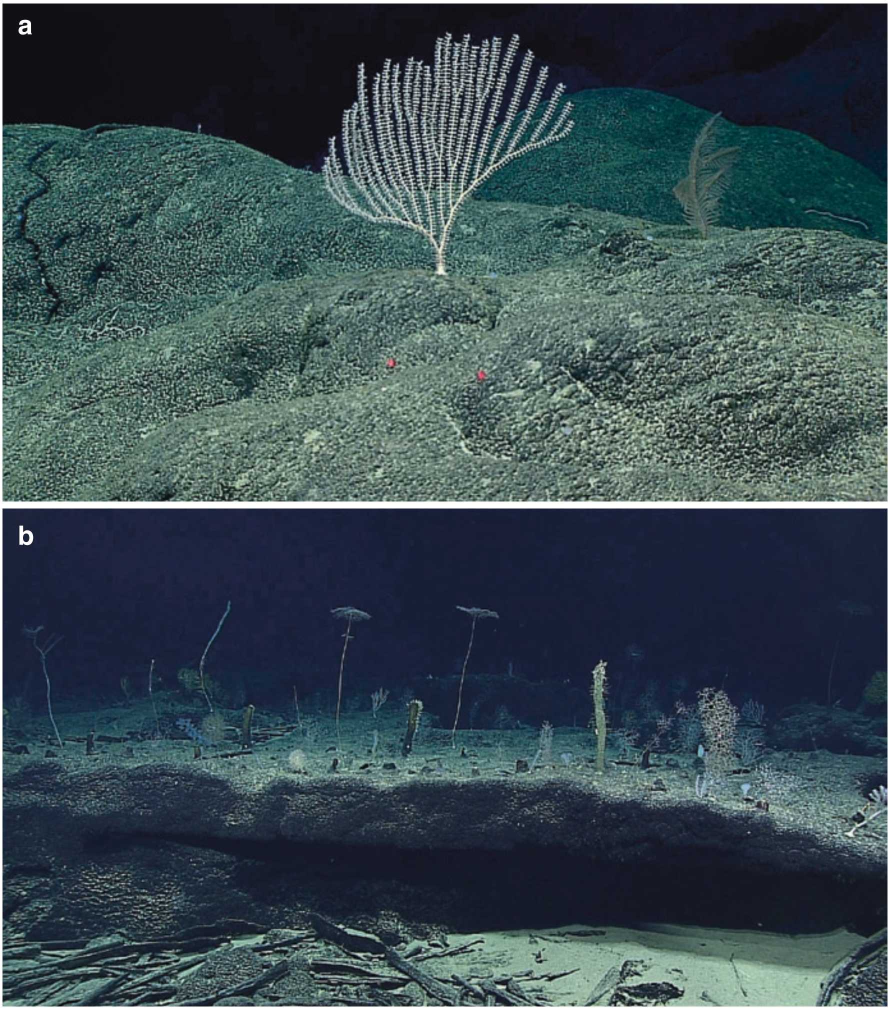


Fig. 11.9 Fauna attached to manganese crust (primnoid octocoral) on two seamounts in the western Pacific. *Images courtesy of the NOAA Office of Ocean Exploration and Research, 2016 Deepwater Exploration of the Marianas*

Mining crusts would involve removing the relatively thin layer of ore from the underlying rocky surface. While the technology to undertake this has not been established, it is generally considered that it will involve grinding or scraping the crust off. This is a difficult process owing to the lack of uniformity in the thickness of the crust and physical conditions likely to occur at the mine sites: fast currents, steep inclines and rugged geomorphology. However, initial cobalt crust mines are likely just to mine the tops of guyots or the upper flanks of a seamount where slopes are reduced. Removing the crust will destroy all the sessile organisms. It is thought that the marine life on the rocky surfaces may recolonize, but this may occur over very long timescales (Rowden et al. 2010).

Insufficient knowledge of recovery times for seamount species and ecosystems once mining has ceased is also an issue. Corals on seamounts at depths where mining may occur may be as old as 2300 years (Carreiro-Silva et al. 2013). Williams et al. (2010) report that seamounts off New Zealand and Australia, which were heavily impacted by bottom trawling, have not shown much evidence of recovery 10 years after trawling has ceased.

11.3.2 The Impact of Sediment-Laden Plumes

The issues with sediment laden plumes are similar to those described for nodule areas. However, the steep slopes on the flanks of many seamounts are likely to enhance the downslope flow of mining-generated plumes along the seabed, considerably increasing the impacted area. Since many ecosystems are depth zoned a range of different ecosystems could be impacted, including ecosystems not actually mined. This is of particular concern on seamounts as many of the taxa found are suspension feeders. Clogging of feeding mechanisms may have a wide variety of lethal and sub-lethal effects. This is also true for midwater gelatinous zooplankton, which may be affected by intermediate nepheloid layers.

11.3.3 Possible Toxic Impacts to Seabed Fauna

Cobalt crusts are inert until they are mined. However, the mining process will involve grinding the crust to prepare it for transport up the riser pipe. This process has the potential to release toxins into the environment, but no studies have been carried out to determine what elements might be released during cobalt crust mining.

11.3.4 Noise and Light

The effects of noise and light during mining of cobalt crusts will be similar to those described for manganese nodule mining. However, seabed noise may be greater because the crusts will need to be ground from the seamount surface. In addition, the mining of crusts is expected to take place in water depths that are within the depth range of marine mammals. While crusts of commercial interest occur on seamounts in largely oligotrophic surface waters, and hence biomass of benthic fauna is likely to be low, many shallower seamounts may attract pelagic communities and so serve as a focal point for marine mammals.

11.3.5 Mitigation of Impacts

Reduction in the volume and spread of plumes generated by the mining vehicle will reduce the impact on organisms in areas adjacent to the mine site. For the returned water plume—returning this as deep as possible in the water column would reduce the midwater impacts, though potentially increase the impact on benthic and bentho-pelagic communities. It is unlikely that measures to rehabilitate impacted areas will be possible and so spatial management measures will be important. Areas adjacent to the mine sites and with similar faunal communities at all depths should be selected for long-term protection. This may require whole seamounts currently under contract for exploration to be protected, especially those that will not be affected by plumes from mining activities (see Clark and Smith 2013).

11.4 Polymetallic Sulphides

Polymetallic sulphides are distributed as localized precipitate deposits at hot springs on volcanic spreading centres (mid-ocean ridges) of oceanic plate boundaries, in water depths from 500 to 5000 m. Hot springs form where seawater is drawn into cracks and fissures in the seabed; water-rock reactions at depth under high temperature and pressure result in hot, acidic fluids rich in hydrogen sulphide and dissolved metals. Metal sulphides precipitate when these thermally buoyant fluids reach the seabed and react with seawater and form hydrothermal chimneys (Fig. 11.10).

Mid-ocean ridges that host hydrothermal vents are linear features and make up a relatively small proportion of the ocean floor. Areas of active venting, where mineral exploration is currently concentrated, cover even smaller areas. Over time (thousands of years), the build-up of particulate sulphides, collapsed chimneys and other mineral debris can form large mounds of metal-sulphide-rich material. Sulphide deposits form as localized, 3-dimensional bodies (unlike crusts and nodules). Deposits of this type can range in size from several thousand to several million tonnes. The seafloor area impacted per million tons of produced ore is small, on the scale of one or a few football pitches. It is estimated that around 600 million tonnes of massive sulphide deposits occur within the easily accessible neovolcanic zone of mid-ocean ridges and ridges of plate boundaries in so-called back-arc basins (Hannington et al. 2011a) (Fig. 11.11). Potentially a greater number of large SMS deposits exist in areas distant from the plate boundaries. They were produced by previous periods of volcanism and hydrothermal activity (Hannington et al. 2011b). These off-axis deposits have the potential to be large 3-dimensional ore bodies comparable to those exploited on land, but improvements in technology are needed to locate the deposits, which likely are covered by some metres of sediment.

Polymetallic sulphide deposits on ocean ridges are classified broadly into two categories: (1) those associated with active hydrothermal systems that support specialist chemosynthesis-based food webs, where biomass is typically dominated by

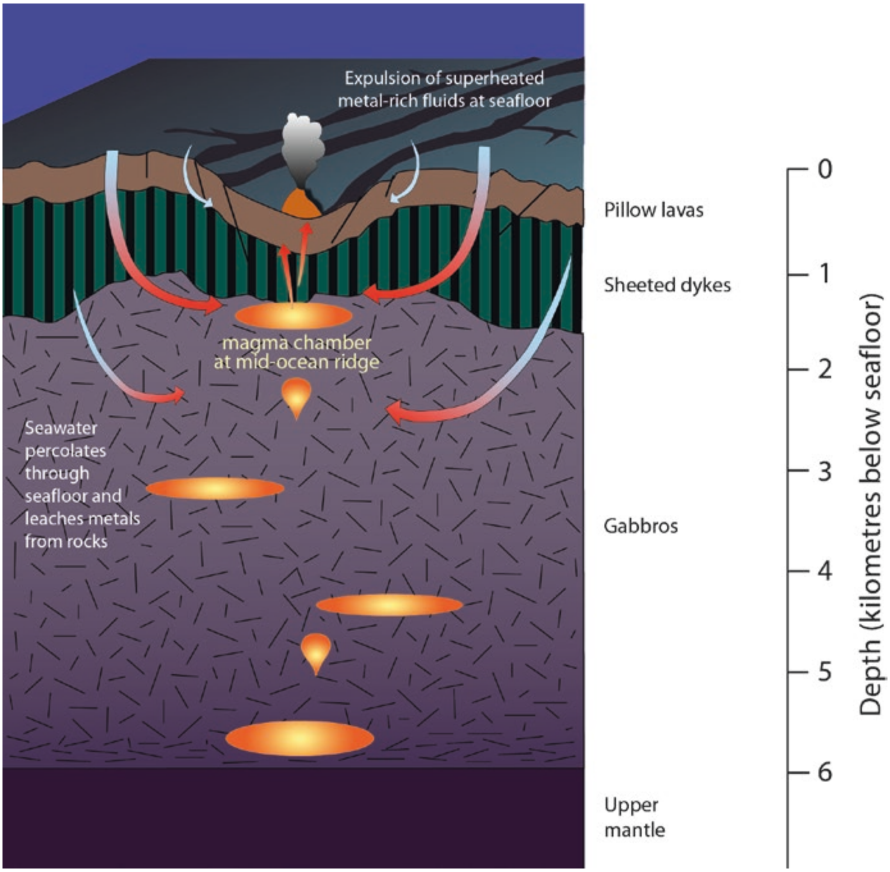


Fig. 11.10 Schematic diagram of hydrothermal vent system

invertebrates that host chemoautotrophic symbionts dependent on venting fluids (Van Dover 2000), and (2) inactive vents, where relatively sparse fauna more typical of hard bottom deep-sea fauna are observed (Boschen et al. 2013; Erickson et al. 2009).

As noted above, Nautilus Minerals plans to mine SMS deposits in the Bismarck Sea (Manus Basin back-arc spreading center) off Papua New Guinea. Their licence area includes the Solwara 1 and Solwara 12 vent fields and contains 2.5Mt of indicated and inferred ore (Lipton 2012). This is a very small by comparison to land-based mines. However, the grade of the Solwara 1 ore (8.1% Cu, 6.4 g/t Au and 34 g/t Ag) is higher than that found in many terrestrial mines (Lipton 2012).

Nautilus Minerals plans to use three different seabed vehicles—an auxiliary cutter to cut flat benches in the seabed, a bulk cutter to mine the benches in a similar fashion to open cast mining on land, and a collector to collect the mined material and pass it to the riser pipe. The ores will be pumped up the riser pipe to the surface ship where they will be dewatered and offloaded into barges for transport to shore.

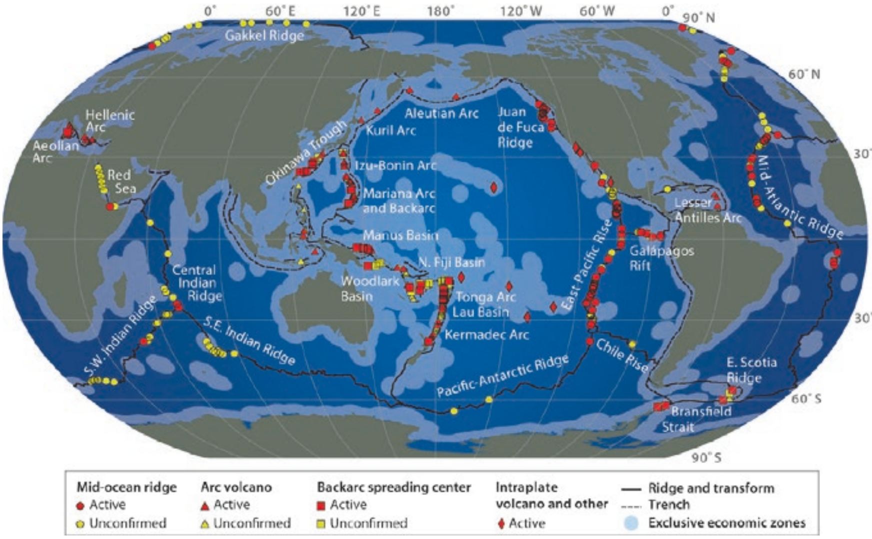


Fig. 11.11 Global distribution of seafloor hydrothermal systems and related mineral deposits. Version 2.0 of the InterRidge Global Database (Beaulieu 2010) used in this study contains information on 554 sites of seafl oor hydrothermal activity (confirmed and unconfirmed) and inactive deposits. About 300 are sites of high-temperature hydrothermal venting; 165 are confirmed sites of massive sulfide accumulation (Table DR1 [see footnote 1]). Credits: S. Beaulieu, K. Joyce, and S.A. Soule (Woods Hole Oceanographic Institution). (From Hannington et al. 2011a). *Courtesy Geological Society of America*

The recovered water will be filtered to remove the larger particles and returned to the ocean. Figure 11.12 shows an idealized scenario for polymetallic sulphide mining.

The main environmental concerns for polymetallic sulphide mining associated with active vent ecosystems are:

11.4.1 Habitat Destruction and Modification

Extraction methods for polymetallic sulphides are expected to be the underwater equivalent of terrestrial open-cut mining (Van Dover 2011), with loss of habitat and associated organisms, degradation of habitat quality (altered topography, substrata, etc), and modification of the fluid flux regime (flow rates, distribution, chemistry) [(Halfar and Fujita 2007); reviewed in (Van Dover 2014a)]. Communities at active hydrothermal vents (Fig. 11.13) are adapted to disturbance, but the scale, frequency, and intensity of disturbance are not the same everywhere on the mid-ocean ridge system. While there is an expectation of rapid recovery of vent communities following a major disturbance such as a volcanic eruption (e.g., Lutz et al. 1994), the

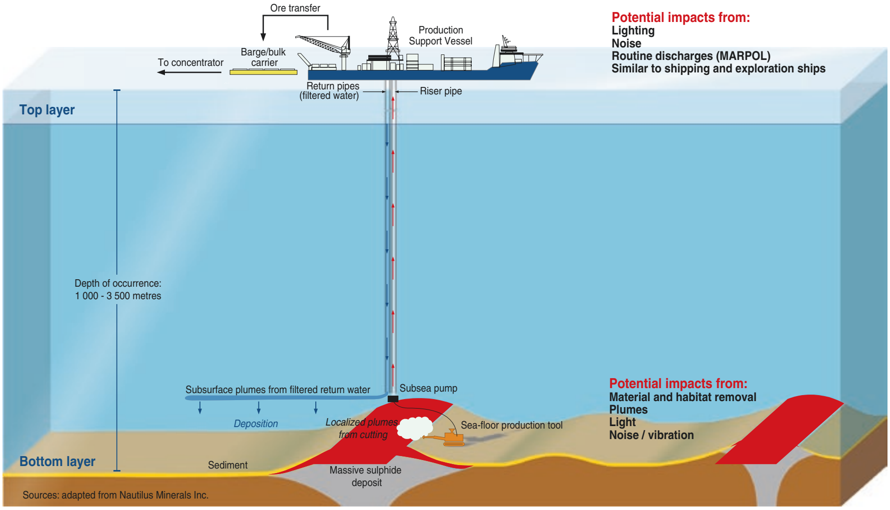


Fig. 11.12 Example of a sea-floor massive sulphide mining system and related sources of potential environmental impact. *Courtesy GRID-Arendal*

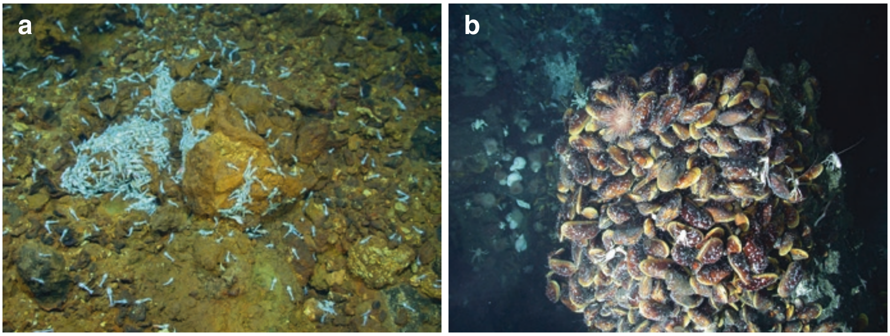


Fig. 11.13 Images of faunas on active hydrothermal vents (**a**) Mid-Cayman Spreading Center hydrothermal vent; diffuse flow habitat. Shrimp (*Rimicaris* spp.) typically dominate hydrothermal vents in the Atlantic Basin. These shrimp have an unusual photoreceptor in their cephalothorax that is derived from a normal shrimp eye; this photoreceptor likely detects dim light that is emitted by high-temperature fluids escaping from the black smoker chimneys on which they typically live in dense 'swarms'. These shrimp feed on symbiotic bacteria that grow on the exoskeletal surfaces of the branchial chamber. Photo courtesy CLVD; obtained by the ROV Jason, operated by the Woods Hole Oceanographic Institution. (**b**) Lau basin diffuse flow habitat. Mussels (*Bathymodiolus* sp.), squat lobsters (*Munidopsis* sp.), and brachyuran crabs (*Austinograea* sp.) on a sulfide mound. The mussels rely on symbiotic bacteria in their gill tissues for their nutrition. Photo courtesy CLVD; obtained by the ROV Jason, operated by the Woods Hole Oceanographic Institution

process and cadence of disturbance and recovery is not documented for all styles of venting and types of communities. For active hydrothermal systems where fluid chemistry is secondarily altered as fluids diffuse through the stockwork, as observed at the TAG mound, for example (Tivey 2007), removal of that stockwork could influence the rate and character of ecosystem recovery. Thus there remains some uncertainty about the response of a vent ecosystem to a mining event.

11.4.2 Cumulative Impacts, Biodiversity Loss, and Alternate States

Most invertebrate taxa that depend on chemoautotrophic symbionts at active hydrothermal settings are considered endemic to the vent environment, although some may be more generalist and able to colonize other sites where there are sources of reduced chemical compounds to support microbial redox reactions (Portail et al. 2015; Watanabe et al. 2010). Destruction of high-density, local populations of these and other taxa at an active hydrothermal vent would eliminate brood stock that contributed to the maintenance of a metapopulation. A single mining event (i.e. removal of a single hydrothermal deposit) may not affect source-sink dynamics metapopulations, except in areas where current flow was predominantly in one direction thus influencing the dispersal of propagules. In such a case the destruction of a local population as a critical source of propagules may have a large effect.

Cumulative impacts from multiple mining events in a region could reduce the size of the brood stock and connectivity to levels that do not allow populations to survive, leading to biodiversity loss and alternate ecosystem states (i.e. shifts in community structure and function) Osman et al. 2010). As in terrestrial and shallow-water ecosystems (Selkoe et al. 2015) there will be a tipping point for species and ecosystems beyond which metapopulations are unable to recover. These tipping points are difficult to anticipate in terrestrial systems; the challenge of recognizing deep-sea ecosystems at risk from cumulative impacts is even more daunting. This is especially important in the deep sea where the financial and logistical challenges of discerning population dynamics, and processes influencing those dynamics, at depth and in remote geographic regions is very difficult.

11.4.3 Sediment Plumes and Ecotoxicology

Active hydrothermal vents spew dissolved and solid-phase metals into the water column, including copper, copper-mineral, and copper-organic complexes, among others (Sander and Koschinsky 2011). These metals are deposited and accumulate on the seafloor to form the ore body and a depositional apron. Copper is one of the most toxic metals to marine invertebrates (Eisler 1998). However, copper bioavailability in the water column and sediments is buffered by the copper-complexation capacity of the system (Rivera-Duarte et al. 2005). Elevated metal toxicity and mortality of (or sublethal effects on) pelagic and infaunal organisms is a potential consequence of seabed mining of polymetallic sulphides where fine particles are dispersed into the water column during cutting and lifting operations. Experimental approaches may be used but it is challenging to undertake toxicity tests that mimic expected conditions, exposures, and target organisms in the deep sea (Simpson and Spadaro 2016). While habitat destruction and modification and cumulative impacts will certainly occur and can be mitigated for, toxicological effects of on pelagic and infaunal organisms due to mining of polymetallic sulphides and the generation of sediment plumes are largely unknown.

11.4.4 Light Pollution

Light pollution is a special environmental concern for active hydrothermal vents colonized by shrimp (and potentially other organisms) with novel photoreceptors (Van Dover et al. 1989). Shrimp are thought to be adapted to detecting ambient light from high-temperature vents (Van Dover et al. 1996). High intensity visible light is known to damage the rhabdom of shrimp eyes (Herring et al. 1999; O'Neill et al. 2009). Although the damage is thought to be irrecoverable (Chamberlain 2000) the ecological consequence of 'blindness' in shrimp is uncertain. Shrimp populations at the TAG hydrothermal site on the Mid-Atlantic Ridge have been qualitatively examined on multiple occasions. Despite numerous visits by submersible systems with high intensity lights and the potential for cumulative impacts resulting from light (and drilling) disturbances (Copley et al. 1999) there has been no indication of decreasing abundances (Copley et al. 2007).

11.4.5 Mitigation of Impacts

Mitigation of environmental impacts at hydrothermal vents is arguably more plausible for ecosystems associated with polymetallic sulphides than other deep-sea mineral resources, given the localized scale of impact and potential for rapid, 'passive' (without human intervention) recovery following disturbance. Consideration should be given to marine spatial planning including marine protected areas (Van Dover et al. 2012) to facilitate recovery and aid restoration approaches (Van Dover et al. 2014b). Such actions will avoid and minimize impacts from SMS mining. However there remain many uncertainties with regard to the efficacy of any mitigation approach.

While hydrothermal vent communities present a special management problem, off-axis SMS mining has the potential to impact a much wider array of marine organisms attached to rock surfaces and within sediments associated with ridge systems. Typically the SMS deposits will occur in areas of complex geomorphology and at a variety of depths. As for cobalt crusts, described above, therefore, there are many potential impacts possible in the vicinity and downslope from the mining activity.

11.5 Conclusions

Man is poised to begin exploitation for minerals in previously untouched areas of the planet, namely the deep sea floor. Mining for cobalt crusts and manganese nodules will strongly differ to mining on land because the minerals lie in very thin layers on the seabed and hence large areas will need to be mined to be profitable. The most promising targets lie in remote areas of the oceans, particularly the Clarion Clipperton Zone of the central Pacific and seamounts in the northwest Pacific. Ecosystems in these areas, and many other deep-sea areas are poorly understood due to this remoteness and their complexity. Many uncertainties remain as to the impact of this mining but widespread habitat loss will be inevitable, albeit in an environment where the faunas are often sparse, such as much of the CCZ. Mining for polymetallic sulphides will be more comparable to mining on land because the deposits are three-dimensional. Thus the degree of habitat loss will be less and some hydrothermal faunas are likely to recolonise quickly. Nevertheless, the generation of seabed plumes of particle charged and potentially toxic material could impact significantly wider areas that those mined. Reduction of plume volume and spread should be seen as a priority. In addition, a precautionary approach will be needed with many areas set aside for protection and regional plans put in place before mining begins.

Acknowledgements P.P.E. Weaver and D.S.M. Billett acknowledge funding from the European Union Seventh Framework Programme (FP7/2007-2013) under the MIDAS project, grant agreement n° 603418.

References

Baco A, Cairns SD (2012) Comparing molecular variation to morphological species designations in the deep-sea coral *Narella* reveals new insights into seamount coral ranges. PLoS One 7(9):e45555

Batker D, Schmidt R (2015) Environmental and social benchmarking analysis of the nautilus minerals Inc. Solwara 1 Project. Nautilus Document Reference SL01-NMN-XEE-RPT-0180-001 http://www.nautilusminerals.com/irm/content/pdf/eartheconomics-reports/earth-economics-may-2015.pdf. Accessed 30 Nov 2016

Beaulieu SE (2010) InterRidge Global Database of Active Submarine Hydrothermal Vent Fields: prepared for InterRidge, Version 2.0. World Wide Web electronic publication. http://www.interridge.org/IRvents

Bertram C, Krätschell A, O'Brien K, Brückmann W, Proelss A, Rehdanz K (2011) Metalliferous sediments in the Atlantis II Deep-Assessing the geological and economic resource potential and legal constraints. Res Policy 36:315–329

Bluhm H (2001) Re-establishment of an abyssal megabenthic community after experimental physical disturbance of the seafloor. Deep-Sea Res II Top Stud Oceanogr 48:3841–3868

Bors EK, Rowden AA, Maas EW, Clark MR, Shank TM (2012) Patterns of deep-sea genetic connectivity in the New Zealand region: implications for management of benthic ecosystems. PLoS One 7(11):e49474

Boschen RE, Rowden AA, Clark MR, Gardner JPA (2013) Mining of deep-sea seafloor massive sulfides: a review of the deposits, their benthic communities, impacts from mining, regulatory frameworks and management strategies. Ocean Coast Manag 84:54–67. doi:10.1016/j.ocecoaman.2013.07.005

Carreiro-Silva M, Andrews AH, Braha-Henriques A, de Matos A, Porteiro FM, Santos RS (2013) Variability in growth rates of long-lived black coral Leiopathes sp. from the Azores. Mar Ecol Prog Ser 473:189–199

Chamberlain SC (2000) Vision in hydrothermal vent shrimp. Philos Trans R Soc Lond Ser B Biol Sci 355:1151–1154. doi:10.1098/rstb.2000.0657

Chung JS (2009) Deep-ocean mining technology III: developments. Proceedings of the Eighth ISOPE Ocean Mining Symposium, Chennai, India, September 20–24, 2009, pp 1–7

Clark M, Smith S (2013) Environmental management considerations. In: Baker E, Beaudoin Y (eds) Deep sea minerals: cobalt-rich ferromanganese crusts, a physical, biological, environmental, and technical review, vol 1C. SPC-Grid Arendal, Arendal, pp 23–40

Clark MR, Schlacher TA, Rowden AA, Stocks KI, Consalvey M (2012) Science priorities for seamounts: research links to conservation and management. PLoS One 7(1):e29232. doi:10.1371/journal.pone.0029232

Copley JTP, Tyler PA, Dover CLV, Schultz A, Dickson P, Singh S (1999) Subannual Temporal Variation in Faunal Distributions at the TAG Hydrothermal Mound (26 N, Mid-Atlantic Ridge). P.S.Z.N. Mar Ecol 20:291–306

Copley JTP, Jorgensen PBK, Sohn RA (2007) Assessment of decadal-scale ecological change at a deep mid-Atlantic hydrothermal vent and reproductive time-series in the shrimp Rimicaris exoculata. J Mar Biol Assoc UK 87:859. doi:10.1017/S0025315407056512

Ecorys (2014) Study to investigate the state of knowledge of deep-sea mining—Final report & Annexes, European Commission, DG Maritime Affairs and Fisheries, Available at https://webgate.ec.europa.eu/maritimeforum/sites/maritimeforum/files/FGP96656_DSM_Final_report.pdf. Accessed 2 Feb 2016

Eisler R (1998) Copper hazards to fish, wildlife, and invertebrates: a synoptic review. Biological Science Report USGS/BRD/BSR—1997-0002 Contaminant Hazard Reviews

Erickson KL, Macko S a, Van Dover CL (2009) Evidence for a chemoautotrophically based food web at inactive hydrothermal vents (Manus Basin). Deep-Sea Res II Top Stud Oceanogr 56:1577–1585. doi:10.1016/j.dsr2.2009.05.002

Halfar J, Fujita RM (2007) Danger of deep-sea mining. Science 316:987

Hannington MD, Jamieson J, Monecke T, Petersen S, Beaulieu S (2011a) The abundance of seafloor massive sulfide deposits. Geology 39:1155–1158

Hannington MD, Jamieson J, Monecke T, Petersen S (2011b) Estimating the metal content of SMS deposits. OCEANS'11 MTS/IEEE KONA, pp 1–4

Hein JR, Koschinsky A (2014) Deep-ocean ferromanganese crusts and nodules, treatise on geochemistry. Elsevier, pp 273–291, http://linkinghub.elsevier.com/retrieve/pii/B9780080959757011116

Hein JR, Mizell K, Koschinsky A, Conrad TA (2013) Deep-ocean mineral deposits as a source of critical metals for high- and green-technology applications: comparison with land-based resources. Ore Geol Rev 51:1–14

Herring P, Gaten E, Shelton P (1999) Are vent shrimps blinded by science ? Nature 398:116

International Seabed Authority (2008a) Rationale and recommendations for the establishment of preservation reference areas for nodule mining in the Clarion-Clipperton Zone. Fourteenth session. Kingston, Jamaica, 26 May–6 June 2008. http://www.isa.org.jm/en/sessions/2008/documents: Legal and Technical Commission, International Seabed Authority. Technical document no. ISBA/14/LTC/2

International Seabed Authority (2008b) Geologic characteristics and geographic distribution of potential cobalt-rich ferromanganese crusts deposits in the Area. In: Mining cobalt-rich ferromanganese crusts and polymetallic sulphides deposits: technological and economic considerations. Proceedings of the International Seabed Authority's Workshop held in Kingston, Jamaica, 31 July–4 August 2006, pp 59–90

International Seabed Authority (2010) Recommendations for the guidance of contractors for the assessment of the possible environmental impacts arising from exploration for polymetallic nodules in the Area. ISBA/16/C/7

International Seabed Authority (2015) Status of contracts for exploration in the Area. Report of the Secretary General. ISBA/21/C/8/Rev.1

Kaschner K (2007) Air-breathing visitors to seamounts: marine mammals. In: Pitcher TJ, Morato T, Hart PJB, Clark MR, Haggan N et al (eds) Seamounts: ecology, fisheries and conservation, Blackwell fisheries and aquatic resources Series, vol 12. Blackwell Publishing, Oxford, pp 230–238

Kato Y, Fujinaga K, Nakamura K, Takaya Y, Kitamura K, Ohta J, Toda R, Nakashima Y, Iwamori H (2011) Deep-sea mud in the Pacific Ocean as a potential resource for rare-earth elements. Nat Geosci 4:535–539. doi:10.1038/ngeo1185

Kvile KO, Taranto GH, Pitcher TJ, Morato T (2013) A global assessment of seamount ecosystems knowledge using an ecosystem evaluation network. Biol Conserv. doi: 10.1016/j.biocon.2013.10.002

Lipton I (2012) Mineral Resource Estimate: Solwara Project, Bismarck Sea, PNG. Technical Report compiled under NI43-101. Golder Associates, for Nautilus Minerals Nuigini Inc. 218pp

Litvinov F (2007) Fish visitors to seamounts: aggregations of large pelagic sharks above seamounts. In: Pitcher TJ, Morato T, Hart PJB, Clark MR, Haggan N et al (eds) Seamounts: ecology, fisheries and conservation, Blackwell fisheries and aquatic resources series, vol 12. Blackwell Publishing, Oxford, pp 202–206

Lodge M, Johnson D, Le Gurun G, Wengler M, Weaver P, Gunn V (2014) Seabed mining: International Seabed Authority environmental management plan for the Clarion-Clipperton Zone. A partnership approach. Mar Policy 49:66–72. doi:10.1016/j.marpol.2014.04.006

Lutz R, Shank T, Fornari D, Haymon R, Lilley M, Von Damm K, Desbruyeres D (1994) Rapid growth at deep-sea vents. Nature 371:663–664

McClain CR (2007) Seamounts: identity crisis or split personality? J Biogeogr 34:2001–2008. doi:10.1111/j.1365–2699.2007.01783.x

McMurray GR (ed) (1987) Gorda ridge: a seafloor spreading Center in the United States' exclusive economic zone Proceedings of the Gorda Ridge Symposium May 11–13, 1987, Portland, Oregon. Springer, 2012

Morato T, Hoyle SD, Allain V, Nicol SJ (2010) Seamounts are hotspots of pelagic biodiversity in the open ocean. Proc Natl Acad Sci U S A 107:9707–9711

O'Hara TD, England PR, Gunasekera RM, Naughton KM (2014) Limited phylogeographic structure for five bathyal ophiuroids at continental scales. Deep Sea Res I: Oceanogr Res Pap 84:18–28

O'Neill PJ, Jinks RN, Herzog ED, Battelle B-A, Kass L, Renninger GH, Chamberlain SC (2009) The morphology of the dorsal eye of the hydrothermal vent shrimp, Rimicaris exoculata. Vis Neurosci 12:861. doi:10.1017/S0952523800009421

Osman R, Munguia P, Zajac R (2010) Ecological thresholds in marine communities: theory, experiments and management. Mar Ecol Prog Ser 413:185–187. doi:10.3354/meps08765

Perez JAA, dos Santos Alves E, Clark MR, Aksel Bergstad O, Gebruk A, Azevedo Cardoso I, Rogacheva A (2012) Patterns of life on the southern Mid-Atlantic Ridge: compiling what is known and addressing future research. Oceanography 25(4):16–31. doi:10.5670/oceanog.2012.102

Popper AN, Hastings MC (2009) The effects of anthropogenic sources of sounds on fishes. J Fish Biol 25:455–489

Portail M, Olu K, Escobar-Briones E, Caprais JC, Menot L, Waeles M, Cruaud P, Sarradin PM, Godfroy A, Sarrazin J (2015) Comparative study of vent and seep macrofaunal communities in the Guaymas Basin. Biogeosciences 12:5455–5479. doi:10.5194/bg-12-5455-2015

Priede IG, Bergstad OA, Miller PI, Vecchione M, Gebruk A, Falkenhaug T et al (2013) Does presence of a mid-ocean ridge enhance biomass and biodiversity? PLoS One 8(5):e61550. doi:10.1371/journal.pone.0061550

Rivera-Duarte I, Rosen G, Lapota D, Chadwick DB, Kear-Padilla L, Zirino A (2005) Copper toxicity to larval stages of three marine invertebrates and copper complexation capacity in San Diego Bay, California. Environ Sci Technol 39:1542–1546. doi:10.1021/es040545j

Rolinski S, Segschneider J, Sundermann J (2001) Long-term propagation of tailings from deep-sea mining under variable conditions by means of numerical simulations. Deep-Sea Res II Top Stud Oceanogr 48:3469–3485. doi:10.1016/S0967-0645(01)00053-4

Rosenbaum H, Grey F (2015) A critique of the Nautilus Minerals environmental and social benchmarking analysis of the Solwara 1 project. https://www.earthworksaction.org/files/publications/REPORT-AccountabilityZERO.pdf. Accessed 30 Nov 2015

Rowden AA, Dower JF, Schlacher TA, Consalvey M, Clark MR (2010) Paradigms in seamount ecology: fact, fiction and future. Mar Ecol 31:226–241

Sander SG, Koschinsky A (2011) Metal flux from hydrothermal vents increased by organic complexation. Nat Geosci 4:145–150

Santos M, Bolten AB, Martins HR, Riewald B, Bjornald KA (2007) Airbreathing visitors to seamounts: sea turtles. In: Pitcher TJ, Morato T, Hart PJB, Clark MR, Haggan N et al (eds) Seamounts: ecology, fisheries and conservation, Blackwell fisheries and aquatic resources series, vol 12. Blackwell Publishing, Oxford, pp 239–244

Secretariat of the Pacific Community (2014) Deep sea minerals potential of the Pacific Islands region. Information Brochure 6. http://www.sopac.org/dsm/public/files/Deep%20Sea%20Minerals%20in%20the%20Pacific%20Islands%20Region%20Brochure%206_V2.pdf

Selkoe KA, Blenckner T, Caldwell MR, Crowder LB, Erickson AL, Essington TE, Estes JA, Fujita RM, Halpern BS, Hunsicker ME, Kappel CV, Kelly RP, Kittinger JN, Levin PS, Lynham JM, Mach ME, Martone RG, Mease LA, Salomon AK, Samhouri JF, Scarborough C, Stier AC, White C, Zedler J (2015) Principles for managing marine ecosystems prone to tipping points. Ecosyst Health Sustain 1:1–18. doi:10.1890/EHS14-0024.1

Shank TM (2010) Deep-ocean laboratories of faunal connectivity, evolution, and endemism. Oceanography 23(1):108–122

Simpson SL, Spadaro DA (2016) Bioavailability and chronic toxicity of metal sulfide minerals to benthic marine invertebrates: implications for deep sea exploration, mining and tailings disposal. Environ Sci Technol 50(7):4061–4070. doi:10.1021/acs.est.6b00203

Smith CR, Galron J, Glover A, Gooday A, Kitazato H, Lambshead J, Menot L, Paterson G, Rogers A, Sibuet M (2008) Biodiversity, species ranges, and gene flow in the abyssal Pacific nodule province: predicting and managing the impacts of deep seabed mining. ISA Technical Study no. 3, International Seabed Authority, Kingston, Jamaica

Steiner R (2009) Independent review of the environmental impact statement for the proposed Nautilus Minerals Solwara 1 Seabed Mining Project, Papua New Guinea. http://www.deepseaminingoutofourdepth.org/wp-content/uploads/Steiner-Independent-review-DSM1.pdf

Taranto GH, Kvile KØ, Pitcher TJ, Morato T (2012) An ecosystem evaluation framework for global seamount conservation and management. PLoS One 7(8):e42950. doi:10.1371/journal.pone.0042950

Thiel H, Foell EJ, Schriever G (1991) Potential environmntal effects of deep seabed mining. Berichte des Zentrums für Meeres- und Klimaforschung der Universität Hamburg, vol 26, 243pp

Thiel H, Bluhm H, Borowski C, Bussau C, Gooday AJ, Maybury C, Schriever G (1992) The impactof mining on deep-sea organisms. The DISCOL-project. Ocean Challenge 3:40–46

Tivey M (2007) Generation of seafloor hydrothermal vent fluids and associated mineral deposits. Oceanography 20:50–65

UNEP-WCMC (2008) National and regional networks of marine protected areas: a review of progress. UNEP-WCMC, Cambridge, p 144

Van Dover C (2000) The ecology of deep-sea hydrothermal vents. Princeton University Press, Princeton. doi:10.2307/177518

Van Dover C (2011) Tighten regulations on deep-sea mining. Nature 470:31–33

Van Dover CL (2014a) Impacts of anthropogenic disturbances at deep-sea hydrothermal vent ecosystems: a review. Mar Environ Res 102:59–72. doi:10.1016/j.marenvres.2014.03.008

Van Dover CL, Aronson J, Pendleton L, Smith S, Arnaud-Haond S, Moreno-Mateos D, Barbier E, Billett D, Bowers K, Danovaro R, Edwards A, Kellert S, Morato T, Pollard E, Rogers A, Warner R (2014b) Ecological restoration in the deep sea: desiderata. Mar Policy 44:98–106. doi:10.1016/j.marpol.2013.07.006

Van Dover C, Szuts EZ, Chamberlain SC, Cann J (1989) A novel eye in "eyeless" shrimp from hydrothermal vents of the Mid-Atlantic Ridge. Nature 337:458–460

Van Dover CL, Reynolds GT, Chave AD, Tyson JA (1996) Light at deep-sea hydrothermal vents. Geophys Res Lett 23:2049. doi:10.1029/96GL02151

Van Dover CL, Smith CR, Ardron J, Dunn D, Gjerde K, Levin L, Smith S (2012) Designating networks of chemosynthetic ecosystem reserves in the deep sea. Mar Policy 36:378–381. doi:10.1016/j.marpol.2011.07.002

Vanreusel A, Hilario A, Ribeiro PA, Menot L, Arbizu PM (2016) Threatened by mining, polymetallic nodules are required to preserve abyssal epifauna. Sci Rep 6:26808. doi:10.1038/srep26808

Watanabe H, Fujikura K, Kojima S, Miyazaki J-I, Fujiwara Y (2010) Japan: vents and seeps in close proximity. In: The vent and seep biota: topics in geobiology. Springer, Dordrecht, pp 379–402. doi:10.1007/978-90-481-9572-5

Williams A, Schlacher TA, Rowden AA, Althaus F, Clark MR, Bowden DA, Stewart R, Bax NJ, Consalvey M, Kloser RJ (2010) Seamount megabenthic assemblages fail to recover from trawling impacts. Mar Ecol 31:183–199. doi:10.1111/j.1439-0485.2010.00385.x

WODA (2013) Technical guidance on underwater sound. http://www.dredging.org/documents/ceda/html_page/2013-06-woda-technicalguidance-underwatersoundlr.pdf. Accessed 20 May 2016

Yesson C, Clark MR, Taylor ML, Rogers AD (2011) The global distribution of seamounts based on 30 arc seconds bathymetry data. Deep Sea Res Part 1 Oceanogr Res Pap 58:442–444

Chapter 12
Dumped Chemical Weapons

Jacek Bełdowski

Abstract Chemical weapons (CW) are a legacy of large conflicts of twentieth century. Those of them which were not used in combat were in part dumped to seas and oceans worldwide. Among many sites used for CW dumping, Baltic Sea is an area where high concentration of dumped munitions are located and for which several research programs produced valuable results regarding their environmental fate and toxicity. In case of the Baltic Sea, warfare agents of concern include mostly sulfur mustard and arsenic based agents, such as Adamsite, Clark I and Clark II. Although there are still many gaps in knowledge, we know that dumped CW are point sources of contaminants on the sea bottom, and can produce chronic effects on marine organisms. Dumped chemical weapons are a growing concern for the international community, therefore also management strategies for such areas are discussed in the following chapter.

Keywords Chemical weapons • Toxicity • Environmental fate • Mustard • Arsenic • Corrosion

12.1 General Description

Chemical weapons (CW) were produced in mass during both World Wars (WW) I and II, but those made during WWII were never used in battle in the European Theater. After both wars worldwide dumping operations were performed in many areas, and continued until 1970s, when the treaty "Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972" was signed (International Maritime Organization 2003). Material dumped included both munitions filled with chemical warfare agents (CWA) or agents themselves enclosed in different types of containers. Modes of dumping included piece by piece disposal or

J. Bełdowski
Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland
e-mail: hyron@iopan.gda.pl

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_12

scuttling of vessels filled with warfare material. Areas, where the dumping operations took place are usually marked on the marine charts, but the exact positions and content of the dumpsites remain in many cases unknown. Also, in some cases en-route dumping operations were commenced, resulting in dispersed munitions or containers between the dumping areas and ports of origin.

In many parts of the world chemical munitions pose a problem to environment—this includes Mediterranean, North Sea, Sea of Japan, Black Sea and Pacific and Atlantic Oceans. Other sites exist in other marine areas, but are not described in details. To large extent, exact positions of those munitions are unknown. Areas which were reasonably well studied include the Baltic Sea (primary dumpsites at Bornholm Deep and Gotland Deep), Mediterranean (vicinity of Bari harbor), Pacific Ocean (close to Oahu, Hawaii), North Sea (close to Paradenmaarkt, Belgium) and Sea of Japan (Kaanda Harbor). Other areas received little attention, or the information was not well distributed. This means that two very prominent gaps in knowledge exist: first, surveys of dumpsites are not complete, and second, information exchange between different sites is limited.

Vast quantities of German chemical warfare agents (CWA) were stored in Wolgast, on the Baltic shore at the end of WWII. Based on the Berlin (Potsdam) Agreement, disposal of the German chemical warfare arsenal was handled by the Allied occupation forces. Munitions, bombs and various containers with CWA were transported to the (nowadays) Eastern German harbour town of Wolgast in the Soviet occupation zone. Accordingly, post-war dumping operations in the Baltic Sea were carried out under control of the Soviet Military Administration in Germany. The vast majority of CWA introduced into the Baltic Sea originates from this era.

By far the largest part of these weapons was dumped in the Baltic Sea and Skagerrak Strait on the orders of the British, Russian and American occupation authorities. At least 170,000 tons of CW was dumped in the Skagerrak, mainly in the Norwegian trench at depth of 600–700 m and in the eastern Skagerrak, off the Swedish coast, where the depth is about 200 m. In most of the dumping operations in the Skagerrak complete ships were sunk with their cargo. In the Baltic Sea at least 50,000 tons of CW were dumped—it is assumed that these contained roughly 15,000 tons of CWA; the most important dumpsites here are located in the Lille Belt, near the island of Bornholm, and in the Gotland basin. Depth in those areas ranges from 40 to 150 m. In most cases, the CW was thrown overboard, either loose (bombs, shells) or in containers, but some ships were also sunk. There are strong indications that part of the CW was thrown overboard during transport to the Baltic dumpsites; how many tonnes were thus dumped is not known. Location of dumpsites is depicted in Fig. 12.1.

There is, though never verified, information that chemical munitions were dumped in the Baltic Sea for many years after the year 1948 by the army of the German Democratic Republic and the Soviet Army, most probably still in the 1980s. Since those suspected operations were unofficial, little is known on the types of munitions or containers dumped (Neffe et al. 2011).

In the Baltic Sea, since 1990s several national projects were devoted to chemical munition studies, which were followed by three major international projects:

Fig. 12.1 Location of CWA dumpsites in the Baltic Sea

Modelling of Ecological Risks Related to Sea-Dumped Chemical Weapons (MERCW, EU FP6 project 2005–2009), Chemical Munitions Search and Assesment (CHEMSEA BSR project 2011–2014) and Towards the Monitoring of Dumped Munition threat (MODUM, NATO SPS Project, 2013–2016). Nowadays, fourth project is starting—Decision Aid for Marine Munitions (DAIMON—interreg project 2016–2018).

12.2 Environmental Fate of Munitions and Chemicals

In general, as time progresses, metallic mantles of munitions and bulk containers rust and are subject to mechanical erosion. At some point, hull integrity will be breached and contact between sea water and the chemical contents of a munition will be established.

Based on corrosion estimations with the corrosion rate of the bombshells estimated to 0.05–0.575 mm/year depending upon shell type, and the fact that corrosion can be increased up to fourfold by moderate stirring/current of the seawater, the highest rate of release of most abundant compound, sulphur mustard would occur after 125 years from dumping over 60 year period. The amount was calculated to be in the order of >6000 tonnes by Sanderson et al. (2008).

The dominant view among the participants of the NATO Advanced Research Workshops, which took place in 1995 in Kaliningrad near Moscow2) was that a large part of the chemical munitions corroded and the harmful chemical compounds underwent hydrolysis to non-toxic or low toxic substances. Some of the experts, however, held the opposite view and estimated that the period of intensive release of harmful compounds is approaching, since the metal shell started to lose containment. According to various calculations, the pace of corrosion is about 0.5 mm/year, which means that the metal shell 2–3 cm thick will lose containment after 40–60 years) (Korotenko 2000).

Examination of munitions in the Baltic dumpsites reveal both completetly corroded objects, and almost completely intact (Fig. 12.2).

While at the time of dumping, bulk containers may only have contained CWA mixtures (including the respective CWA parent compounds, production and storage side products, stabilizers and solvents), other munitions will have contained explosives used as bursting charges, although the fuse was likely removed for dumping. Still, just like in the case of dumped conventional munitions, the latter has to be considered as UneXploded Ordnance (UXO).

Both CWA mixtures and explosives are chemicals that may have reacted with other materials in the container or with themselves. Effectively, this aging process may have changed the properties of the chemical contents. With regard to CWA, compounds with less pronounced or without warfare capabilities may have emerged. Explosives, on the other hand, may have lost their handling safety and might have become sensitive to shocks and thus more dangerous.

When sea water comes into contact with these chemicals, it may act as solvent or suspension agent. Consequently, the chemicals will leak into the environment, first

Fig. 12.2 Chemical bomb inspection at Gdansk Deep

spread locally, possibly enter a sediment sorption/desorption equilibrium process, and will, with time, be distributed on a larger scale by hydrological processes and anthropogenic activities.

Once under the influence of environmental factors, chemicals may also undergo changes by abiotic (e.g. reactions with sea water and its components like dissolved oxygen or hydrogen sulfide, or closer to the surface, sunlight-mediated degradation) or biotic processes (e.g. bacteria-mediated biotransformation).

The propensity to undergo chemical transformations and the pathways and modes of environmental distribution, taken together can be defined as the *environmental fate* of a chemical. The environmental fate depends on the nature of the chemical (e.g. reactivity, polarity) and on the prevailing ambient conditions (e.g. temperature, reaction partners, bacterial population). Resulting from these transformations are chemicals which may have properties similar to or quite unlike the parent compounds.

Some parent or transformation chemicals will undergo fast reactions, in other cases transformations will occur only very slowly. The latter chemicals are persistent in the environment and, given suitable hydrophobic (fat-soluble) properties, have the potential to bioaccumulate in living organisms via food webs (food chains). Persistent organic pollutants (POPs) is one of the principal issues of environmental pollution.

With regard to organic chemicals, the highest possible stage of chemical break-down is mineralization—conversion to e.g. carbon dioxide, ammonia, water and hydrogen sulfide. In the case of organometallic (e.g. organoarsenic-based CWA) or inorganic (e.g. metals from containers or the primary explosive lead(II)azide or mercury fulminate from detonators) chemical warfare materials, transformations will lead to inorganic species of heavy metals which can be converted to different organometallic species by biotic processes. These latter inorganic and organometallic species do occur naturally and their toxic properties depend on the chemical "wrapping", oxidation state and nature of the metal atom and may either be pronounced or even negligible (e.g. arsenobetaine). Nonetheless, since the amounts of bioavailable heavy metals introduced by anthropogenic activities is considerable in comparison to the naturally bioavailable amounts, discharge of heavy metals into the environment is one of the principal issues of environmental pollution.

Speed of corrosion and subsequent start of release of all chemical contents is strongly dependent on the local environment a given chemical warfare material container rests. In general, the presence of oxygen and engulfing currents will promote corrosion of a container, while burial in sediment and a low oxygen environment will preserve its original state. Even if the outer hull is still pristine, the chemical contents of a bulk container or, even more likely due to its more complex composition, of a munition may have changed with time.

A total of eight active CWA compounds and one additive compound have been reported dumped east of the Danish island Bornholm in the Baltic Sea (Table 12.1). The largest single active CWA constituent of the total production of German CWAs

Table 12.1 Confirmed dumped chemical warfare agents east of Bornholm (Sanderson et al. 2008)

Compound	CAS number	Dumped (tonnes)
Chloroacetophenone (CAP)[a]	532-27-4	515
Sulphur mustard gas (Y perite)[b]	505-60-2	7027
Adamsite[c]	578-94-9	1428
Clark I[d]	712-48-1	711.5
Triphenylarsine[d]	603-32-7	101.5
Phenyldichloroarsine[d]	696-28-6	1017
Trichloroarsine[d]	7784-34-1	101.5
Zyklon B[e]	74-90-8	74
Monochlorobenzene[f]	108-90-7	1405

[a]Riotcontrolagent
[b]Blistering agent
[c]Organoarsenic blistering agent
[d]Arsineoilconstituents–organoarsenicblisteringagent
[e]Bloodagent
[f]Additive

that were dumped in the Baltic Sea, at 38%, is the vesicant blistering agent, sulphur mustard gas (Yperite), occurring also as Nitrogen mustard and viscous mustard, which are also powerful and persistent blister agents (Sanderson et al. 2008).

It is believed, that other chemical warfare agents might be present in scattered deposits in the Baltic Sea (i.e. at Gotland Deep). This includes Lewisite, other chemicals based on Arsinic oil and nitrogen mustard (Missiaen et al. 2006). In the Little Belt Tabun and Phosgene munitions were dumped, but they were largely recovered (Glasby 1997). Abovementioned arsenic-containing CWAs (also referred to as Arsine oil of which 2033 tonnes were dumped) are made up of 50% phenyldichloroarsine, 35% Clark I, 5% trichloroarsine and 5% triphenylarsine, and 5% unidentified carrier co-solvent (Sanderson et al. 2008). Zyklon B, appearing in the table, is the only 'other' CWA mentioned in the HELCOM report of 1993 (HELCOM 1995), and since it moreover is very toxic Sanderson et al. (2008) ascribed the entire 'other' category (74 tonnes) to Zyklon B.

Based on their toxicity and properties, those chemical warfare agents can be classified into the following groups:

- tear gases (lachrymators): chloroacetophenone (CAP),
- nose and throat irritants: Clark I, Clark II, Adamsite,
- blister gases (vesicants): sulphur mustard, nitrogen mustard, Lewisite,
- nerve gases: tabun, phosgene,
- additives, such as monochlorobenzene, are made to the warfare agents in order to change their physico-chemical properties.

Furthermore, the dumped chemical munitions might also contain certain amounts of explosives, which could leach persistent and bioaccumulable substances (HELCOM 1994).

12.3 CWA Behavior in Seawater

The behaviour of chemical substances in the marine environment depends both on the chemical and physico-chemical properties of the substances, and on the impact of environmental factors. Solution of chemical warfare agents in the sea is considered to be an important, first stage of their decomposition.

The maximum solubility of CWAs in water is about 2300 mg/l (triphenyl chloroarsine). Cylkon B is an exception, as its solubility in water amounts to about 95,000 mg/l (Sanderson et al. 2008). In real conditions in the sea water, the maximum concentration of CWAs will be less than 10% of their theoretical solubility, and even that for a short period of time. As a result of further dissolving, dilution and the reaction of decomposition, the possibility of occurrence of high concentrations of CWAs in the sea water is unlikely. For phosgene and tabun, which easily solve in water, the initial concentration after release may be much higher.

In the marine environment tabun hydrolyses into H_3PO_3 and hydrogen cyanide, which further breaks down to HCOOH. At the temperature of 7 °C its half life time equals to approximately 5 h. Thus, it poses a rather short-term threat to the marine environment, only when it occurs in high concentrations (Korzeniewski 1996).

Phosgene hydrolysis is even faster, as the halflife even at 0 °C equals 20 s (for 1% solution). This is caused by the pH of the seawater, which buffers HCl and CO_2 resulting from phosgene decomposition (Korzeniewski 1996).

Remaining CWA's are characterized by lower breakdown rates and can be considered persistent pollutants.

Despite the initial rapidity of the hydrolysis reaction, mustard persists in the marine environment for decades. During such a long exposure to the impact of sea water and sediments, the hydrolysis of dissolved mustard usually is relatively fast, whereas the hydrolysis of undissolved mustard is slow, so both hydrolysis rate and the dissolution rate of mustard gas must be taken into account. This factor causes mustard degradation process to take weeks or years. Many varieties of mustard are present in the Baltic Bottom—this includes mustard gas, sulphur mustard (referred as viscous mustard) and nitrogen mustard. Mustard gas main degradation pathway is supposed to be thiodyglycol and hydrochloric acid, while sulphur mustard degradation reaction is similar, but even slower, due to the presence of water insoluble thickening agents. Nitrogen Mustard hydrolysis pattern is more complex—first stage occurs in 24 h, while remaining two stages take 3 weeks in freshwater, no data is available on reaction rates in seawater. Compounds produced are probably less toxic and water soluble.

In the years 1998–1999, detailed laboratory tests of the mustard gas lump caught on 9 January 1997 were performed in the Military University of Technology in Warsaw. During the tests, chromatographic techniques (GC-MS, GC-AED) were employed. About 50 various chemical compounds of differing toxicity were found in the lump of mustard gas, while their chemical structure was identified in 30 cases. Those included sesquiyperite and its analogues as well as oxygenic compounds.

However, no thiodiglycol was detected, probably due to high solubility of this compound (Mazurek et al. 2001).

Pursuant to the MEDEA Report, the most probable time of decomposition of mustard gas lumps weighing 1 kg amounts to about 8 months (typical chemical ammunition), about 18 months for lumps weighing 10 kg (chemical artillery shell) and about 31 months for lumps weighing 100 kg (air bomb). However, mustard gas has got the tendency to form gels with a jelly or rubbery consistency, with a polymer skin preventing further decomposition (Mazurek et al. 2001).

Beside mustard gas, also arsenic compounds (Clark I and II, lewisite and adamsite), as well as phenacyl chloride (Chloroacetophenone) are not readily water-soluble and hydrolyse even harder than mustard gas. During the research, carried out under the MERCW Project, a lump was found on one of the wrecks, the analysis of which revealed that it was chloroacetophenone. Chemical structure of this compound suggests that no biodegradation could occur. After dehalogenation (due to hydrolysis), non toxic compounds are created, which might decompose completely in the seawater.

CLARK I hydrolysis in water will lead to diphenylarsenious acid (DPAA) and hydrochloric acid and CLARK II will lead to hydrogen cyanide and diphenylarsenious oxide (DPAO). Both hydrochloric acid and hydrogen cyanide are toxic, but they will be detoxified quickly in water, so the toxic effects are short-term and local. Both arsenoorganic compounds decompose later into toxic, inorganic arsenic compounds—which are assimilated by organisms, adsorbed to the sediments and suspensions, desorbed and transported in dissolved form in the column of water.

Adamsite hydrolyzes into phenarsazinic oxide and hydrochloric acid. Similarly to CLARKs, degradation products are persistent, spread slowly and can undergo bioaccumulation.

Lewisite reacts with water to form chlorovinyl arsine oxide, which can be further decomposed into toxic arsenic acid and acetylene.

Several attempts were undertaken in order to evaluate overall release of CWA into Baltic.

Witkiewicz (1997) claims that the transition of toxic agents into the surrounding water will take place mainly by way of diffusion. It is, by nature, a slow process, and will additionally be hindered by the fact that the toxic agents escaping the ammunition and containers may be covered by a layer of seabed sediments. Therefore, he claimed that the concentration of toxic agents in the surrounding water will not be high. Also the concentration of products of hydrolysis of toxic agents will be small.

Sanderson et al. (2008) found that conservative use of the EPI Suite model (http://www.epa.gov/opptintr/exposure/pubs/episuite.htm) can be used to predict the environmental toxicity and physical chemical properties of CWAs, noting that the physical chemical properties of CWAs will be governed also by the hydrological conditions found at 50–100 m depth, as also outlined in the EU TGD (2003) regarding persistence of chemicals in marine environments.

All chemical compounds belonging to the CWA category react with the sea water. As a result of hydrolysis, there are created new compounds, with reduced toxic properties compared to the toxicity of the chemical warfare agents. Such products of reactions are usually less toxic and generally highly soluble in water. It may not be excluded though that there will be created compounds, which, being quite permanent interim products, may be as toxic as the initial compound.

12.4 Risks and Impacts on the Marine Environment

Scarcity of data results in gaps in information regarding the effects on environment. Both completely corroded munitions and intact pieces were found in the dumpsites. However corrosion rates, their dependence on environmental factors and fluxes of warfare agents and explosive degradation products to the environment were only briefly described, so no definite answer exists. Chemical Warfare Agents (CWA) degradation products were observed in the sediments on distances up to 40 m from objects, but in some instances the range was considerably smaller. Arsenic based agents seem to spread further than mustard degradation products—analysis of samples collected at distances 0.5 and 25 m containing both types of agents, show steeper decline in mustard concentration than As based (Fig. 12.3). Model studies

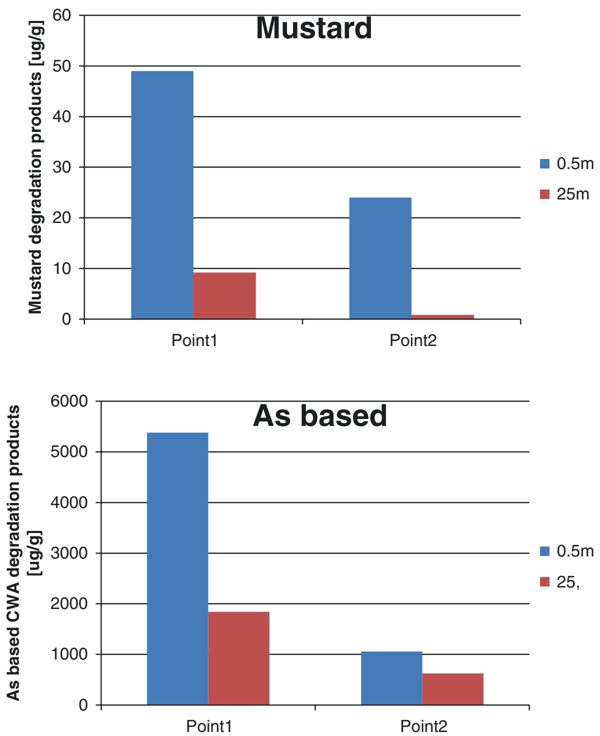


Fig. 12.3 Mustard degradation products and As based agents degradation products concentration next to the object and at 25 m distance in two points at Bornholm Deep

show, that the penetration of CWA and their degradation products should be limited to meters—such discrepancy shows that further studies are needed in an area of CWA degradation and transport.

During the CHEMSEA project and Mediterranean studies biomarker effects of environmental stress were observed in organisms close to munition dumpsites, but no clear link could be provided to CWA, because biomarkers used were too general. Lack of specific, CWA oriented biomarkers, and toxicity studies is another gap in the current state of the art.

The substances which are dealt with by the environmental models assessing the environmental risk from munitions dumping sites include mainly mustard gas, agents based on arsenic oil (Clark I and Clark II, adamsite and lewisite) and less frequently tabun.

Because of their high toxicity, extremely slow hydrolysis and the equally toxic breakdown products, the greatest environmental threat is generally believed to be posed by Clark I and Clark II, as well as nitrogen mustard gas and sulphur mustard gas.

Mustard gas is extremely toxic to all species, and its degradation products cause a variety of adverse effects towards microorganisms, changing both their composition and abundance (Medvedeva et al. 2009).

In the case of the Baltic dumps, the extent of dispersion in the seabed sediments through sub-surface leakage, the quantity of toxic agents which may penetrate to the near-bottom water and the duration of contamination are the important aspects of assessment of the risk related to possible leakage of chemical warfare agents. Moreover, there is a potentially significant overlap between the dump site, fertile fishing grounds and the breeding grounds of cod (*Gadus morhua*) east of Bornholm, suggesting that this economically and ecologically important fish species to the Baltic Sea might be particularly at risk from dumped CWAs (Sanderson et al. 2008).

Based on the measured concentrations of parent CWA compounds in the sediments of the Bornholm deep, there are no concern for direct acute risks towards the fish community. The potential chronic and indirect ecosystem effects are however not clarified (Sanderson et al. 2010). CWA conditions, levels, and risks elsewhere in the Baltic Sea are less well analysed.

According to Russian studies during MERCW project, enhanced numbers of mustard resistant bacteria were found in the nearbottom water at all Baltic dumpsites, also decreased biodiversity of bacteria was observed close to the identified objects. This indicates a probable leakage of CWA into the nearbottom waters and pollution of both surface sediments and water. Microorganisms from those areas were characterized with enhanced resistance to CWA degradation products and they were able to use some of those compounds as a carbon source, which could explain low spreading of those substances to the adjacent areas (Medvedeva et al. 2009).

Both original CHEMU report and the 2010 thematic report on hazardous substances in the Baltic Sea (HELCOM Baltic Sea Environment Proceedings no. 120B n.d.) concluded that dissolved warfare agents do not pose a wide-scale threat to the marine environment. The main reason is that these compounds cannot occur in higher concentrations in the water.

This can also be concluded from the MERCW project that studied bottom samples from within a primary dump site. No intact warfare agent chemicals were found.

However, the project documented findings of degradation products of chemical warfare agents, such as sulphur mustard, Tabun, ά-chloroacetophenone, Adamsite, Clark I, Clark II or phenyldichloroarsine.

In the recent years, there have been carried out a significant number of ecotoxicological tests (Sanderson et al. 2008, 2009; Emelyanov et al. 2010) in the light of which it can be concluded that the considered chemical warfare agents do not accumulate in living organisms or the tendencies for bioaccumulation are low. Such threat cannot be ruled out, however, in particular in the case of arsenic CWAs. The compounds, after breakdown to non-organic compounds, due to possible accumulation in the organisms of fish, constitute a threat also to people. In the opinion of experts, further research is needed in that scope, in particular with respect to poorly soluble compounds, such as viscous mustard gas mixed with organic arsenic compounds.

As indicated by the research performed in CWA contaminated area of Bari, Italy, new ecotoxicological tools, as biomarkers, can point at threats to the marine ecosystem posed by CWA, which were not identified by studying the concentrations of CWA compounds alone. It is mostly a threat to demersal fish, which are especially vulnerable for sediment associated contaminants. The ammunitions dumped in the Bari area are similar in composition to that dumped in the Baltic Sea. It contains artillery shells and aerial bombs filled with mustard and arsenic based CWAs—lewisite and CLARK. The As content in eels from this area was elevated as compared to fish from the control area, while in other fish, with no apparent differences in arsenic concentrations in tissues, adverse effects of CWA were visible by means of biomarkers assays. Fish from the dumping area had disturbed enzymatic system, DNA damage and damaged internal organs (AMATO et al. 2006).

There are of course gaps in our knowledge concerning the properties of chemical warfare agents at 50–100 m depth in the Baltic. The investigations so far reveal a further need to refine the chemical analytical methods. However, with the state-of-the-art analysis performed by Finnish research institute, VERIFIN, the detection frequency of parent CWA compounds is very low. Degradation products have been found more frequently in the primary dump site of the Bornholm Deep.

12.5 Management Requirements

Dumped chemical munitions are no doubt point sources of contaminants to the benthic ecosystems and they are also a threat to commercial operations on the seabottom. Due to unknown degree of corrosion and decomposition of chemical warfare agents contained in the munitions, it is hard to predict the magnitude of fluxes released into the environment, and possible temporal trends in the contaminants release. Therefore, a number of management options was suggested in the past (Duursma and Surikov 1999).

The most simple and environmentally friendly option is the monitoring of dumpsites, in order to control possible spreading of contaminants outside of dumpsite area. Such monitoring includes condition of munitions, levels of CWA degradation products in the sediments and nearbottom water, but also environmental parameters responsible for water and suspended matter movements, corrosion rate and transformation of toxic chemicals—especially turbulence, currents speed and direction, oxygen concentration and parameters related to organic matter decomposition.

Other options can create potential adverse effects in the environment, therefore they are recommended only in cases where the impact of dumped munitions on the environment is well proven, and exceeds threats created by remediation activity. Those options can be divided into in-situ methods and removal.

In-situ methods include hydrolysis of munition constituents in underwater domes and various sediment capping options (Duursma and Surikov 1999), which could either transform toxicants into less toxic compounds or separate them form the bottom water for long enough to be buried by sediment layers or for the natural depuration processes to complete. Disadvantage of such option is the elimination of selected seabottom areas from the ecosystem, in terms of habitat, and other ecosystem roles and services they normally provide. Such methods were successfully demonstrated in the Black Sea, where post soviet chemical munitions were sarcophaged by concrete sediment capping (Korendovych 2012).

Removal options include various means of retrieval, although most environmentally friendly option seem to be in-situ overpacking partially corroded munitions into hermetic containers. Retrieval operation creates a risk of resuspension of contaminated sediments and release of toxic agents into the water, however such risks may be minimized by careful operation of divers and underwater robots. Retrieved munitions may be neutralized by various means, including shipboard installations and land based facilities. Various options include plasma ovens, detonation chambers or combustion chambers, with specialized off gas treatment (Knobloch et al. 2013).

Due to the fact, that all the options are costly, they should be preceded with careful risk assessment, both for potential munition spreading and consequences of different management options. To this end, EU has funded an integrated project Decision aid for munition Management (DAIMON), which is aimed at the development of risk assessment methods and remediation option selection.

Acknowledgement Presented results were obtained in the frame of DAIMON project - in which the research work was fund by the European Union (European Regional Development Fund) under the Interreg Baltic Sea Region Programme 2014–2020, project #R013 DAIMON, cofunded by the Ministry of Science and Higher Education (Poland) from the 2016–2019 science funding allocated for the implementation of international co-financed project.

References

Amato E, Alcaro L, Corsi I, Della Torre C, Farchi C, Focardi S, Marino G, Tursi A (2006) An integrated ecotoxicological approach to assess the effects of pollutants released by unexploded chemical ordnance dumped in the southern Adriatic (Mediterranean Sea). Springer, Heidelberg

Duursma EK, Surikov BT (1999) Dumped chemical weapons in the sea: options: a synopsis. A.H. Heineken Foundation for the Environment, Amsterdam, Netherlands

Emelyanov E, Kravtsov V, Savin Y, Paka V, Khalikov I (2010) Influence of chemical weapons and warfare agents on the metal contents in sediments in the Bornholm Basin, the Baltic Sea. Baltica 23(2):77–90

Glasby GP (1997) Disposal of chemical weapons in the Baltic Sea. Sci Total Environ 206(2–3):267–273
HELCOM (1994) Report to the 16th meeting of Helsinki Commission 8–11 March 1994 from the ad hoc working group on dumped chemical munition (HELCOM CHEMU). Danish Environmental Protection Agency
HELCOM (1995) Final report of the ad hoc working group on dumped chemical munition (HELCOM CHEMU) to the 16th meeting of the Helsinki Commission (March 1995) I. HELCOM
HELCOM (2015) Chemical Munitions Dumped in the Baltic Sea. Report of the ad hoc Expert Group to Update and Review the Existing Information on Dumped Chemical Munitions in the Baltic Sea (HELCOM MUNI). Baltic Sea Environment Proceeding (BSEP) 142:1–128
International Maritime Organization (2003) London convention 1972: convention on the prevention of marine pollution by dumping of wastes and other matter, 1972 and 1996 protocol, 2003rd edn. International Maritime Organization, London
Knobloch T, Bełdowski J, Böttcher C, Söderström M, Rühl N-P, Sternheim J (2013) Chemical munitions dumped in the Baltic Sea. Report of the ad hoc Expert Group to update and review the existing information on dumped Chemical Munitions in the Baltic Sea. Baltic Sea Environment Proceeding (BSEP) 142:1–128
Korendovych V (2012) Enhancing abilities to counter WMD proliferation – Ukrainian experience. Paper presented at the countering WMD threats in maritime environment, Riga
Korotenko KA (2000) Chemical weapons dumped in the Baltic Sea: facts, tendency and prediction of level and scales of possible ecological disaster. John D. and Catherine T. MacArthur Foundation, Moscow
Korzeniewski K (1996) Bojowe środki trujące w wodach południowego Bałtyku. Wiadomości chemiczne 50:9–10
Mazurek M, Witkiewicz Z, Popiel S, Sliwakowski M (2001) Capillary gas chromatography-atomic emission spectroscopy-mass spectrometry analysis of sulphur mustard and transformation products in a block recovered from the Baltic Sea. J Chromatogr A 919(1):133–145
Medvedeva N, Polyak Y, Kankaanpää H, Zaytseva T (2009) Microbial responses to mustard gas dumped in the Baltic Sea. Mar Environ Res 68:71–81
Missiaen T, Paka V, Emalyanov E (2006) Modelling of ecological risks related to sea-dumped chemical weapons synthesis report of the available data. MERCW
Neffe S, Bełdowski J, Fabisiak J, Kasperek T, Popiel S (2011) REPORT concerning the issues included in decisions no. 23 and 24, made at the 1st meeting of the Expert Group concerning updating and reviewing available information on chemical weapons dumped in the Baltic Sea "HELCOM MUNI 1/2010. Chief Inspectorate of Environmental Protection, Warsaw
Sanderson H, Fauser P, Thomsen M, Sorensen PB (2008) Screening level fish community risk assessment of chemical warfare agents in the Baltic Sea. J Hazard Mater 154(1–3):846–857. doi:10.1016/j.jhazmat.2007.10.117
Sanderson H, Fauser P, Thomsen M, Sorensen PB (2009) Human health risk screening due to consumption of fish contaminated with chemical warfare agents in the Baltic Sea. J Hazard Mater 162(1):416–422. doi:10.1016/j.jhazmat.2008.05.059
Sanderson H, Fauser P, Thomsen M, Vanninen P, Soderstrom M, Savin Y, Khalikov I, Hirvonen A, Niiranen S, Missaen T, Gress A, Borodin P, Medvedeva N, Polyak Y, Paka V, Zhurbas V, Feller P (2010) Environmental hazards of sea-dumped chemical weapons. Environ Sci Technol 44(12):4389–4394. doi:10.1021/Es903472a
Witkiewicz Z (1997) Stan techniczny zatopionej amunicji chemicznej i przewidywane tego konsekwencje. In: Broń chemiczna zatopiona w Morzu Bałtyckim, Gdynia. AMW

Chapter 13
Marine Climate Engineering

David P. Keller

Abstract As a means of countering climate change, some scientists have proposed that climate engineering, which is a deliberate action designed to alter the Earth's climate, could be done. In this chapter an overview is given of the proposed climate engineering methods that involve the direct manipulation of marine systems. This includes methods that enhance the ocean's natural physical, chemical, and biological CO_2 sequestration pathways, as well as purely technical ones that either use the ocean as a carbon storage reservoir or alter it's properties to affect the Earth's radiation budget. Few methods have been thoroughly evaluated and there are still many unknowns, at both the level of basic understanding and as to whether or not it would even be technologically feasible to implement any of them. Research so far has shown that some CE methods do have the potential to alter certain aspects of the climate system. Some have more potential than others and most of them appear to have significant side effects.

Keywords Climate engineering • Climate intervention • Geoengineering • Carbon dioxide removal (CDR) • Greenhouse gas removal • Earth radiation management • Ocean iron fertilization • Ocean alkalinization • Ocean fertilization • Ocean alkalinity enhancement • Solar radiation management (SRM) • Artificial ocean upwelling • Ocean afforestation • Climate change • Blue carbon • Radiation management • Bioenergy with carbon capture and storage (BECCS)

13.1 Introduction

The Earth's climate is undergoing changes as a result of human activities that have increased the concentration of greenhouse gases (GHGs), such as CO_2, in the atmosphere. These changes are already having a profound and often, detrimental impact

D.P. Keller
GEOMAR Helmholtz Centre for Ocean Research Kiel,
Kiel, Germany
e-mail: dkeller@geomar.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_13

on humans and the natural environment (IPCC 2014) (see also Chaps. 18 and 19). If GHG emissions keep increasing, then the current scientific consensus is that the climate will be seriously altered by the end of the century (IPCC 2013). The obvious solution to this problem is to reduce fossil fuel use and limit other GHG emitting activities. Unfortunately, despite some efforts, global GHG emissions continue to increase (Friedlingstein et al. 2014). Since emission reduction efforts do not appear to be working, some scientists have suggested that it could be possible to manipulate or "engineer" the climate to stop or mitigate climate change.

Climate engineering (CE), which is also called geoengineering or climate intervention, can be defined as a deliberate action that has the intent of changing some specific aspect of the Earth's climate. CE methods can be classified according to whether they *treat the causes* of climate change (mainly the build-up of CO_2) or *treat the symptoms* of climate change, such as global warming. Methods proposed to treat the causes of climate change are often called Carbon Dioxide Removal (CDR) or GHG removal methods since they work by removing CO_2 or other GHGs from the atmosphere. Methods proposed to treat the symptoms of climate change are often called Radiation Management (RM), Solar Radiation Management (SRM), or Earth Radiation Management (ERM) and work primarily by manipulating either the amount of incoming short-wave solar radiation (sunlight) that is absorbed by the Earth or the amount of long-wave radiation (essentially heat) that leaves the Earth. In this chapter an overview of proposed CE methods that directly involve the manipulation of marine systems is given (Table 13.1 and Fig. 13.1).

13.2 Why Have Ocean-Based Climate Engineering Methods Been Proposed?

The ocean covers ~71% of the Earth's surface and plays a key role in the climate system. It impacts the planet's radiation budget (mostly the amount of heat from the sun that is absorbed or released), the carbon cycle (the exchange of carbon, i.e. CO_2, between the atmosphere, biosphere, geological reservoirs, the ocean, and terrestrial systems that include soils and freshwater), and the exchange of aerosols and radiatively important gases, such as water vapor, with the atmosphere. Since the ocean plays such a large role in the climate system, if its processes or properties that affect the climate could be purposefully manipulated, the climate could in theory be steered in a desired direction. Ocean-based CE methods aim to do just this.

13.3 Carbon Dioxide Removal Methods

Most proposed ocean-based CDR methods work by enhancing the ocean's natural carbon sequestration mechanisms, which act through a variety of biological, chemical, and physical pathways. There are also a few methods that directly capture CO_2 from the atmosphere or seawater through technological means.

Table 13.1 Classification and description of proposed climate engineering methods that involve the direct manipulation of marine systems

Climate engineering type	Method	General description
Carbon dioxide removal (CDR)	Artificial downwelling	Artificially enhance the transport of carbon that has been taken up at the surface ocean into the deep ocean where it will be stored for hundreds to thousands of years
	Artificial upwelling	Use pipes or other methods to pump nutrient rich deep ocean water to the surface where it has a fertilizing effect; see ocean fertilization below
	Direct air capture of CO_2 with ocean storage	Technology that chemically or electro-chemically removes CO_2 from air and concentrates it for storage; the deep ocean has been proposed as one potential storage site via direct injection
	Removal of CO_2 from surface seawater with deep ocean storage	Technology that chemically or electro-chemically removes CO_2 from seawater and concentrates it for storage, also increases the oceanic uptake of CO_2 as seawater chemistry compensates for it's removal; the deep ocean could be a potential storage site via direct injection
	Dumping terrestrial biomass in the ocean	Harvest and dump terrestrial biomass, which contains the carbon that vegetation has removed from the atmosphere during growth, in the deep ocean or bury it in coastal sediments
	Ocean alkalinization	Increase the alkalinity of the upper ocean to chemically increase the carbon storage capacity of seawater and thus, also increase CO_2 uptake
	Coastal management	Plant and manage mangroves, wetlands, seagrass beds, or macroalgae to increase CO_2 uptake and burial in sediments
	Ocean fertilization	Add micronutrients like iron or macronutrients like nitrogen and phosphorus to increase phytoplankton growth (CO_2 fixation) and ocean carbon storage via the biological pump (the transport of this fixed carbon into the deep ocean)
	Bioenergy with capture and storage	Grow algae or macroalgae and use the biomass to create biofuels that can be burned in conjunction with carbon capture and storage technology; the deep ocean could be a potential storage site for captured CO_2 via direct injection

(continued)

Table 13.1 (continued)

Climate engineering type	Method	General description
Radiation management (RM)	Ocean albedo modification	Increase the reflectivity of the ocean's surface so that less short-wave radiation (sunlight) is absorbed by the ocean
	Marine cloud brightening	Add aerosols to low clouds over the ocean to increase cloud cover and enhance the properties that make them more reflective; seawater could be sprayed to generate the aerosols
	Thermal bridging technologies	Methods that uses chimneys, tall towers, or other technology to transfer heat from the Earth's surface to the upper atmosphere; seawater could be used in the heat transfer process
	Downdraft evaporative cooling towers	Technology that uses seawater sprayed into tall towers in desert regions to create an evaporation induced downdraft of cold air that cools the land and allows latent heat to escape into space

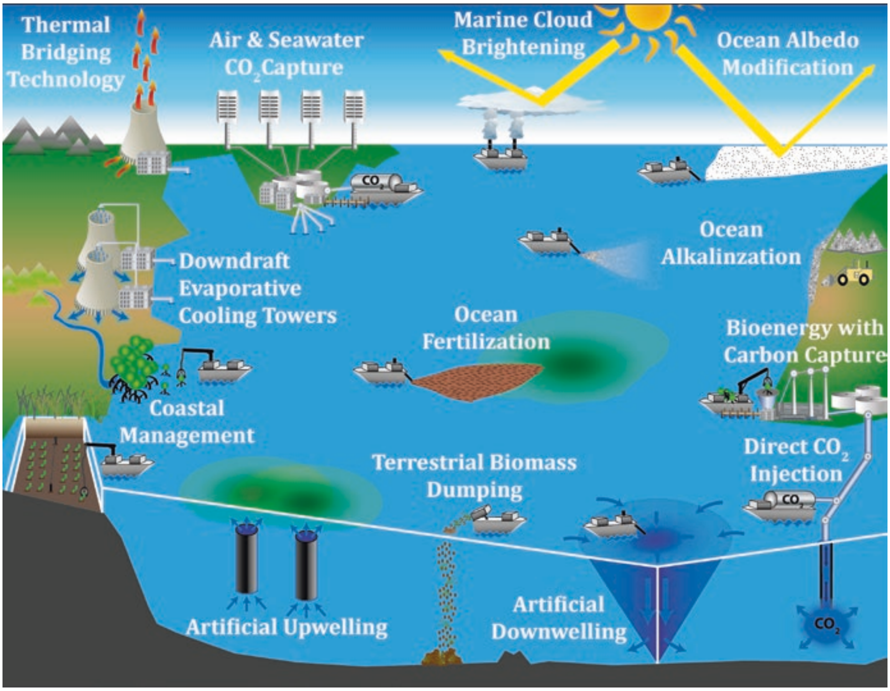


Fig. 13.1 Schematic illustration of the CE methods that involve the direct manipulation of marine systems

What are the natural oceanic CO_2 sequestration processes that could potentially be manipulated for CE? The solubility and biological pumps are the processes that currently remove the most atmospheric CO_2. These processes "pump" CO_2, which dissolves upon entering the ocean and is mostly converted into ions that can collectively be called dissolved inorganic carbon (DIC), into the deep ocean where most of it is temporarily stored for hundreds to thousands of years until ocean circulation brings the water back to the surface again. A process called chemical weathering, which involves both the ocean and land, also removes some CO_2 and ultimately stores it in the ocean. In addition, in the coastal ocean some carbon is removed by the flocculation and sedimentation of terrestrial carbon that is transported into it (via rivers, runoff, or groundwater) or through wetland and macroalgae uptake and burial in sediments (Bauer et al. 2013). Over the last 20 years these processes have removed approximately a quarter of the CO_2 emitted by human activity (~ 9.4 Gt CO_2/year) and stored it in the ocean (Heinze et al. 2015). The ocean, which already contains about 50 times more carbon than the atmosphere, is also known to have much more storage capacity (Heinze et al. 2015) so it is appealing from a CE perspective to try to enhance these sequestration processes.

13.3.1 Physical Methods for Enhancing Oceanic CO_2 Uptake

13.3.1.1 Artificial Downwelling

The surface ocean naturally takes up more CO_2 as the atmospheric concentration increases due to physical and chemical processes that work to maintain a balance between the amounts of CO_2 in each reservoir. Some of this carbon ends up being stored in the deep ocean when large-scale ocean circulation processes transport it there. This overall process is called the solubility pump. CE ideas have been proposed to enhance this pump by artificially increasing the rate at which surface water is transported to the deep ocean, e.g., artificial downwelling, since this is the solubility pump process that most limits the rate at which emitted CO_2 is stored in the deep ocean. Most methods focus on enhancing the formation of North Atlantic Deep Water (Zhou and Flynn 2005), which moves surface water to the deep ocean through sinking when the water becomes very dense as a result of environmental conditions in the winter. For artificial downwelling to work, the density of water in this region would have to be artificially increased through cooling and/or increases in its salinity. The proposed methods include using existing industrial techniques to enhance the exchange of heat between the water and air and/or using seawater to form ice, which would lead to an increase in salinity (density) as salt is ejected during ice formation. So far it does not appear that these methods would be energetically feasible and their potential side effects have not been thoroughly assessed.

13.3.1.2 Artificial Upwelling

Pumping water up from the sub-surface ocean, e.g., artificial upwelling, is another proposed CE method (Lovelock and Rapley 2007). Although it might initially seem counter-intuitive since this is somewhat the opposite of what the natural "pumps" do (i.e., transport carbon to deeper waters), the proposed method is focused on enhancing the biological pump to such a high level that it overcomes any reversal of natural ocean CO_2 uptake. The idea behind artificial upwelling is that while most of the surface ocean is depleted in the nutrients required for phytoplankton growth, they tend to be plentiful only a few hundred meters below (Karl and Letelier 2008). Thus, if this water is pumped up, it could have a fertilizing effect and potentially enhance the biological pump (see Sect. 20.2). To significantly draw down CO_2 in this manner modelling studies have shown that artificial upwelling would have to be implemented on a massive scale (over 50% of the ocean) (Keller et al. 2014). Depending on how rapidly the water is pumped up and whether or not heat is exchanged along the way, direct surface cooling could be a side effect of artificial upwelling, since deeper water is generally much colder than surface water. Simulations show that pumping up cold water could cool the Earth's surface by a few degrees, but not in a sustainable manner. The ocean would continue to take up heat from the sun and store it under the pumped up cold water. Thus, the cooling effect would stop once deeper waters have warmed sufficiently. In addition to the direct marine side effects of cooling the surface, atmospheric circulation and precipitation patterns would also be severely altered by the cooling (Kwiatkowski et al. 2015). Another problem with this is that if the upwelling were ever stopped, all of the stored heat would be rapidly released and the Earth would become warmer than if the method had never been deployed (Keller et al. 2014). When initially proposed, artificial upwelling received quite a bit of attention and a method that involved wave-powered upwelling "pipes" was patented, developed, and tested at a very small scale (White et al. 2010). However, after modelling assessments of this technology suggested that it might have severe side effects, as mentioned above and in Sect. 20.2, the company that was developing the upwelling pipes abandoned the idea for CE purposes. Pipes in which the upwelling is driven by water column temperature and salinity differences were also developed and tested (Maruyama et al. 2011), and although the purpose of these was more focused on enhancing fisheries, the technology could also potentially be used to enhance the biological pump.

13.3.1.3 Direct Injection of CO_2 into the Deep Ocean

Using the deep ocean as a reservoir for storing carbon was first proposed in the 1970s as a carbon capture and storage (CCS) approach (Marchetti 1977). However, the initial proposal cannot be considered CE since it involved capturing CO_2 before it is emitted into the atmosphere (e.g., at a power plant). To technically be considered CE, CO_2 would have to be removed from the atmosphere where it will have already affected the climate as a GHG. Recently, methods have been proposed and tested at a small scale to do just this, although not necessarily with the intent of storing the captured carbon in the ocean. These methods are called direct-air capture (Lackner et al. 2012). A method has also been proposed and tested in a laboratory to directly remove CO_2 from seawater and concentrate it for storage (Eisaman et al. 2012). In addition to removing CO_2, this method would also cause the surface ocean to take up more atmospheric CO_2 as it compensates for what has been removed. Regardless of how it is captured, directly injecting or pumping CO_2 into the deep ocean would have an effect on local seawater chemistry and could significantly reduce the pH, thereby enhancing ocean acidification (Orr 2004) (see Chap. 19). This would undoubtedly have a local effect on deep-sea ecosystems, but has not yet been thoroughly assessed. Storage would also be temporary since any injected CO_2 would eventually be returned to the atmosphere by ocean circulation. Model simulations suggest that if CO_2 was simply discharged at depths of 3000 m, within 500 years around half of it will have again reached the atmosphere (Orr 2004) (the exact amount of leakage depends on how and where it is injected and how future climate change affects ocean circulation and the carbon cycle). To prevent this leakage and make storage more permanent there have been proposals to inject the CO_2 in a manner that would prevent it from reacting or exchanging with seawater. This could include high-density, supercritical CO_2, CO_2 clathrates, or CO_2 emulsions that would reside on or near the ocean bottom and not be subjected to circulation (Rau 2014).

13.3.1.4 Dumping of Terrestrial Biomass into the Deep Ocean

There have also been proposals to directly dump terrestrial biomass (crop residues), which contains the carbon that vegetation has removed from the atmosphere during growth, into the deep ocean as a means of sequestering carbon (Strand and Benford 2009). If this material became permanently buried in marine sediments, it could sequester carbon for hundreds of thousands of years or longer. However, if bacteria on the ocean floor or in sediments consumed it and released most of the carbon again during respiration, then like direct injection, storage would only be temporary. Bacteria would also consume oxygen during respiration, which could potentially lead to the formation of hypoxic (low oxygen) or anoxic (no oxygen) regions near the dumped biomass. Very little is known about how quickly terrestrial biomass would be utilized by bacteria in the deep ocean, although it does appear that it is more resistant to degradation than biomass of a marine origin (Burdige 2005). Thorough assessments have also not been made on what dumping large amount of biomass into the ocean would do to marine ecosystems, chemistry, or circulation. There would also be side effects on land and in coastal margins that would have to be considered if a significant amount of vegetation was grown for this purpose (see Chap. 14).

13.3.2 Chemical or Electro-Chemical Methods for Enhancing Oceanic CO_2 Uptake

Proposed chemical methods for increasing ocean CO_2 uptake have mostly focused on increasing the alkalinity of seawater, e.g., enhancing chemical weathering or ocean alkalinization. This basically allows more CO_2 to dissolve in seawater and be stored as ions such as bicarbonate (HCO_3^-) or carbonate (CO_3^{2-}), i.e., the general methodology increases the carbon storage capacity of seawater. Most of the proposed methods involve using carbonate (lime or limestone) or silicate (olivine) minerals as an alkalizing agent (Kheshgi 1995; Köhler et al. 2010). Some proposals simply involve mining, grinding, and dumping naturally abundant limestone or olivine rocks into the ocean or on beaches where they will dissolve and increase the alkalinity of seawater (Harvey 2008; Hangx and Spiers 2009; Köhler et al. 2013). Other methods are more complex and are designed to electrochemically speed up the weathering reaction and would need to occur in a special chamber with pumped in seawater, the mineral, and a concentrated stream of CO_2 (Caldeira and Rau 2000; Rau 2008; Rau et al. 2013).

Modelling studies have shown that increasing the alkalinity of seawater could potentially remove large amounts of CO_2 from the atmosphere (up to 450 ppm) and keep it there even if the additions were stopped (Köhler et al. 2013; Ilyina et al. 2013a; Keller et al. 2014). However, there is an upper limit as to how much seawater alkalinity could be changed before elevated levels of oversaturation were reached and the spontaneous, abiotic, precipitation of minerals such as $CaCO_3$ began to occur, at which point adding more alkalinity would not result in more CO_2 uptake. When exactly this would occur in the real ocean is poorly known (Marion et al. 2009). However, the modelling studies indicate that alkalinity could be changed by considerable amounts before any theoretical limits are reached (Ilyina et al. 2013b). One of the other main constraints on the potential of these methods appears to be the mining, processing, and transportation of the minerals, since sequestering significant amounts of CO_2 requires massive amounts of mineral rock (Hartmann et al. 2013; Renforth et al. 2013). For example, to offset current emissions of ~34 Gt CO_2/year would require mineral rock on the order of 100 billions tons (National Reseach Council 2015). For comparison, only about 8 billon tons of coal are mined globally per year.

Known side effects include, reducing the rate of ocean acidification, something that would likely be desirable, and the potential addition of toxic heavy metals that are often found in the mineral rocks (Köhler et al. 2013). If olivine rock were used, nutrients such as silicate or iron could also be added to seawater (Köhler et al. 2013) and have a fertilizing effect (see Sect. 20.2). Some organisms have also been found to be physiologically affected by increases in alkalinity (Cripps et al. 2013). However, few laboratory studies have been conducted so it is unknown how the majority of species or ecosystems would respond to large changes in alkalinity.

13.3.3 Biological Methods for Enhancing CO_2 Uptake

Proposed biological methods for increasing oceanic CO_2 uptake mostly focus on enhancing the biological pump or the permanent burial of carbon in coastal sediments. There are also a few proposals that involve growing phytoplankton or macroalgae to make biofuels (N'Yeurt et al. 2012; Flynn et al. 2013) that could potentially be utilized in combination with carbon capture and storage (BioEnergy with Carbon Capture and Storage; BECCS) technology (National Reseach Council 2015) to remove CO_2 from the atmosphere.

13.3.3.1 Coastal Management

For a variety of reasons there has been an increasing emphasis on conserving, restoring, and managing coastal ecosystems, of which carbon sequestration or the enhancement of "Blue Carbon" is one (Duarte et al. 2013). Blue carbon describes carbon sequestered and stored for millennia in sediments by a variety of processes in coastal ecosystems such as mangrove forests, seagrass meadows, and salt marshes. Although, blue carbon is not typically mentioned in the context of CE, if coastal ecosystems were extensively managed and expanded on a massive scale with the intent of using them to sequester large amounts of atmospheric CO_2 it could be considered a form of CE. There have also been proposals to grow marine macroalgae for BECCS (N'Yeurt et al. 2012; Duarte et al. 2013). The feasibility and side effects of trying to manage coastal ecosystems on a scale needed to engineer the climate or as a carbon negative source of bioenergy have not been thoroughly assessed.

13.3.3.2 Ocean Fertilization of Phytoplankton

In most of the surface ocean one or more nutrients are often the main factor limiting phytoplankton growth either seasonally or on a year-round basis. Thus, if the correct nutrient(s) is added, it could potentially enhance the biological pump, which is the uptake (fixation) of carbon by growing phytoplankton during photosynthesis and its temporary storage in the deep ocean when some of this fixed carbon makes its way into the deep ocean (mostly through the sinking of biomass). Phytoplankton may also fix more carbon than they need and release some of it in a dissolved form (dissolved organic carbon; DOC) that can end up in the deep ocean too. While making its way into the deep ocean or upon reaching the sediments much of the carbon bound in biomass or that is DOC will be recycled by bacteria and returned to the DIC pool via respiration. In the open ocean less than 1% of biologically fixed carbon even reaches the seafloor (Heinze et al. 2015) and becomes permanently buried. Some carbon can also be stored as DOC for thousands of years, if biological or chemical processes make it inedible to bacteria.

Ocean fertilization methods have been proposed that use either the micronutrient iron, of which only a very small amount is needed, the macronutrients nitrogen and phosphorus, which are required in larger quantities, or a combination of iron and phosphorus (Karl and Letelier 2008; Lampitt et al. 2008). Many proposals have suggested obtaining the nutrients from industrial sources, e.g., mining or the Haber-Bosch process for nitrogen. However, as mentioned in Sect. 18.2 these nutrients are often abundant in the sub-surface ocean (away from the sunlight zone). Thus, with a method like artificial upwelling the nutrients could be obtained from marine sources (Karl and Letelier 2008).

Iron fertilization CE proposals have been motivated by observations that phytoplankton growth in approximately 25% of the surface ocean appears to be limited by iron. The potential for iron fertilization to work in these regions has been extensively researched and in addition to laboratory and modelling research, several small-scale in situ experiments have been conducted (Boyd et al. 2007; Oschlies et al. 2010; Smetacek et al. 2012), including a controversial privately-funded one (Tollefson 2012). Much of this research was not originally done for climate engineering purposes, but only to understand the role of iron in ocean productivity, biogeochemical cycling, and the global climate. Although the theoretical potential of iron fertilization is high (Martin 1990), many of the actual experiments have been inconclusive as to whether or not more carbon was sequestered in the deep ocean even though phytoplankton growth and CO_2 uptake at the surface increased in response to the iron additions (Boyd et al. 2007). Only in one experiment was there an observed transport of some biomass to a depth of 1000 m (Smetacek et al. 2012). Modelling studies have suggested that even if the method was to work as proposed, e.g., relieving phytoplankton iron limitation, the potential to sequester CO_2 is low (only a few Pg C/year) when compared to current emissions, even if for example, the whole Southern Ocean were to be continuously fertilized (Gnanadesikan et al. 2003; Aumont and Bopp 2006; Keller et al. 2014).

Macronutrient CE proposals have been motivated by observations that phytoplankton growth in approximately 70% of the surface ocean appears to be limited by macronutrients (Matear and Elliot 2004). Although, the theoretical potential of adding macronutrients to enhance phytoplankton growth is high (Matear and Elliot 2004; Lawrence 2014), like with iron fertilization, the few experiments that have been conducted have been inconclusive as to how much carbon could actually be sequestered (Karl and Letelier 2008). Modelling simulations also suggest that there are many processes that could make this method less effective than theoretically predicted and that only a few Pg C/year would be sequestered even if large amounts of nutrients were added directly or via artificial upwelling (Matear and Elliot 2004; Keller et al. 2014). If nutrients were to be directly added, there is also the potential that it would be infeasible to mine phosphorus or fix nitrogen (an energy intensive process) and ship it to the open ocean in the quantities (billions of tons) needed to remove significant amounts of carbon.

There are several general side effects associated with ocean fertilization, many of which are similar to the problems caused by eutrophication (see Chap. 22). First, fertilization usually results in a bloom of phytoplankton, which changes the composition and structure of the previous planktonic community (Boyd et al. 2007;

Smetacek et al. 2012). This would affect higher trophic levels like fish, biogeochemical cycles, and may even favor the growth of toxic phytoplankton species (Lampitt et al. 2008). Second, large blooms of phytoplankton will reduce the penetration of light, e.g., have a shading effect, which could affect deeper organisms. Third, as the extra organic matter that was produced in response to fertilization makes its way into the deep ocean, bacteria will consume much of it. This will consume oxygen, which cannot easily be replenished in waters that are not in contact with the surface. Modelling studies have shown that this can cause regions of the ocean where oxygen is already very low to expand or even for new regions to develop (Keller et al. 2014). Since the ocean is projected to lose oxygen as the climate changes (warm water holds less oxygen) (Gruber 2011) ocean fertilization would only enhance this effect unless the method were successful enough to prevent climate change. Moreover, low oxygen waters are also intolerable for many species (Ekau et al. 2010) so this could force some species to leave their previous habitats. Low oxygen waters can also produce GHGs such as nitrous oxide (Zamora et al. 2012), so this could potentially have a feedback effect on the climate. Finally, adding macronutrients such as phosphate could also alter the carbonate chemistry (alkalinity) of seawater (Matear and Elliot 2004).

13.3.3.3 Bioenergy from Marine Sources with Carbon Capture and Storage

As mentioned in Sect. 20.1, there have been proposals to grow macroalgae for BECCS (N‘Yeurt et al. 2012; Duarte et al. 2013). However, more research and even “demonstration” scale facilities have been built to explore culturing algae (phytoplankton) for biofuels (Schenk et al. 2008; Beer et al. 2009) that could potentially be utilized in combination with CCS (see Sect. 18.3). In the course of this development, some research has investigated using genetically modified (GM) organisms to make the methodology more efficient (Schenk et al. 2008; Beer et al. 2009; Flynn et al. 2013). This raises the possibility that these GM organisms could accidently end up in the natural environment since the most efficient and cost-effective culturing methods are open pond systems (Schenk et al. 2008). If GM algae escaped it could have important implications for marine ecosystems that have not been thoroughly assessed (Flynn et al. 2013). Massive amounts of nutrients may also be needed for open or closed marine BECCS and depending on how they were sourced, applied, and disposed of (if not recycled), this could result in other side effects.

13.4 Radiation Management Climate Engineering Methods

Proposed RM methods are designed to manipulate the properties of the ocean that control the amount of incoming short-wave solar radiation (sunlight) that is absorbed or to use thermal properties of seawater to increase the amount of long-wave radiation (essentially heat) that leaves the Earth. Since these methods only treat symptoms of climate change, if implemented they would have to remain in place until the causes of climate change, i.e., mostly the build up of atmospheric CO_2, had been dealt with or there would be consequences upon termination.

13.4.1 Ocean Albedo Modification

The ocean absorbs a large amount of incoming solar radiation because of its low albedo, i.e., it's not very reflective, and stores it as heat. A number of CE ideas have been proposed to increase the reflectivity of the ocean surface and prevent it from warming as much. These include generating reflective micro-bubbles (Seitz 2011), increasing the amount of sea-ice (Ming et al. 2014), or adding reflective floating glass spheres (Walter 2011) or floating foams (Evans et al. 2010; Aziz et al. 2014) to the ocean. Simulations where the ocean albedo was increased only in the Arctic region, indicate that in a high CO_2 world only limited local cooling would occur with sea-ice cover only being partially stabilized (Cvijanovic et al. 2015; Mengis et al. 2016). However, atmospheric circulation and precipitation far outside of the targeted region would also be affected. The potential and side effects of directly altering the global ocean's albedo have not been thoroughly assessed. However, it is reasonable to assume that all such methods would at least have an impact on marine ecosystems and photochemistry by altering the underwater light field.

13.4.2 Marine Cloud Brightening

There have also been proposals to brighten marine clouds (marine cloud brightening; MCB) by adding aerosols to them to increase cloud cover and enhance the properties that make them naturally reflective. MCB is closely linked to the ocean since it would occur over certain oceanic regions and because most of proposals involve spraying a fine mist of seawater into the marine boundary layer to generate the aerosols (Latham 2002; Partanen et al. 2012). So far MCB has been investigate mostly with respect to it's cooling potential, which is likely low (<1 °C globally), and atmospheric side effects such as changes in precipitation (Bala et al. 2011; Partanen et al. 2012). Aside from cooling, which could be up to several degrees locally, little is known on how it would directly affect the marine environment, especially if large amounts of seawater were pumped up and sprayed into the atmosphere.

13.4.3 Earth Radiation Management

There have been several proposals to use specially engineered chimneys, tall towers, or other methods to transfer heat away from the Earth's surface and into the upper atmosphere where it can be radiated back out into space (Ming et al. 2014).

Although many of these methods have nothing to do with the ocean, a few involve using pumped-in seawater during the heat transfer process. There have also been proposals for downdraft evaporative cooling towers, which use seawater sprayed into tall towers in desert regions to create evaporation-induced downdrafts of cold air that cool the land and allow latent heat to escape into space (Ming et al. 2014).

The feasibility and side effects of pumping the massive amounts of seawater needed for any of these methods has not been thoroughly assessed. However, some of the side effects of pumping seawater may be similar, although on a much larger scale, to using seawater to cool conventional power plants. Aquatic life may be affected if trapped on filtering screens or drawn into the pumping system. If discharged water were at a different temperature than the local environment this would also cause problems. If the water evaporates during the processes it could also leave salt or concentrated brines behind that would have to be dealt with.

13.5 Conclusion

Although, some CE methods were proposed decades ago, it is only within the last few years that a significant amount of research on these topics has taken place. Most of the research has been done theoretically or with computer models. For some methods laboratory and small-scale field experiments have also been conducted to gain an understanding of fundamental processes. However, experiments large enough to actually affect the global climate for a prolonged period of time have never been conducted. For all proposed methods there are still many unknowns, at both the level of basic understanding and as to whether or not it would even be technologically feasible to implement any of them. Research so far has shown that some CE methods do have the potential to alter certain aspects of the climate system. Some have more potential than others and most of them appear to have significant side effects. The scale at which CE would need to be implemented also needs carefully consideration since to be even somewhat effective, most methods would involve manipulating massive ocean regions. It is also worth noting that since the ocean covers approximately 71% of the Earth's surface, if proposed land- or atmospheric-based CE methods, were to be implement, due to the large scales involved (i.e., large areas of land or the atmosphere), they too would have a substantial impact upon marine systems through atmosphere-ocean or land-ocean interactions (Keller et al. 2014) and would have to be considered from the perspective of marine environmental protection.

References

Aumont O, Bopp L (2006) Globalizing results from ocean in situ iron fertilization studies. Glob Biogeochem Cycles 20:GB2017. doi:10.1029/2005gb002591

Aziz A, Hailes HC, Ward JM, Evans JRG (2014) Long-term stabilization of reflective foams in sea water. RSC Adv 4:53028–53036. doi:10.1039/C4RA08714C

Bala G, Caldeira K, Nemani R et al (2011) Albedo enhancement of marine clouds to counteract global warming: impacts on the hydrological cycle. Clim Dyn 37:915–931. doi:10.1007/s00382-010-0868-1

Bauer JE, Cai W-J, Raymond PA et al (2013) The changing carbon cycle of the coastal ocean. Nature 504:61–70. doi:10.1038/nature12857

Beer LL, Boyd ES, Peters JW, Posewitz MC (2009) Engineering algae for biohydrogen and biofuel production. Curr Opin Biotechnol 20:264–271. doi:10.1016/j.copbio.2009.06.002

Boyd PW, Jickells T, Law CS et al (2007) Mesoscale iron enrichment experiments 1993–2005: synthesis and future directions. Science 315:612–617. doi:10.1126/science.1131669

Burdige DJ (2005) Burial of terrestrial organic matter in marine sediments: a re-assessment. Global Biogeochem Cycles 19:1–7. doi:10.1029/2004GB002368

Caldeira K, Rau GH (2000) Accelerating carbonate dissolution to sequester carbon dioxide in the ocean: geochemical implications. Geophys Res Lett 27:225–228

Cripps G, Widdicombe S, Spicer JI, Findlay HS (2013) Biological impacts of enhanced alkalinity in Carcinus maenas. Mar Pollut Bull 71:190–198. doi:10.1016/j.marpolbul.2013.03.015

Cvijanovic I, Caldeira K, MacMartin DG (2015) Impacts of ocean albedo alteration on Arctic sea ice restoration and Northern Hemisphere climate. Environ Res Lett 10:044020. doi:10.1088/1748-9326/10/4/044020

Duarte CM, Losada IJ, Hendriks IE et al (2013) The role of coastal plant communities for climate change mitigation and adaptation. Nat Clim Chang 3:961–968. doi:10.1038/nclimate1970

Eisaman MD, Parajuly K, Tuganov A et al (2012) CO_2 extraction from seawater using bipolar membrane electrodialysis. Energy Environ Sci 5:7346. doi:10.1039/c2ee03393c

Ekau W, Auel H, Pörtner H-O, Gilbert D (2010) Impacts of hypoxia on the structure and processes in pelagic communities (zooplankton, macro-invertebrates and fish). Biogeosciences 7:1669–1699

Evans J, Stride E, Edirisinghe M et al (2010) Can oceanic foams limit global warming? Clim Res 42:155–160. doi:10.3354/cr00885

Flynn KJ, Mitra A, Greenwell HC, Sui J (2013) Monster potential meets potential monster: pros and cons of deploying genetically modified microalgae for biofuels production. Interface Focus 3:20120037. doi:10.1098/rsfs.2012.0037

Friedlingstein P, Andrew RM, Rogelj J et al (2014) Persistent growth of CO_2 emissions and implications for reaching climate targets. Nat Geosci 7:709–715. doi:10.1038/ngeo2248

Gnanadesikan A, Sarmiento JL, Slater RD (2003) Effects of patchy ocean fertilization on atmospheric carbon dioxide and biological production. Glob Biogeochem Cycles 17:1050. doi:10.1029/2002gb001940

Gruber N (2011) Warming up, turning sour, losing breath: ocean biogeochemistry under global change. Philos Trans A Math Phys Eng Sci 369:1980–1996. doi:10.1098/rsta.2011.0003

Hangx SJT, Spiers CJ (2009) Coastal spreading of olivine to control atmospheric CO_2 concentrations: a critical analysis of viability. Int J Greenhouse Gas Control 3:757–767. doi:10.1016/j.ijggc.2009.07.001

Hartmann J, West AJ, Renforth P (2013) Enhanced chemical weathering as a geoengineering strategy to reduce atmospheric carbon dioxide, supply nutrients, and mitigate ocean acidification. Rev Geophys 51:113–149. doi:10.1002/rog.20004.1.Institute

Harvey LDD (2008) Mitigating the atmospheric CO_2 increase and ocean acidification by adding limestone powder to upwelling regions. J Geophys Res Ocean 113. doi:10.1029/2007jc004373

Heinze C, Meyer S, Goris N et al (2015) The ocean carbon sink – impacts, vulnerabilities and challenges. Earth Syst Dynam 6:327–358. doi:10.5194/esd-6-327-2015

Ilyina T, Wolf-Gladrow D, Munhoven G, Heinze C (2013a) Assessing the potential of calcium-based artificial ocean alkalinization to mitigate rising atmospheric CO_2 and ocean acidification. Geophys Res Lett 40:5909–5914. doi:10.1002/2013GL057981

Ilyina T, Wolf-Gladrow D, Munhoven G, Heinze C (2013b) Assessing the potential of calcium-based artificial ocean alkalinization to mitigate rising atmospheric CO_2 and ocean acidification. Geophys Res Lett. doi:10.1002/2013GL057981

IPCC (2014) Climate change 2014: impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. In: Field CB, Barros VR, Dokken DJ, Mach KJ (eds) Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge and New York

IPCC (2013) Climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change

Karl D, Letelier R (2008) Nitrogen fixation-enhanced carbon sequestration in low nitrate, low chlorophyll seascapes. Mar Ecol Prog Ser 364:257–268. doi:10.3354/meps07547

Keller DP, Feng EY, Oschlies A (2014) Potential climate engineering effectiveness and side effects during a high carbon dioxide-emission scenario. Nat Commun 5:1–11. doi:10.1038/ncomms4304

Kheshgi HS (1995) Sequestering atmospheric carbon dioxide by increasing ocean alkalinity. Energy 20:915–922. doi:10.1016/0360-5442(95)00035-F

Köhler P, Abrams JF, Völker C et al (2013) Geoengineering impact of open ocean dissolution of olivine on atmospheric CO_2, surface ocean pH and marine biology. Environ Res Lett 8:14009

Köhler P, Hartmann J, Wolf-Gladrow DA (2010) Geoengineering potential of artificially enhanced silicate weathering of olivine. Proc Natl Acad Sci U S A 107:20228–20233. doi:10.1073/pnas.1000545107

Kwiatkowski L, Ricke KL, Caldeira K (2015) Atmospheric consequences of disruption of the ocean thermocline. Environ Res Lett 10:034016. doi:10.1088/1748-9326/10/3/034016

Lackner KS, Brennan S, Matter JM et al (2012) The urgency of the development of CO_2 capture from ambient air. Proc Natl Acad Sci U S A 109:13156–13162. doi:10.1073/pnas.1108765109

Lampitt R, Achterberg E, Anderson T et al (2008) Ocean fertilization: a potential means of geoengineering? Philos Trans R Soc A Math Phys Eng Sci 366:3919–3945. doi:10.1098/rsta.2008.0139

Latham J (2002) Amelioration of global warming by controlled enhancement of the albedo and longevity of low-level maritime clouds. Atmos Sci Lett 3:52–58. doi:10.1006/asle.2002.0048

Lawrence MW (2014) Efficiency of carbon sequestration by added reactive nitrogen in ocean fertilisation. Int J Glob Warming 6:15–33

Lovelock JF, Rapley CG (2007) Ocean pipes could help the Earth to cure itself. Nature 449:403. doi:10.1038/449403a

Marchetti C (1977) On geoengineering and the CO_2 problem. Clim Chang 1:59–88

Marion GM, Millero FJ, Feistel R (2009) Precipitation of solid phase calcium carbonates and their effect on application of seawater SA-T-P models. Ocean Sci 5:285–291. doi:10.5194/os-5-285-2009

Martin JH (1990) Glacial-interglacial CO_2 change: the iron hypothesis. Paleoceanography 5:1–13. doi:10.1029/PA005i001p00001

Maruyama S, Yabuki T, Sato T et al (2011) Evidences of increasing primary production in the ocean by Stommel's perpetual salt fountain. Deep Res Part I Oceanogr Res Pap 58:567–574. doi:10.1016/j.dsr.2011.02.012

Matear RJ, Elliot B (2004) Enhancement of oceanic uptake of anthropogenic CO_2 by macronutrient fertilization. J Geophys Res 109:C04001. doi:10.1029/2000JC000321

Mengis N, Martin T, Keller DP, Oschlies A (2016) Assessing climate impacts and risks of ocean albedo modification in the Arctic. J Geophys Res Ocean:8271–8295. doi:10.1002/2015JC011433

Ming T, de Richter R, Liu W, Caillol S (2014) Fighting global warming by climate engineering: is the Earth radiation management and the solar radiation management any option for fighting climate change? Renew Sust Energ Rev 31:792–834. doi:10.1016/j.rser.2013.12.032

N'Yeurt ADR, Chynoweth DP, Capron ME et al (2012) Negative carbon via ocean afforestation. Process Saf Environ Prot 90:467–474. doi:10.1016/j.psep.2012.10.008

National Reseach Council (2015) Climate intervention: carbon dioxide removal and reliable sequestration. The National Academies Press, Washington, DC

Orr JC (2004) Modelling the ocean storage of CO_2 – the GOSAC study. Report
Oschlies A, Koeve W, Rickels W, Rehdanz K (2010) Side effects and accounting aspects of hypothetical large-scale Southern Ocean iron fertilization. Biogeosciences 7:4017–4035
Partanen AI, Kokkola H, Romakkaniemi S et al (2012) Direct and indirect effects of sea spray geoengineering and the role of injected particle size. J Geophys Res Atmos 117:1–16. doi:10.1029/2011JD016428
Rau GH (2014) Enhancing the ocean's role in CO_2 mitigation. In: Global environmental change. Springer Netherlands, Dordrecht, pp 817–824
Rau GH (2008) Electrochemical splitting of calcium carbonate to increase solution alkalinity: implications for mitigation of carbon dioxide and ocean acidity. Environ Sci Technol 42:8935–8940. doi:10.1021/es800366q
Rau GH, Carroll SA, Bourcier WL et al (2013) Direct electrolytic dissolution of silicate minerals for air CO_2 mitigation and carbon-negative H_2 production. Proc Natl Acad Sci U S A 110:10095–10100. doi:10.1073/pnas.1222358110
Renforth P, Jenkins BG, Kruger T (2013) Engineering challenges of ocean liming. Energy 60:442–452. doi:10.1016/j.energy.2013.08.006
Schenk PM, Thomas-Hall SR, Stephens E et al (2008) Second generation biofuels: high-efficiency microalgae for biodiesel production. Bioenergy Res 1:20–43. doi:10.1007/s12155-008-9008-8
Seitz R (2011) Bright water: hydrosols, water conservation and climate change. Clim Chang 105:365–381. doi:10.1007/s10584-010-9965-8
Smetacek V, Klaas C, Strass VH et al (2012) Deep carbon export from a Southern Ocean iron-fertilized diatom bloom. Nature 487:313–319. http://www.nature.com/nature/journal/v487/n7407/abs/nature11229.html#supplementary-information
Strand SE, Benford G (2009) Ocean sequestration of crop residue carbon: recycling fossil fuel carbon back to deep sediments. Environ Sci Technol 43:1000–1007. doi:10.1021/es8015556
Tollefson J (2012) Ocean-fertilization project off Canada sparks furore. Nature 490:458–459. doi:10.1038/490458a
Walter AGN (2011) Controlling the Earth's albedo using reflective hollow glass spheres. Int J Glob Environ Issues 11:91. doi:10.1504/IJGENVI.2011.043508
White A, Björkman K, Grabowski E et al (2010) An open ocean trial of controlled upwelling using wave pump technology. J Atmos Ocean Technol 27:385–396. doi:10.1175/2009JTECHO679.1
Zamora LM, Oschlies A, Bange HW et al (2012) Nitrous oxide dynamics in low oxygen regions of the Pacific: insights from the MEMENTO database. Biogeosciences 9:5007–5022. doi:10.5194/bg-9-5007-2012
Zhou S, Flynn P (2005) Geoengineering downwelling ocean currents: a cost assessment. Clim Chang 71:203–220

Part III
Impacts of Land-Based Activities

Chapter 14
Agriculture

Oene Oenema, Qian Liu, and Jingmeng Wang

Abstract Agriculture is a main contributor of nitrogen (N) and phosphorus (P) to the marine environment, and thereby a main cause of eutrophication of marine ecosystems. By the end of the twentieth century, roughly half of the total N and P input into the aquatic environment originated from agriculture. The relative contribution of agriculture has increased by a factor of 8 for N, and by a factor of 1.6 for P during the last century. As a result, the N/P ratio of the inputs have strongly increased. Contributions from agriculture increased especially from the 1960s, following the rapid rise in fertilizer use and manure production. Enlarged areas of agricultural land at the expense of natural areas including forests have also contributed. Leaching and runoff are the main pathways for N losses, while runoff is the main pathway for P losses from agriculture to sea.

There are huge differences between countries in N and P use efficiencies and N and P surpluses, and hence in N and P losses. In Sub-Saharan countries, N and P surpluses are small or negative. Surpluses are high and increasing in countries in transition (China, India, Brazil). Many affluent countries (US, EU) have relatively high but decreasing surpluses, following the implementation of good agricultural practices and environmental regulations in practice.

Forecasts indicate that global food production may have to increase by 50% or more relative to the production level in 2010 during the next five decades, while N and P losses will have to decrease at the same time, to halt eutrophication and biodiversity losses. For this to happen, N and P use efficiencies in food production have to increase drastically, and N and P from manure, sludge, and wastes have to be recycled and reused more effectively.

Keywords Food • Land use • Management • Nitrogen • Phosphorus • Fertilization • Euthrophication • Nutrient balances • Driving forces

---

O. Oenema (✉) • Q. Liu • J. Wang
Wageningen University and Research, Wageningen, The Netherlands
e-mail: oene.oenema@wur.nl

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_14

14.1 Introduction

Agriculture is a dominant land user and has a large impact on the aquatic environment. The main purpose of agriculture is to provide sufficient, safe and diverse food and fibre to consumers, and sufficient income to farmers. Agriculture is diverse and dynamic. It responds to external driving forces (changes in markets, education, technology and governmental policy). It depends on environmental conditions (climate, geomorphology and soil). Changes in agriculture have enabled huge production increases; agriculture managed to produce sufficient food for the one billion people in 1850 as well as for the seven billion people in 2015 (Smil 2000; Tilman et al. 2011). Yet, there are currently about one billion people with undernutrition, especially in Asia and Africa (Black et al. 2013), which is mainly related to poor distribution of food and to the limited affordability of food to poor people.

Agriculture has large effects on the environment, through land use changes, the domestication of a limited number of crops and animals, the use of yield-enhancing inputs (fertilizers, water), the use of crop and animal-protecting inputs (pesticides, medicines), and the use of facilitating inputs (machines, fossil energy). Agriculture is implicated for its contributions to global biodiversity loss, increased greenhouse gas emissions, fresh water depletion, soil erosion, and water pollution (Sachs 2008; Pimentel and Pimentel 2008; Steinfeld et al. 2010). Biodiversity loss is the result of land use change and the enrichment of the environment with nitrogen (N) and phosphorus (P). Greenhouse gas emissions mainly result from land use change, animal production (mainly ruminants), paddy rice production, and the uses of fertilizer N and fossil energy. Soil erosion mainly follows from poor soil management (intensive soil cultivation, annual cropping), overgrazing, and large-scale mechanization. Depletion of fresh water resources is the result of irrigation, while pollution may follow from the use of some types of fertilizers, pesticides and medicines.

Direct impacts of agriculture on the marine environment occur through the transport of gaseous substances (ammonia, pesticides) via air and of dissolved and particulate substances (nutrients, metals, pesticides, antibiotics, wastes, soil) via rivers. Indirect impacts may occur through the impact of agriculture on greenhouse gas emissions (mainly CO_2, CH_4 and N_2O) and climate change, as well as through the globalisation of food production and processing and the associated increased transport of food and feed across the oceans. Direct impacts are much larger than the indirect ones.

Awareness of the environmental effects of agriculture mainly dates from the second half of the twentieth century. The alarming story of Silent Spring (Carson 1962) marks a change-point; the detrimental effects of some pesticides on life and nature were put in the spot light. At about the same time, it was found that losses of nitrogen (N) and phosphorus (P) from land-based activities contributed to pollution and eutrophication of lakes and rivers (Rodhe 1969). Recognition of coastal eutrophication by agricultural nutrient inputs dates from the 1980s (Nixon 1995). This holds also for aquaculture (Bergheim et al. 1982). This increased awareness has initiated a range of governmental policy measures to decrease the impacts of agriculture on the environment, especially in Europe and Northern America (Schloen, Chap. 35).

This chapter focusses on N and P losses from agriculture to the marine environment, and on the background and causes of these losses. Enrichment of coastal zones with N and P increases the incidence of harmful algae blooms and hypoxic conditions, and may have detrimental consequences for benthic and pelagic ecosystems (Van Beusekom, Chap. 22). Changes in the loss of N and P from agriculture reflect changes in inputs and agricultural production methods. At global scale, there are relatively strong correlations between inputs of nutrients and the inputs of pesticides and other agrochemicals to agriculture (Tilman et al. 2001, 2002). Changes in the inputs and loss of N and P from agriculture may be seen therefore as rough proxies for the impact of agriculture on the marine environment. This chapter is based on literature review; estimates of the impact of agriculture on the environment are in general based on modelling and monitoring studies combined with farm surveys (statistics).

14.2 Nitrogen and Phosphorus Losses from Global Agriculture

Modelled N deposition rates show a strong land-sea gradient (EMEP 2015, 2016). Total N deposition (reduced and oxidized N) ranges from 8–12 kg ha/year in coastal seas near densely populated countries to 2–4 kg ha/year in the Mediterranean and to <2 kg ha/year in oceans. Less than half is reduced N (mainly NH_3). Atmospheric N deposition is yet a minor source of N from agriculture to the oceans (Fig. 14.1; Beusen et al. 2016). Main sources of NH_3 in agriculture are animal manures and urea-based N fertilizers (Amann 2014; Bittman et al. 2014).

The total N and P inputs to surface waters have strongly increased in the twentieth century (Fig. 14.1), mainly through the increasing contributions from agriculture. The delivery of N from agriculture occurs through leaching and subsequent groundwater seepage (about 60%) and through overland flow (i.e. surface runoff, erosion; about 40%). The delivery of P from agriculture occurs mainly through overland flow (i.e. erosion), because P is strongly bound to soil particles and downward leaching to groundwater is therefore small (Pierzynsky et al. 2005). Note that the estimated contributions from natural ecosystems (including forests) have slightly decreased during the twentieth century (mainly through the decreasing areas), while the contribution of sewage from households and industry has strongly increased. The relative contribution of agriculture to the total loading of surface waters has increased from about 6% in 1900 to 51% in 2000 for N, and from 35% in 1900 to 56% for P (Beusen et al. 2016). These strong increases are related to the huge changes in agriculture during this period (see next paragraphs).

There is considerable uncertainty in the estimated total river N and P export to the marine system and in the relative contributions of agriculture to this loading.

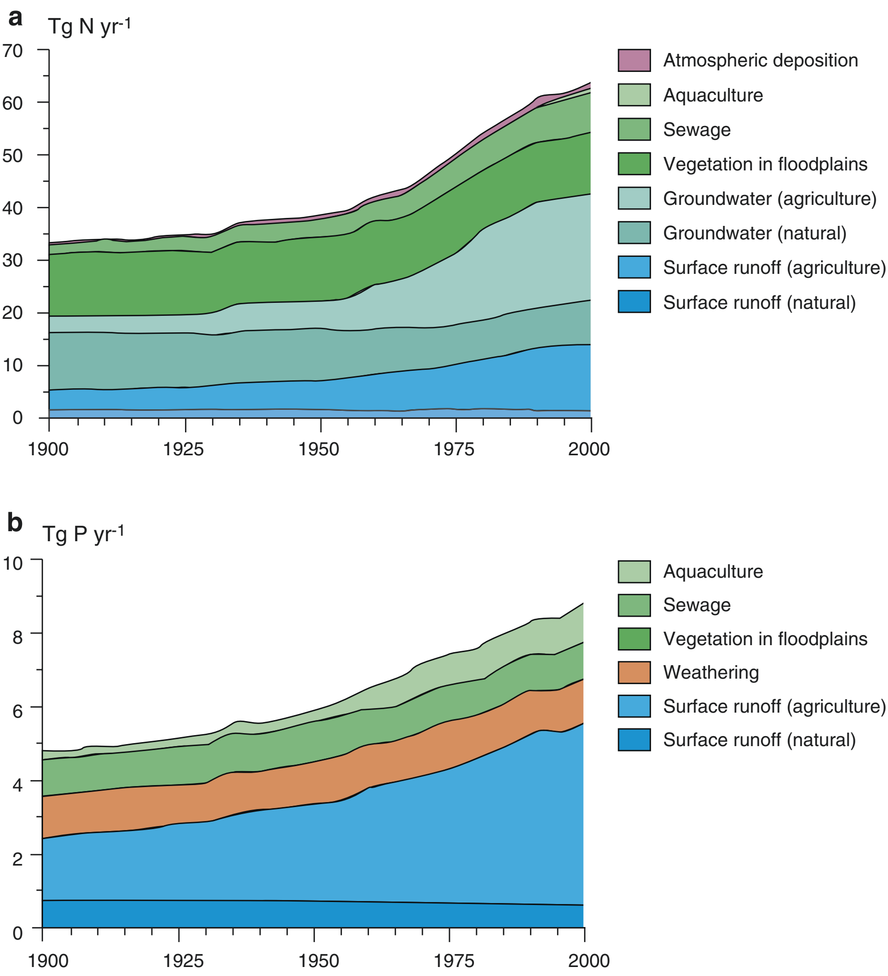


Fig. 14.1 Global N and P delivery to surface waters from different sources in the twentieth century. Note that 55–59% of the total N and 42–47% of the total P delivered to surface waters reaches the coastal system, the remainder is retained in streams, rivers, lakes and reservoirs (Beusen et al. 2016)

Estimates of the total river N export range from 36 to 60 Tg, and those for P from 4 to 22 Tg/year (Beusen et al. 2016). These wide ranges are related to the huge variation in agricultural systems across the globe, the complexity of the N and P loss pathways, and the complexity of the riverine systems (Schlesinger and Bernhardt 2013). Bouwman et al. (2013) describe the complexity of the nutrient transfer, retention and delivery from land to oceans, and the different concepts that are being used in modelling studies. Great progress has been made in model concepts during the last 30 years, but further progress is needed.

14.3 Changes in the Areas of Agricultural Land and Forests

Currently, about one-third of the land cover (149 million km^2) of our planet is used for agriculture (49 million km^2). Slightly less than one-third of the global land area is covered by forest and wood land (41 million km^2). Deserts and other bare areas cover about 15%, snow and glaciers about 10%, wetlands 3% and artificial areas nearly 1% of the total land area (Table 14.1). However, there is considerable uncertainty in land cover areas, due to (1) gradual transitions between land use types, which make it not easy to define the land use precisely, and (2) changes over time in land use. Changes in land use result from global changes in the human needs of food, feed, biofuel and timber, and from changes in climate, combined with fires. Deforestation, i.e., the transformation of forest into crop land and pastures, is as old as there are humans on earth, but the rate of change has strongly increased from the 1950s, following the rapid increase in the human and animal populations, and the rapid development of technology, transport, industry, and urban areas (Vitousek et al. 1997; Smil 2001; Williams 2003).

Currently, about one-third of the total agricultural area in the world is used for the production of plant-derived food, i.e., cereals, vegetables, fruits, roots, oil, nuts (Table 14.2). The three main cereals, i.e., rice, wheat and maize together, provide

Table 14.1 Global distribution of land cover classes, including Antarctica in 2010 (Latham et al. 2014)

Land cover class	Percentage
Artificial surfaces	0.6
Cropland	12.6
Grassland/shrubs/herbaceous/sparse vegetation	31.5
Tree covered area (forest)	27.7
Bare areas	15.2
Snow and glaciers (including Antarctica)	9.7
Wetlands and mangroves	2.7
Total	100

Table 14.2 Areas of forest and agricultural land per continent in 2013, in million km^2

Land use types	World	Africa	Americas	Asia	Europe	Oceania
Total land area	130.1	29.7	38.8	31.0	22.1	8.5
Forest area	40.1	6.3	16.0	5.9	10.2	1.7
Permanent grassland	33.5	9.0	8.3	10.8	1.8	3.6
Crop land	15.8	2.7	4.0	5.7	2.9	0.5
Cereal crops	7.2	1.1	1.3	3.4	1.2	0.2
Oil crops	2.9	0.4	1.1	1.1	0.4	0.1
Tuber crops	0.6	0.3	0.1	0.2	0.1	0.0
Vegetables crops	0.6	0.1	0.0	0.4	0.0	0.0
Fruit crops	0.6	0.1	0.1	0.3	0.1	0.0

Antarctica is excluded in the total land area (Source: FAOSTAT (2015) about 60% of the total calorie intake by humans. Total wheat production was about 710 Tg, rice production 740 Tg and maize production 1020 Tg in 2013 (1 Tg = 10^{12} g = 1 million ton). Almost all rice is consumed by humans, but about one-third of the wheat and more than half of the maize are consumed by domestic animals. The area of wheat and rice production have only slightly increased during the last 5 decades, the areas of maize, vegetables and fruits have doubled, while the areas of oil crops (soybean, oil palm, rapeseed, sunflower) have increased by a factor of about 4.

About two-third of the total agricultural area in the world is used for the production of animal feed. This includes 34 million km^2 of pastures, used for the production of dairy, beef, sheep and goat production. Global milk and beef production have both increased by ~5% per year during the last 50 years, whereas grassland (and arable land) areas have not increased much (<10% in 50 years). In addition, an increasing fraction of the arable land is used for the production of maize, soybean and wheat, fed to the increasing number of pigs and poultry. The increases in animal production in the world are driven by the increasing demand for animal derived food by the increasing human population, and facilitated by the increasing prosperity of part of this population (Steinfeld et al. 2010). This so-called livestock revolution is supported by developments in science and technology, transnational corporations, the agglomeration of production and processing near large markets, and not hindered much by regulations so far. The increases in the number of animals is especially rapid in Asia (Fig. 14.2).

14.4 Changes in Crop and Animal Productivity

Crop yields per unit surface area have increased by a factor of 3–4 in most affluent countries during the last 5 decades. Low crop yields are mainly related to shortages of nutrients and/or water (Mueller et al. 2012). Animal productivity has also increased greatly, but productivity still differs greatly between continents; e.g., mean milk yield per cow was <1000 L per year in Africa and >3000 L per year in America, Australia and Europe during the period 2005–2010 (Table 14.3), and >7000 L per cow in northern America and western Europe (not shown). The steady increase in crop productivity has been made possible through improvements in breeding, irrigation, fertilization, and improvements in crop husbandry practices and in pest and disease management. The steady increase in animal productivity has been made possible through animal breeding and improvements in animal feeding and herd and disease management.

The increased productivity has been facilitated by scientific and technological developments, education, extension services, and the availability of relatively cheap energy, irrigation water, fertilizers, herbicides and pesticides, and antibiotics. Food processing industries and the retail sector have at the same time diversified the food and have added value to the products, facilitated through processing technology, cooling and marketing. However, farmers have not much benefitted

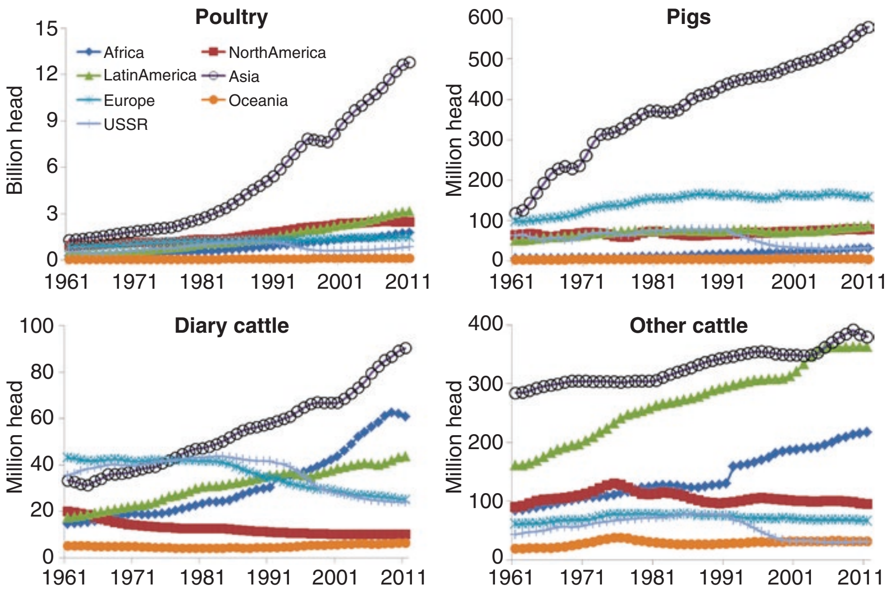


Fig. 14.2 Total number of poultry, pigs, dairy cattle and other cattle per continent in the world between 1961–2012. Number of poultry is expressed in billion head, other animals in millions. Data source: FAOSTAT (2015)

Table 14.3 Crop and animal productivity per continent; means for the period 2005–2010

Crop and animal productivity	America	Africa	Asia	Australia	Europe	World
Wheat, kg/ha	2815	2292	2848	1490	3614	2943
Rice, kg/ha	4977	2501	4310	6824	5964	4242
Maize, kg/ha	6831	1870	4408	6529	5853	5015
Soybean, kg/ha	2698	1134	1400	2149	1633	2385
Milk yield, kg/dairy cow	3238	497	1589	4125	5100	2301
Beef, kg/head other cattle	258	161	147	223	240	207
Pork, kg/head	87	50	74	63	87	79
Egg, kg/layer	12	5	9	11	13	10
Poultry, kg/head broilers	2	1	1	2	2	2

Source: FAOSTAT (2015)

from the increased productivity and added value generation in the food chain. For example, the real price of milk received by dairy farmers in the Netherlands has decreased by a factor of 5 since 1950, while the price of milk in super markets has decreased only by a factor of 2 (Schelhaas 2009). To be able to survive, dairy farmers (as well as other farmers) greatly increased labour productivity; in the Netherlands, milk production per labourer increased from <5 kg milk per hour in 1960 to >150 kg/h in 2010. The increased labour productivity has been accompanied by an exodus of farmers and labourers; while total milk production doubled, the number of dairy farms decreased by a factor of 6 between 1960 and 2010.

Similar trends have been observed for the major cereals as corn, soybeans and wheat in the US.

Governmental policies have supported agricultural production in many countries, through facilitation of the build-up of a good knowledge and physical infrastructure, through market and product support and through subsidies on inputs (including fertilizers). Increased productivity has been facilitated also by liberalization and internationalization of markets and increased competition.

14.5 Changes in Fertilizer Use

The use of fertilizers has greatly increased in the second half of the twentieth century, when the technology for manufacturing fertilizers became more mature, transport facilities became cheaper, and the knowledge among farmers on how and how much fertilizer to use greatly increased (Erisman et al. 2008). Figure 14.3 shows the changes over time in fertilizer nitrogen (N), phosphorus (P), and potassium (K) use in the world and per continent. There are large differences in the changes over time between continents. Fertilizer use started relatively early in Europe and North America, but the increase slowed down from the 1980s and in Europe decreased due to saturation of markets and the implementation of environmental policies.

Asia has become the largest user from the 1980s; it has the largest area of crop land and the largest population (Table 14.2). Fertilizer application rates are often very high in Asia, because of the rapidly increasing food demand by the increasing human population, and the subsidies on fertilizers. Use of potassium (K) fertilizers in Asia is relatively low compared to other continents, although it is increasing due to increased awareness of K limitations in soils. Fertilizer use is still very low in Africa, relative to its large population and large agricultural area, mainly because of market and infrastructure constraints.

Total fertilizer use in Europe decreased strongly from the early 1990s due to (1) political changes and the removal of subsidies on fertilizers in central European countries, and (2) the implementation of environmental policies in the European Union (EU) countries. The implementation of the Nitrates Directive in the EU in 1991 has strongly increased the utilization of nutrients from animal manures and thereby decreased the need for mineral fertilizer input. This Directive aims at reducing the pollution of water resources by nitrate from agriculture through a number or regulatory measures, including the leak-tight storage of animal manure and fertilizer, and a ban on the application of animal manures and fertilizers during winter periods and on wet land and near water courses (Oenema et al. 2011). Political changes had a large effect on fertilizer use in the former countries of the Union of Soviet Socialist Republics (USSR) in the 1990s (Fig. 14.3). Forecasts indicate that the fertilizer NPK use will more or less stabilise during the next decades in EU-countries. Recent policy initiatives suggest a zero growth of fertilizer use in China by 2020. Fertiliser use in other Asian countries and especially in Africa will likely increase due to the increasing need for food by the increasing population.

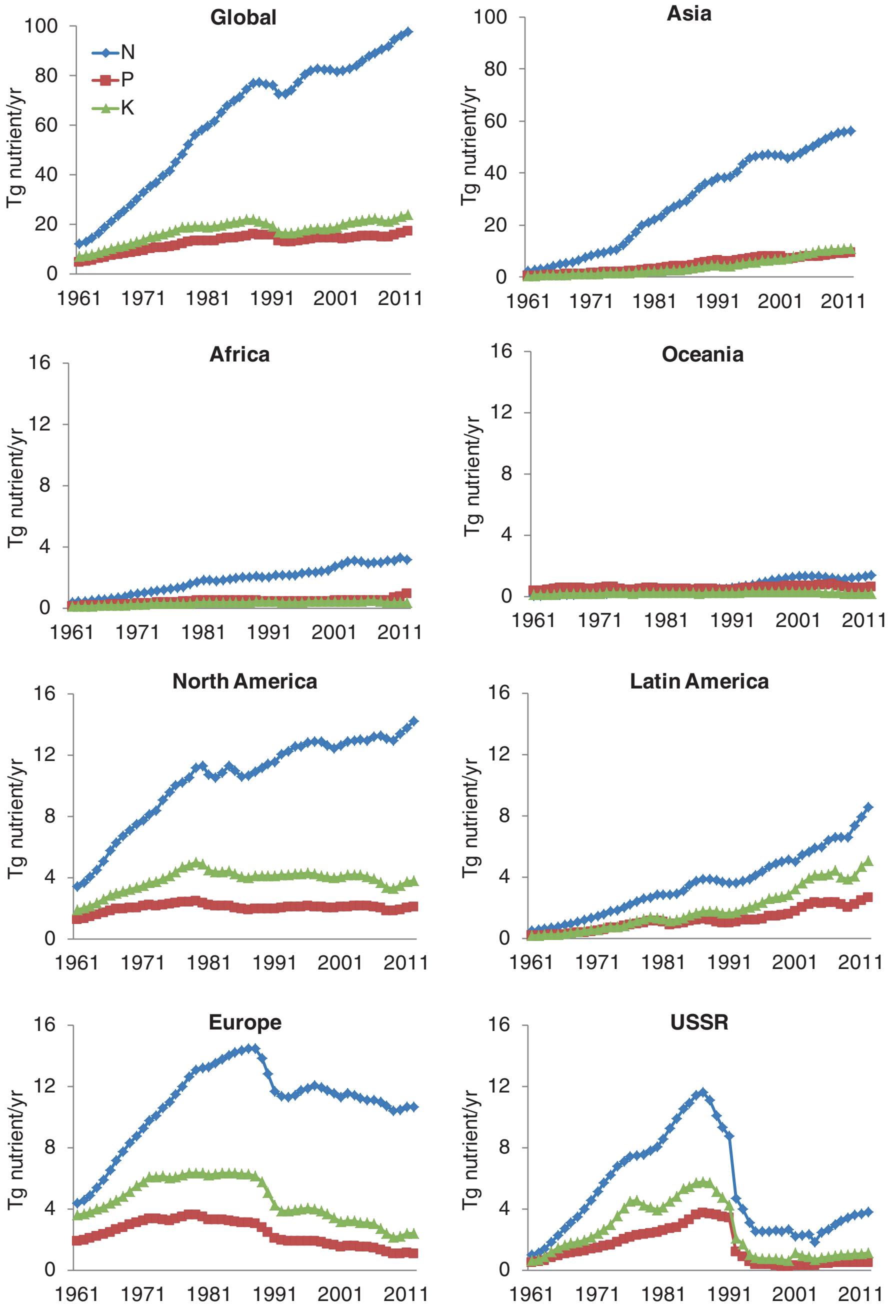


Fig. 14.3 Consumption of nitrogen (N), phosphorus (P), and potassium (K) fertilizers in the world (*upper left panel*) and per continent between 1961–2012. Note the differences in Y-axis between the upper two panels and the lower six panels. Data source: FAOSTAT (2015)

14.6 Changes in the Amounts of N and P in Animal Products and Manures

Animals retain only a fraction of the carbon and nutrient elements in the animal feed in live-weight gain, milk and egg (Fig. 14.4). For N and P, these fractions range from about 10% in live-weight gain of ruminants used for beef and mutton production, to 20–30% for dairy production, to 30 up to 45% for pork and poultry production. The remainder is excreted in faeces and urine. The total amounts of N and P in manure are larger than the total use of fertilizer N and P in the world throughout the indicated period. However, the increase in fertilizer N and P use has been larger than the increase in the production of animal manure N and P.

Cattle (dairy and other cattle) contribute approximately half to the total amounts of N and P in animal manures. Pigs and poultry contribute approximately one-third, while sheep and goat, buffaloes, horses, camels, donkeys and various other small animal make up the rest.

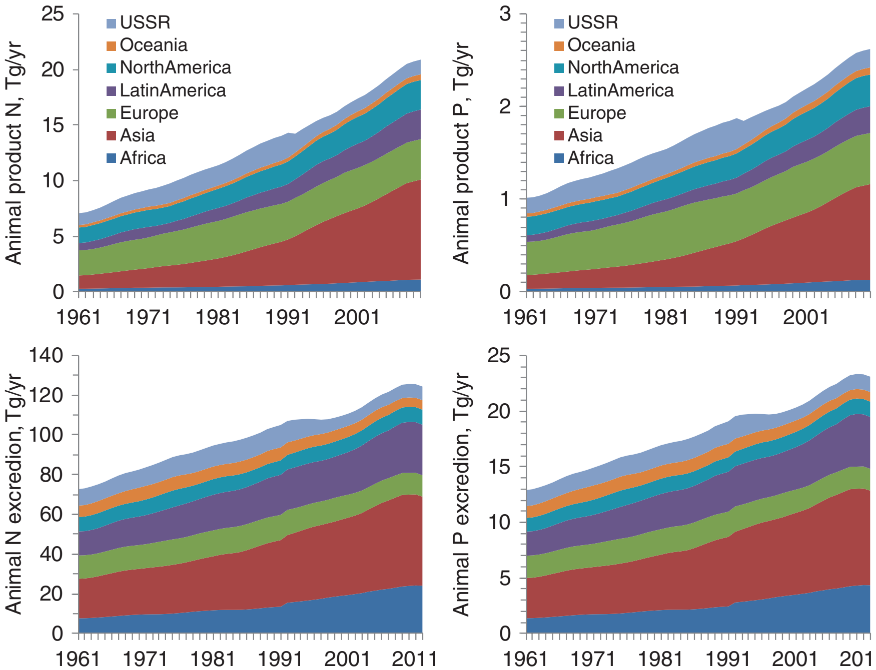


Fig. 14.4 Total amounts of nitrogen (N) and phosphorus (P) in animal live-weight gain, milk, and eggs produced (*upper two panels*), and the total amounts of N and P excreted in faeces and urine (*lower two panels*) by all animals per continent between 1961–2011. Data source: FAOSTAT (2015) and own calculations, using IPCC (2006) N excretion coefficients

14.7 Changes in the Trade of Food and Feed

In the second half of the twentieth century, agricultural systems became more specialized and agglomerations of specialized systems further developed. At the same time, more and more people started to live in urban areas. As a result, food and feed products needed to be transported over longer distances. The specialization and agglomeration of food production systems was facilitated also by Transnational Corporations (TNCs), which increasingly influence the food production—consumption chain (UNCTAD 2009). These TNCs contribute also to the diversification of food products in super markets, increase the length of the food chain and add value to the products. They become increasingly powerful; the value of the ten largest retailers in the world was roughly similar to the total value of the total produce of farmers in 2005 (Von Braun and Díaz-Bonilla 2008).

The urbanization, specialization, and separation of crop and livestock production systems have contributed to a rapid increase in cross-border transport of crop and animal products. Expressed in amounts of N, the total sum of imported crop products (which is equal to the total sum of exported crop products) was about 20 Tg in 2010, equivalent to about 20% of the total amount of N in the harvested crop. Similarly, the amounts of P in imported animal products was 3.5 Tg in 2010, which is also about 20% of the total amount of P in livestock products produced. Europe and Asia were relatively large importers in 2010 of both crop products and animal products. Biggest exporters were North America, Latin America, and Europe. Europe was a net importer of crop products, while the import and export of animal products roughly balanced. Evidently, Europe is heavily involved in the trade of food and feed.

14.8 Nutrient Flows in Food Systems

The nutrients embedded in plant and animal derived food are ultimately consumed/used by humans (households). This holds as well for non-food products. Figure 14.5 shows the P flows in the whole food production and consumption chain of the EU for 2005. Inputs are shown on the left-hand side and outputs (export and losses) on the right-hand side. Total P inputs (2392 Gg) were much larger than total P outputs (1448 Gg) in 2005; the difference (924 Gg) represents the net accumulation of P in agricultural soils. The results indicate that about 4 kg of P input was needed to get 1 kg of P in food entering into households; the remainder was either stored in agricultural soil or lost to the wider environment. This is a typical pattern of affluent societies; between 4 and 10 kg of N and P need to be imported into the food chain to be able to reach 1 kg of N and P in the food entering households (Galloway and Cowling 2002; Ma et al. 2012).

The total human population in the EU-27 is about 500 million, suggesting that households imported on average 1.1 kg P per capita per year. The amounts actually consumed were less (about 0.8 kg). Next to food, households imported slightly more than 0.4 kg per capita per year in non-food products. Most of the imported P

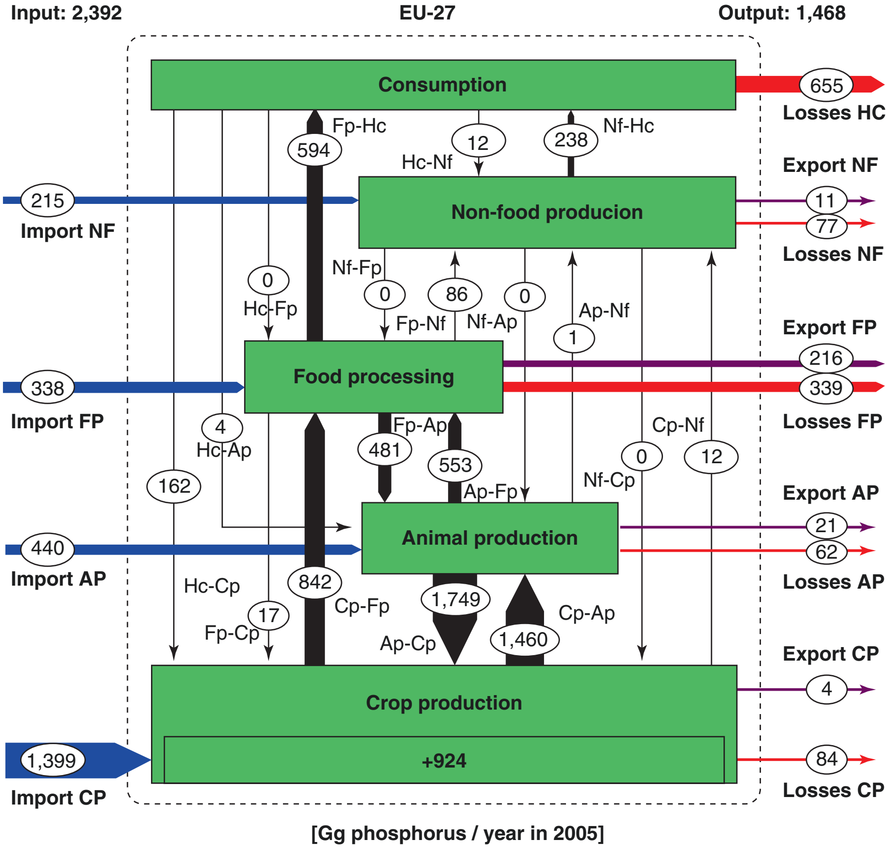


Fig. 14.5 Phosphorus (P) use in the food production—consumption chain of the EU-27 in 2005 (Gg P/year). *Arrows* indicate P flows; *blue arrows* indicate imports, *purple arrows* exports, *red arrows* losses, and *black arrows* indicate internal upward/downward flows between sectors within the whole food chain. The *thin black broken line* indicates the boundaries of the EU food production-consumption chain (Van Dijk et al. 2015)

in households was lost to the environment (~1.1 kg per capita per year), either to surface waters or landfill, and less than 0.2 kg per capita per year was recycled in crop and animal production in 2005. Many suggestions have been proposed and measures initiated to increase the utilization of P from residues, wastes and agricultural soil (Withers et al. 2015; Rowe et al. 2015).

Nitrogen (N) flows in the food production—consumption chain differ from P flows, because of the much greater mobility of N (Smil 2001). Unlike for P, losses of N from the crop and animal production compartments to atmosphere, groundwater and surface water bodies are large, while no significant accumulation takes place within agricultural soils. Losses of N via leaching to groundwater and surface waters were 3.3 Tg N, and N losses via ammonia volatilization and (de)nitrification processes were 9 Tg in the EU-27 in 2005 (Fig. 14.6). Losses from the households and processing compartments were not considered (Westhoek et al. 2014).

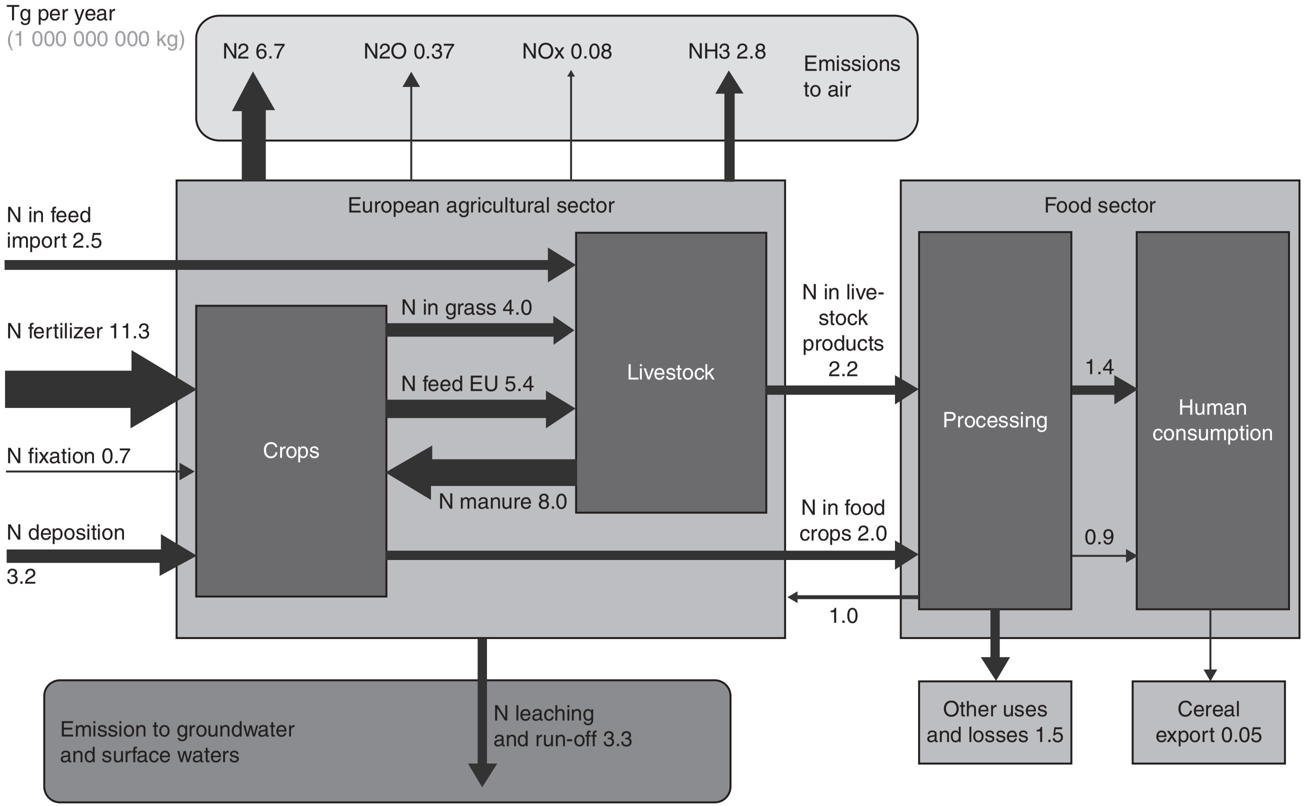


Fig. 14.6 Nitrogen (N) use in the food production—consumption chain of the EU-27 in 2005 (in Tg year). Four main sectors were distinguished within the food chain. *Upper box* represents the atmosphere, *lower box* groundwater and surface waters (*left-hand side*) and other sectors and countries (*right-hand side*) (Westhoek et al. 2014)

14.9 Changes in Nutrient Balances

Input-output balances at country level reflect the net use of nutrients (surpluses or deficits). During the second half of the twentieth century, the N and P inputs increased more than the N and P outputs, and as a result surpluses increased in most countries. Surpluses are indicators for potential losses (especially for N) and/or for accumulation in the system (especially for P).

Figure 14.7 shows different patterns between countries in the development of N and P surpluses between 1961 and 2010. In China and Brazil, the N and P surpluses continued to increase nearly linearly during the whole period. In United States, N surpluses slowly but steadily increased, while P surpluses started to decrease from the 1970s–1980s following the increased awareness of the build-up of soil P levels and of the effects of P losses on the eutrophication of surface waters. In EU countries (e.g., France, Germany), the N and P surpluses increased initially, but decreased from the 1970s–1980s following the increased awareness of increased soil P test values and the implementation of agri-environmental policies.

The input-output balances have been established at the food system level in a country. Any recycling of N and P from residues and wastes was implicitly taken into account. The patterns for P are rather similar for those of N, but the decreases in surplus in the EU countries from the 1980s are stronger and start earlier for P than for N. China and Brazil are expected to show similar patterns in the near future, when the soil P levels have built up to satisfactorily levels. Most of the surplus P has accumulated in agricultural soils, but a significant fraction is also lost to surface waters or is landfilled in wastes (Van Dijk et al. 2015). Evidently, the challenge is to utilize this so-called legacy soil P again (Withers et al. 2014; Rowe et al. 2015) and to explore options for the recycling of landfilled and sequestered P.

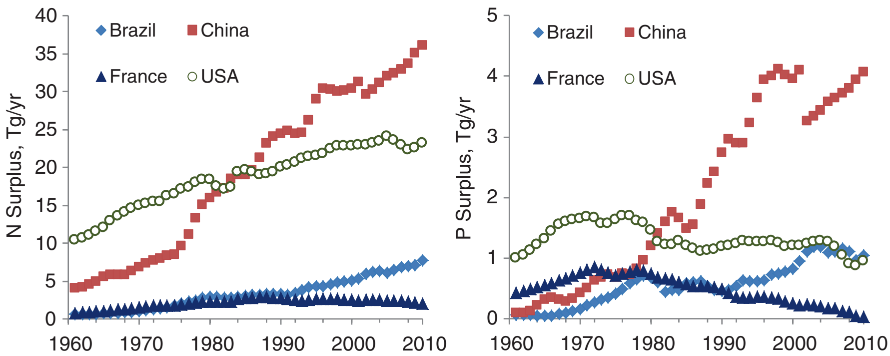


Fig. 14.7 Changes in the N and P balances (surpluses) of food systems of Brazil, China, France and United States between 1961–2010. The apparent 'break' in the curve for P in China at about the year 2002 is related to changes in the methodology of the statistical surveys and data processing. Note: Nutrient Balance = Fertilizer consumption + Biological N_2 fixation + Lighting + Import of crop and animal products—Export of crop and animal products. Data source: FAOSTAT (2015) and own calculations

14.10 Some Final Comments

Coastal eutrophication is an increasing problem, as it increases the incidences of harmful algae blooms, hypoxic zones and fish kills, changes marine ecosystems, and negatively affects the bathing quality of coastal waters (Van Beusekom, Chap. 22). It has been suggested that the N and P loading of surface waters has exceeded critical boundaries (Steffen et al. 2015). More than half of the N and P input to surface waters is from agriculture, and this fraction is increasing (Beusen et al. 2016). In addition, there are impacts from the use of pesticides in agriculture and of antibiotics in aquaculture. Global pesticide use has steadily increased during the second half of the twentieth century. Total production reached more than 3 Tg in 2000 (Tilman et al. 2002), and although application rates for some pesticides have decreased, the dependence on some other have increased. Decreased use of some pesticides may be related to decreasing effectiveness (increased resistance by the biota), replacement by improved pesticides, and/or governmental regulations. Several pesticides have been banned and less systemic/more specific ones have been developed. Although losses of pesticides to the aquatic environment are <0.5% of the total use, the effects on aquatic life and biodiversity can be large (Helfrich et al. 2009; Beketov et al. 2013). Pesticides are traced in marine biota, but impacts of pesticides are less well documented for marine biota than for freshwater biota.

There are significant differences between continents in the changes over time in the use of fertilizers, the production and consumption of plant and animal derived food, residues, manures and wastes, and of their impacts on the marine environment (Sutton et al. 2013; Beusen et al. 2016). These differences are related to socio-economic (income, demographics, education, land area and tenure), environmental (climate, geomorphology, soil), and cultural factors (diet, religion). Yet, the patterns discussed also show some commonalities. With population growth and economic development, fertilizer use, food production, consumption of animal-derived food, nutrient surpluses and losses to the environment all increase. When income (gross domestic production) surpasses a certain level and population growth stabilizes, environmental awareness increases and governmental regulations force farmers to use manure and nutrients more efficiently, and as a result nutrient losses decrease (Zhang et al. 2015). Further incentives for a transition in nutrient use and losses may come from the relative scarcity and depletion of some critical nutrient resources, including phosphorus (Van Kauwenbergh 2010; Reijnders 2014; Withers et al. 2015).

There are various measures that may contribute to a reduction of the loading of N and P from agriculture to surface waters. Many of these measures have been included in EU environmental policies, but the effects are often not optimal, for various reasons (Oenema et al. 2010). A main measure is the proper collection, leak-tight storage, and low-emission application of animal manures to agricultural land at the appropriate times. A second important measure is balanced N and P fertilization, i.e. applying those quantities of N and P via manures, fertilizers and composts that precisely match the nutrient demands by growing crops in time, i.e. precision fertilization (Velthof et al. 2009; Oenema et al. 2009). These two main measures are important for basically all agricultural systems. In addition, there is a wide range of site and system specific measures. These include the planting of cover crops after the harvest of the main crops to minimize leaching, soil conservation measures to minimize erosion, and buffer zones along surface waters to minimize inputs via overland flow. Spatial zoning of animal farms near areas that produce the animal feed, precision animal feeding, animal breeding for robust and productive animals, and herd and disease management are all important measures for minimizing the total excretion of N and P in animal manures, and for utilizing the manure N and P in feed production. Implementing these measures in practice requires training and guidance to farmers, incentives, demonstration farms, and monitoring and control.

Our societies will have to put much greater emphasis on recycling and reuse. Crop residues and animal manures contained some 50 and 120 Tg N and 7 and 24 Tg P in 2010, respectively. These large nutrient resources are often not utilized in an effective manner, especially in China (Ma et al. 2012; Strokal et al. 2016). Wastes from households are another significant source of nutrients, which are currently not utilized effectively. The average total consumption of plant and animal derived protein in the world is about 28 kg per capita per year, which is equivalent to about 4.5 kg N per capita per year. Similarly, the amount of P in the food used by households is about 0.8 kg P per capita per year. This indicates that the total amounts of N and P in household wastes were about 32 Tg N and 6 Tg P in 2010.

There are several reasons/barriers for not using the nutrients crop residues, animal manures and wastes effectively, including (1) residues, manures and wastes are often voluminous (bulky) and thus expensive to store and transport, and produced in quantities too large to be utilized all effectively on the farm and/or on nearby farms, (2) the possible presence of pollutants, pathogens, odour nuisance, etc. make the transport, handling and use elsewhere of residues, manures and wastes less attractive or even prohibitive, and (3) the availability of the nutrients is often unknown and unpredictable. Such barriers can be removed through targeted research and policies.

The next few decades will be critical for agriculture and the aquatic environment. Forecasts indicate that food production may have to increase by 50% or more relative to the level of production in the period 2000–2010, while impacts of agriculture on the (marine) environment will have to decrease significantly (Godfray et al. 2010; Sutton et al. 2013; Steffen et al. 2015). Evidently, this requires that N and P use efficiency in food production has to increase drastically, and that N and P from manure, sludge, and wastes have to be recycled more effectively (Zhang et al. 2015; Withers et al. 2015).

References

Amann M (ed) (2014) The final policy scenarios of the EU clean air policy package TSAP report 11, version 1.1a. International Institute for Applied Systems Analysis, Laxenburg, Austria

Beketov M, Kefford B, Schäfer R, Liess M (2013) Pesticides reduce regional biodiversity of stream invertebrates. Proc Natl Acad Sci U S A 110:11039–11043. doi:10.1073/pnas.1305618110

Bergheim A, Hustveit H, Kittelsen A, Selmer-Olsen A (1982) Estimated pollution loadings from Norwegian fish farms: I. Investigation 1978–79. Aquaculture 28:346–361

Beusen AHW, Bouwman AF, Van Beek L, Mogollón JM, Middelburg JJ (2016) Global riverine N and P transport to ocean increased during the twentieth century despite increased retention along the aquatic continuum. Biogeosciences 13. doi:10.5194/bg-13-2441-2016

Bittman S, Dedina M, Howard CM, Oenema O, Sutton MA (eds) (2014) Options for ammonia mitigation: guidance from the UNECE task force on reactive nitrogen. Centre for Ecology and Hydrology, Edinburgh, UK. 96p

Black RE, Victora CG, Walker SP et al (2013) Maternal and child undernutrition and overweight in low-income and middle-income countries. Lancet 382:427–451

Bouwman AF, Bierkens MFP, Grioen J, Hefting MM, Middelburg JJ, Middelkoop H, Slomp CP (2013) Nutrient dynamics, transfer and retention along the aquatic continuum from land to ocean: towards integration of ecological and biogeochemical models. Biogeosciences 10:1–22. doi:10.5194/bg-10-1-2013

Carson R (1962) Silent spring. Houghton Mifflin Company, Boston

EMEP (2015) Transboundary particulate matter, photo-oxidants, acidifying and eutrophying components. EMEP status report 2015. Norwegian Meteorological Institute

EMEP (2016) http://www.emep.int/mscw/mscw_ydata.html#ASCIIdata. Retrieved June 2016

Erisman JW, Sutton MA, Galloway JN, Klimont Z, Winiwarter W (2008) How a century of ammonia synthesis changed the world. Nat Geosci 1:636–639

FAOSTAT, Food and Agriculture Organization (2015) http://faostat.fao.org/site/291/default.aspx. Retrieved Dec 2015

Galloway JN, Cowling EB (2002) Reactive nitrogen and the world: two hundred years of change. Ambio 31:64–71

Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Pretty J, Robinson S, Thomas SM, Toulmin C (2010) Food security: the challenge of feeding 9 billion people. Science 327:812–818

Helfrich LA, Weigmann DL, Hipkins P, Stinson ER (2009) Pesticides and aquatic animals: a guide to reducing impacts on aquatic systems. Publication 420-013. Virginia Polytechnic Institute and State University, USA

IPCC (2006) Guidelines for National Greenhouse Gas Inventories. http://www.ipcc-nggip.iges.or.jp/public/2006gl/

Latham J, Cumani R, Rosati I, Bloise M (2014) Global land cover SHARE (GLC-SHARE) database beta-release version 1.0. FAO, Rome

Ma L, Velthof GL, Wang FH, Qin W, Zhang WF, Liu Z, Zhang Y, Wei J, Lesschen JP, Ma WQ, Oenema O, Zhang FS (2012) Nitrogen and phosphorus use efficiencies and losses in the food chain in China at regional scales in 1980 and 2005. Sci Total Environ 2012(434):51–61

Mueller ND, Gerber JS, Johnston M, Ray DK, Ramankutty N, Foley JA (2012) Closing yield gaps through nutrient and water management. Nature 490:254–257. doi:10.1038/nature11420

Nixon SW (1995) Coastal marine eutrophication: a definition, social causes and future concerns. Ophelia 41:199–219

Oenema O, Witzke HP, Klimont Z, Lesschen JP, Velthof GL (2009) Integrated assessment of promising measures to decrease nitrogen losses from agriculture in EU-27. Agric Ecosyst Environ 133:280–288

Oenema O, Bleeker A, Braathen NA et al (2011) Nitrogen in current European policies. In: Sutton MA, Howard CM, Erisman JW et al (eds) The European nitrogen assessment. Cambridge University Press, Cambridge

Pierzynsky GM, McDowell RW, Sims JT (2005) Chemistry, cycling and potential movement of inorganic phosphorus in soils. In: Sims JT, Sharpley AN (eds) Phosphorus: agriculture and the environment. Agron. Monogr. 46. ASA, CSSA, and SSSA, Madison, WI. p. 53–86

Pimentel D, Pimentel MH (2008) Food, energy, and society. CRC Press, London. 380p

Reijnders L (2014) Phosphorus resources, their depletion and conservation, a review. Resour Conserv Recycl 93:32–49. doi:10.1016/j.resconrec.2014.09.006

Rodhe W (1969) Crystallization of eutrophication concepts in North Europe. In: Eutrophication, causes, consequences, correctives. National Academy of Sciences, Washington, DC, pp 50–64

Rowe H, Withers PJA, Baas P, Chan NI, Doody D, Holiman J, Jacobs B, Li H, MacDonald GK, McDowell R, Sharpley AN, Shen J, Taheri W, Wallenstein M, Weintraub MN (2015) Integrating legacy soil phosphorus into sustainable nutrient management strategies for future food, bioenergy and water security. Nutr Cycl Agroecosyst. doi:10.1007/s10705-015-9726-1

Sachs J (2008) Common wealth. Economics for a crowded planet. Penguin Press, New York. 386p
Schelhaas H (2009) De landbouw tussen voedselcrises en overschotten, 160p. ISBN: 978-90-8686-127-9
Schlesinger WH, Bernhardt ES (2013) Biogeochemistry. An analysis of global change. Duke University, Durham, NC
Smil V (2000) Feeding the World. A Challenge for the Twenty-first Century. MIT Press, Cambridge, 360 pp.
Smil V (2001) Enriching the Earth. Fritz Haber, Carl Bosch and the Transformation of World Food Production. MIT Press, 358 pp.
Steffen W, Richardson K, Rockström J, Cornell SE, Fetzer I, Bennett EM, Sörlin S (2015) Planetary boundaries: guiding human development on a changing planet. Science 347(6223). doi:10.1126/science.1259855
Steinfeld H, Mooney H, Schneider F, Neville LE (eds) (2010) Livestock in a changing landscape: drivers, consequences and responses. Island Press, Washington, DC. 396p
Strokal M, Ma L, Bai Z, Luan S, Kroeze C, Oenema O, Velthof G, Zhang FS (2016) Alarming nutrient pollution of Chinese rivers as a result of agricultural transitions. Environ Res Lett 11(2016):024014. doi:10.1088/1748-9326/11/2/024014
Sutton MA, Bleeker A, Howard CM, Bekunda M, Grizzetti B, de Vries W, van Grinsven HJM, Abrol YP, Adhya TK, Billen G, Davidson EA, Datta A, Diaz R, Erisman JW, Liu XJ, Oenema O, Palm C, Raghuram N, Reis S, Scholz RW, Sims T, Westhoek H, Zhang FS, Global Overview of Nutrient Management (2013) Our nutrient world: the challenge to produce more food and energy with less pollution. CEH/UNEP, Edinburgh/Nairobi
Tilman D, Fargione J, Wolff B, D'Antonio C, Dobson A, Howarth R, Schindler D, Schlesinger W, Simberloff D, Swackhamer D (2001) Forecasting agriculturally driven global environmental change. Science 292:281–284
Tilman D, Cassman KG, Matson PA, Naylor R, Polasky S (2002) Agricultural sustainability and intensive production practices. Nature 418:671–677. doi:10.1038/nature01014
Tilman D, Balzer C, Hill J, Befort BL (2011) Global food demand and the sustainable intensification of agriculture. Proc Natl Acad Sci U S A 108:20260–20264
UNCTAD (2009) Transnational corporations, agricultural production and development. World Investment Report 2009. United Nations conference on trade and development, Geneva
Van Dijk KC, Lesschen JP, Oenema O (2015) Phosphorus flows and balances of the European Union Member States. Sci Total Environ 542:1078–1093. doi:10.1016/j.scitotenv.2015.08.048
Van Kauwenbergh SJ (2010) World phosphate rock reserves and resources. International Fertilizer Development Centre (IFDC), Muscle Shoals, USA
Velthof GL, Oudendag DA, Witzke HP, Asman WAH, Klimont Z, Oenema O (2009) Integrated assessment of nitrogen losses from agriculture in EU-27 using MITERRA-EUROPE. J Environ Qual 38:402–417
Vitousek PM, Mooney HA, Lubchenco J, Melillo JM (1997) Human domination of Earth's ecosystems. Science 277:494–499
Von Braun J, Díaz-Bonilla E (2008) Globalization of food and agriculture and the poor. Oxford University Press, Oxford
Westhoek H, Lesschen JP, Rood T, Wagner S, De Marco A, Murphy-Bokern D, Leip A, Van Grinsven H, Sutton MA, Oenema O (2014) Food choices, health and environment: effects of cutting Europe's meat and dairy intake. Glob Environ Chang 26:196–205
Williams M (2003) Deforesting the earth: from prehistory to global crisis. University of Chicago Press, Chicago, IL. 689p
Withers PJA, Neal C, Jarvie HP, Doody DG (2014) Agriculture and eutrophication: where do we go from here? Sustainability 6:5853–5875. doi:10.3390/su6095853
Withers PJA, van Dijk KC, Neset T-SS, Nesme T, Oenema O, Rubæk GH, Schoumans OF, Smit B (2015) Stewardship to tackle global phosphorus inefficiency: the case of Europe. Ambio 44:193–206. doi:10.1007/s13280-014-0614-8
Zhang X, Davidson EA, Mauzerall DL, Searchinger TD, Dumas P, Shen Y (2015) Managing nitrogen for sustainable development. Nature 528:51–59. doi:10.1038/nature15743

Chapter 15
Land-Based Industries

Elisabeth Schmid

Abstract The release of pollutants to the marine environment poses an extreme threat to oceans and seas worldwide. Toxic substances are found in seawater, sediments and marine organisms and excess organic substances and nutrient input threatens aquatic life. Land-based industries are significant contributors to this pollution. Looking at data from the North-East Atlantic, the Baltic Sea and the Mediterranean Sea, the relevant contaminants and main industrial sectors become evident. It can be shown, that implementing pollution control measures for relevant industrial activities leads to substantial reduction of their emissions and discharges. Therefore regulating land-based industrial sites is a central issue for the protection of the marine environment.

Keywords Land-based industries • Marine pollutants • Nutrients • Hazardous substances • Best Available Technology (BAT) • Best Environment Practice (BEP) • North-East Atlantic • Baltic Sea • Mediterranean Sea • North-West Pacific

15.1 Introduction

Emissions and discharges from land-based industries are significant contributors to the pollution of the marine environment. The pollutants reach oceans and seas via atmospheric transport and through riverine or direct input (UN 2016: 2). The aim of this chapter is to give an overview of relevant industrial activities and their typical emissions and to outline the impacts of marine pollutants from land-based industrial sources. This is done by referring to information from global and regional data, though a closer look is taken at the following three marine regions: the North-East-Atlantic (Fig. 15.1), the Baltic Sea and the Mediterranean Sea.

E. Schmid
German Advisory Council on the Environment, Berlin, Germany
e-mail: Elisabeth.schmid@umweltrat.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_15

Fig. 15.1 Industrial plant near Hamburg (Germany). Foto: Jerzy Sawluk/pixelio.de

These regions were chosen because they are examples of industrialized areas with heavy impact on the adjacent seas. Moreover, in each region a convention for the protection of the marine environment was established (see Box 15.1) and the North-East-Atlantic and the Baltic Sea have a long-standing practice of assessment of the state of the marine environment (UN 2016: 21–22). Additionally, the effect of measures to reduce pollution from industrial sources has been monitored in these areas. These results are presented at the end of this chapter. They demonstrate the importance of implementing control measures for land-based industries in order to reduce releases from industrial sources to the marine environment.

Box 15.1: The conventions for the protection of the marine environment of the North-East-Atlantic, the Baltic Sea and the Mediterranean Sea

The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention) was opened for signature in 1992 and entered into force in 1998. The Contracting Parties are Belgium, Denmark, the European Union, Finland, France, Germany, Iceland, Ireland, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom. The OSPAR Commission (OSPAR) is the managing organization for the OSPAR Convention (OSPAR 2015c).

The Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention), was opened for signature in 1992 and entered into force in 2000. The Contracting Parties are Denmark, Estonia, the European Union, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. The Helsinki Commission (HELCOM) is the governing body of the Helsinki Convention (HELCOM 2016).

The Mediterranean Action Plan (MAP), a Regional Sea Programme under UNEP's umbrella, was adopted in 1975 by 16 Mediterranean countries and the European Community. In 1976 these Parties adopted the Convention for the Protection of the Mediterranean Sea against Pollution (Barcelona Convention). The Barcelona Convention was amended in 1995 and renamed Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (UNEP 2014b).

15.2 Impacts of Industrial Pollutants

Land-based industries are sources of various marine pollutants. Depending on the industry sector, these inputs contain nutrients (phosphorus or nitrogen compounds), oxygen depleting substances (i.e. organic matter), and/or various hazardous substances. Sulphur dioxide as acidifying substance is a relevant pollutant as well. Table 15.1 lists important representatives of these substance groups and their main industrial sources. The pollutants were chosen taking into account the Baltic Sea Action plan of the Helsinki Convention (see Box 15.1; HELCOM 2007), the list of chemicals for priority action of the OSPAR Convention (see Box 15.1; OSPAR 2013) and the list of industrial emission indicators established under the UNEP Action plan for the Mediterranean Sea (see Box 15.1; EEA 2014: 105). Additionally to the substance groups the respective sum parameters are given, as these are commonly used to detect the amount of pollution instead of analyzing single substances.

Nutrients like nitrogen dioxide are mainly emitted by power plants, iron and steel industry and pulp and paper industry, whereas the fertilizer industry represents the dominant source for phosphorus compounds. Excess inputs of nutrients into the marine environment leads to increased algal growth (eutrophication), followed by detrimental effects on the ecosystem and the decay of organic matter. As in the latter process oxygen is consumed, the body of water can become hypoxic or anoxic (i.e. only little or no dissolved oxygen is available), with a reduced ability to support aquatic life. The input of oxygen depleting substances, i.e. organic matter like hydrocarbons, which can be oxidized or broken down by bacteria, can also result in oxygen deficient zones (cf. von Beusekom, Chap. 22; UN 2016: 40). Hydrocarbons are released by a large variety of industrial sources (see Table 15.1).

Hazardous substances are defined as substances which are toxic, persistent and liable to bioaccumulate, or which give rise to an equivalent level of concern (UN 2016: 3). Important hazardous substance groups are heavy metals such as mercury, cadmium or lead, and organic pollutants, e.g. polycyclic aromatic hydrocarbons (PAHs), tributyltin (TBT), perfluorooctane sulphonates (PFOS) or polychlorinated

Table 15.1 Relevant marine pollutants and their industrial sources (UNEP 2014a; OSPAR 2008; HELCOM 2007)

Substance group (sum parameter)	Substance	Industrial sector
Nutrients [tot N, tot P]	Nitrogen compounds (e.g. Nitrogen dioxide, nitrates)	Power generation, iron and steel, pulp and paper
	Phosphorus compounds	Fertilizer
Oxygen depleting substances [BOD_x, COD]	Hydrocarbons	Textile, cement, leather, metallurgy, fertilizer, food processing, petroleum, pulp and paper, chemicals, power generation (1)
Heavy metals	Lead (Pb)	Primary ferrous and non-ferrous metals, mining, glass production, ceramics, waste incineration
	Cadmium (Cd)	Primary iron and steel, non-ferrous metals, power generation, textile
	Mercury (Hg)	Chlor-alkali, power generation, iron and steel, non-ferrous metals
	Chromium (Cr)	Leather
Organic compounds [BOD, COD, AOX, TOC]	Polycyclic aromatic hydrocarbons (PAH)	Power generation, organic chemicals, iron and steel, non-ferrous metals
	Tributyltin (TBT)	Ferrous metals, pulp and paper, surface treatment of metals
	Polychlorinated dibenzo-dioxins/ dibenzofurans (PCDDs, PCDFs)	Waste incineration, metals, pulp and paper (using chlorine), organic chemicals, textile
	Perfluorooctane sulphonates (PFOS)	Photographic industry, semiconductor industry
	Trichlorobenzenes	Organic chemicals, metals
Other compounds	Sulphur dioxide	Power generation, iron and steel, non-ferrous metals, pulp and paper

Sum parameters: *tot N* total nitrogen, *tot P* total phosphorus, *BODx* Biochemical Oxygen Demand during x days (normally 5 or 7) (indicating the amount of biodegradable organic matter in waste water), *COD* Chemical Oxygen Demand (indicating the amount of chemically oxidisable organic matter in waste water), *AOX* Adsorbable Organic Halides, *TOC* = Total Organic Carbon (cf. EC 2003: 437–439)

dibenzodioxins (cf. Table 15.1; Broeg et al., Chap. 20). Key industrial sources for heavy metals are the primary ferrous and non-ferrous metals industry, glass and ceramics production, power generation and waste incineration. A specific source for mercury is the chlor-alkai industry, for chromium the leather industry. The various organic pollutants have different industrial sources, like power generation for PAHs, surface treatment of metals for TBT, photographic industry for PFOS and waste incineration for dioxins (cf. Table 15.1).

The fate and effects of hazardous substances depends i.a. on their chemical stability, physical-chemical properties and biological effects (Broeg et al., Chap. 20). They are found in seawater, sediments and marine organism (UN 2016: 19-38). Effects may occur at very low concentrations (e.g. tributyl tin, see below) and persistent substances can impact the marine ecosystems for a long time (Broeg et al., Chap. 20). As most of the hazardous substances are not only persistent but as well liable to bioaccumulate, many of them can be detected in fish or shellfish, sometimes even at concentration levels which are not safe for human consumption (OSPAR 2010). The most frequently recorded substance to reach or exceed safe levels is mercury, followed by i.a. PAH and dioxins. High concentrations of these substances are found in animals at the end of the food chain, one example being mercury found in beluga whales at levels sufficient to cause concern (UN 2016: 25).

Pollution is generally high in coastal areas near populated and industrialized sites. However, organic pollutants that are relatively volatile—the so called persistent organic pollutants (POP)—can be carried long distances through the atmosphere and may be deposited in remote marine areas. The same phenomenon is monitored for volatile heavy metals, again especially for mercury, where high levels in fish are detected even in the open ocean. Other pollutants, transported by ocean currents, are still significant issues for the Arctic (UN 2016: 20f.).

Some hazardous substances have the potential to disrupt endocrine systems (endocrine disruptors) and thus affect the ability of individuals and populations to reproduce successfully. This has been well documented for the compound tributyl tin (TBT). TBT had a severe effect on molluscs at very low concentrations; in some harbours, whole populations of molluscs disappeared (UN 2016: 37; Broeg et al., Chap. 20). A new pollutant category is formed by anthropogenic particles like microplastics and engineered nanoparticles, although the knowledge about these substances is still rare (cf. Broeg et al., Chap. 20).

15.3 Relevance of Industrial Sources

The relevance of industrial activities with respect to marine pollution differs from region to region. Moreover, whether and to what extent a pollutant is discharged or emitted from an industrial activity depends on the specific technology applied and on the effectiveness of implemented emission abatement (see Sect. 15.4).

On a global scale, the United Nations Environment Programme (UNEP) gives "priority to the treatment and management of waste water and industrial effluents", looking specifically at impacts from i.a. persistent organic pollutants, heavy metals, oils (hydrocarbons) and nutrients (UNEP 1995, No. 1 and 16). The relevance of land-based industries with regard to marine pollution is generally particularly high for industrialised countries. For example the industry within the catchment area of the Baltic Sea "remains to be one of the main sources of contamination of the Baltic Sea" (HELCOM n.d.). For the Mediterranean Sea (Fig. 15.2) it is stated, that "industrial pollution is one of the major environmental pressures" (EEA 2014: 101). The pollution by heavy metals and hazardous substances of the Northwest Pacific Region is increasing, especially in areas next to industrial complexes, harbors and densely populated urban areas. In some parts of this region the major sources of heavy metal pollution are ore-mining and ore-chemical production.

Fig. 15.2 Port of Lisbon. Foto: Holger Brackemann/private

Industrial enterprises (including thermal power plants) are a main source of nitrogen oxides (Pido et al. 2015: 97–98).

The "First Global Integrated Marine Assessment" of the United Nations (UN 2016: 10ff.) specified some of the most significant point sources responsible for the pollution of marine waters with hazardous substances. Apart from desalination plants (not covered here) the following industrial sources are mentioned (in brackets their most relevant emissions): coal fired power stations (mercury, but also cadmium, zinc and PAH); cement production (heavy metals, esp. mercury); chlor-alkali plants (mercury), polyvinyl chloride plants (dioxins and furans, vinyl chloride monomer); titanium dioxide plants (acid waste); mining (waste containing heavy metals); ferrous and non-ferrous smelting (heavy metals); aluminium (PAH); paper industry (dioxins, furans); incinerators (dioxins, furans) and fertilizer production (heavy metals, esp. cadmium). Mercury emissions from artisanal gold mining is a specific problem for West Africa (UN 2016: 28). Important industrial sources for organic matter and for nutrients are food and related industries (UN 2016: 46).

On a regional scale, comprehensive assessment was carried out in the North-East Atlantic Sea and in the Baltic Sea. OSPAR (see Box 15.1) has identified that large combustion plants, the manufacturing of iron, steel, aluminium, textiles, chlorine, pharmaceuticals, organic chemicals, pulp and paper and vinyl chloride and the refining of crude oil are relevant land-based industries (OSPAR 2010: 38, cf. Table 15.4). Example given, combustion processes in power plants and industry are major sources for heavy metals emissions to the atmosphere. According to model calculations of the deposition of heavy metals to the OSPAR Regions carried out in 2007 and 2008, the contribution of these combustion sources to the total deposition of heavy metals was in the range of 70 to 90% (OSPAR 2009a: 5).

For the Baltic Sea, HELCOM (see Box 15.1) has established in 1992 a list of significant land-based pollution sites around the Baltic Sea, the so called hot spots in the Baltic Sea catchment area. Out of the originally 132 hot spots, 50 were classified as industrial hot spots (Huuska and Forsius 2002), representing the following industrial sectors: manufacture of pulp and paper, oil shale power plants, chemical industry (pharmaceutical and fertilizer), metal-Industry (e.g. steel, aluminium) and oil refineries. Until June 2013 more than two thirds of these industrial hot spots were deleted from the list (HELCOM 2013: 23–27)—either because they were closed down or because they had implemented pollution prevention measures (see Sect. 15.4). Table 15.2 gives an overview of these industrial hot spots and their reported pollutants, they were classified as hot spot for (HELCOM 2013: 33–42).

With regard to the Mediterranean Sea, in 2003 and 2008 the major polluting industrial sectors were energy production, food packing and manufacture of cement, fertilizers, metals, refined petroleum products, textiles and leather (EEA 2014: 106–107). The main pollutants from these industrial activities are nutrients, oxygen depleting substances, volatile organic compounds (VOCs) and some heavy metals (see Table 15.3).

Table 15.2 Industrial hot spots in the Baltic Sea catchment Area (1991–2012) (HELCOM 2013)

Industrial sector	Reported pollutants (reason for being a hot spot)	
	Air	Water
Power plant	NO_x, SO_x, dust	
Fertiliser industry	Dust	Oxygen depleting substances (ODS, measured as BOD), nutrients, heavy metals, phosphorus, fluorides, suspended solids
Chemical industry	High emissions of hazardous organic substances	High emissions of Hg-sludge, organic compounds, AOX, ODS (measured as BOD or COD), nitrogen, phosphorus
Titanium dioxide industry		Acidic wastewater containing heavy metals
Mining		Saline water from coal mines containing heavy metals
Pulp and paper	NO_x, SO_x	Organic substances (COD, BOD, AOX), nutrients, Suspended solids, tot-P
Metal industry	Dust, heavy metals, SOx,	Heavy metals
Food processing industry		Nutrients (tot N, tot P), ODS (measured as BOD or COD)
Oil refinery		Oil (BOD, COD), tot N, tot P
Cocing plant	Gaseous and dust emissions	

tot N total nitrogen, *tot P* total phosphorus, *ODS* Oxygen depleting substances, *BOD* Biochemical Oxygen Demand, *COD* Chemical Oxygen Demand, *AOX* Adsorbable Organic Halides, SO_x sulphur oxides (e.g. sulphur dioxide), NO_x nitrogen oxides (e.g. nitrogen dioxide)

Table 15.3 Overview of industrial sectors in the Mediterranean Region and their most representative pollutants reported in 2003 and 2008 (EEA 2014)

Industrial sector	Overview of emitted substances, reported in 2003 and 2008
Food packing	ODS (measured as BOD_5), Cd, Cr, Pb, Hg, tot N, tot P, VOC
Manufacture of cement	ODS (BOD_5), Cd, Cr, Pb, Hg, tot N, tot P
Manufacture of fertilisers	ODS (BOD_5), Cd, Cr, Pb, tot N, tot P, VOC
Manufacture of metals	ODS (BOD_5), Cd, Cr, Pb, PAH, tot N, tot P, VOC
Manufacture of chemicals	ODS (BOD_5), Pb, tot N, tot P, TSS, VOC
Manufacture of paper	ODS (BOD_5), tot N, tot P, VOC
Manufacture of refined petroleum products	ODS (BOD_5), Cr, tot N, VOC
Manufacture of textiles	ODS (BOD_5), tot N, tot P, VOC
Production of energy	Cd, Cr, Hg, tot N
Tanning and dressing of leather	ODS (BOD_5), Cr, tot N, tot P, TSS, VOC

ODS Oxygen depleting substances, *BOD_5* biochemical oxygen demand during 5 days, *Cd* Cadmium, *Cr* Chromium, *Pb* Lead, *Hg* Mercury, *tot N* total nitrogen, *tot P* total phosphorus, *VOC* Volatile organic compounds, *TSS* total suspended solids

15.4 Reducing Pollution from Industrial Sites

Various techniques exist that reduce or eliminate emissions and discharges from industrial sources. From 1980 onwards, OSPAR (cf. Box 15.1) promoted the application of such techniques in its maritime area for the most important industries (OSPAR 2008). Furthermore, since 1992, the OSPAR Convention requires Contracting Parties to apply Best Available Techniques (BAT) and Best Environmental Practice (BEP) in order to prevent and eliminate marine pollution from land-based sources (OSPAR 1992, Art. 1; see also Box 15.2).

Box 15.2: The concept of Best Available Techniques (BAT) and Best Environmental Practice (BEP)

OSPAR Convention, Appendix 1 (OSPAR 1992):

"…

2. The term "best available techniques" means the latest stage of development (state of the art) of processes, of facilities or of methods of operation which indicate the practical suitability of a particular measure for limiting discharges, emissions and waste……

6. The term best environmental practice means BEP is "the application of the most appropriate combination of environmental control measures and strategies….

8. It follows that BAT and BEP for a particular source will change with time in the light of technological advances, economic and social factors, as well as changes in scientific knowledge and understanding…"

Following this concept, OSPAR has adopted several Recommendations and legally-binding Decisions on BAT and BEP for various industrial technologies and sources of land-based pollution (OSPAR 2015a). With these Recommendations and Decisions OSPAR countries were required to implement BAT, BEP and to achieve specified emission or discharge limit values (OSPAR 2010: 38). Table 15.4 lists industrial sectors and examples for Recommendations and Decisions relevant for the respective sector (cf. OSPAR 2008, Table 3.1).

The Best Available Techniques specified in these Decisions or Recommendations include techniques for high-efficiency dust removal (e.g. cold electrostatic filters, bag filters, ceramic filters or activated carbon regenerative processes), flue gas depollution equipments (e.g. wet process sulphur removal, selective catalytic reduction) in order to prevent or reduce emissions of heavy metals and persistent organic pollutants (cf. Recommendation 97/2). Examples for Best Environmental Practices are the substitution of hazardous substances (e.g. chlorinated solvents) in the electroplating industry (surface treatment of metals) by substances which are readily biodegradable, non-bioaccumulating, non-mutagenic and have a low toxicity, or the treatment of process baths using suitable techniques (e.g. membrane filtration, ion exchange, electrolysis, thermal processes and evaporation) in order to have the longest possible service life (cf. Recommendation 92/04). In Decision 90/3 the contracting parties agreed upon phasing out existing mercury cell chlor-alkali plants by 2010, and in Decision 96/1 it was decided to phase-out the use of hexachloroethane in the non-ferrous metal industry.

Overall, there are a huge number of technical measures in order to reduce the inputs of substances from industries ranging from management of waste or waste-water and waste-gas treatment to technology improvements (e.g. switch to chlorine free bleaching in the pulp and paper industry).

The effectiveness of implementing BAT and BEP can be seen in the reduction achievements reported for the OSPAR maritime area (i.e. the North-East Atlantic)—e.g. decrease in deposition of airborne nitrogen and heavy metals (OSPAR 2014) and decrease of waterborne inputs of heavy metals and nutrients (OSPAR 2009b). For hazardous substances the greatest emission reductions occurred during the 1990s (OSPAR 2010: 42). For Germany it was calculated, that the inputs of heavy metals from industrial sites into the German North Sea catchment area declined significantly (more than 90% for mercury, nickel, cadmium, lead, zinc and chromium) between 1983–1987 and 2006–2008. The reduction of discharges is primarily attributable to reduction measures in industry, but partly as well due to the scaling down of industrial activities (BMUB and UBA 2013: 90).

Another success story is the reduction of mercury losses from the chlor-alkali industry: Between 1982 and 2013 the total mercury losses through product, waste-water discharging into the OSPAR catchment area plus atmospheric emissions from all national plants for all contracting parties were reduced by about 97% (OSPAR 2015b). This was mostly achieved through the closure of facilities or change of production techniques (OSPAR 2008: 15).

Table 15.4 Industrial sector (contributing to marine pollution), examples for related OSPAR-Recommendations and Decisions and their targeted substances (OSPAR 2008, 2015a)

Industrial sector	Recommendation (R), Decision (D)[a]	Targeted substances	
		Air emissions	Water discharges
Iron and steel industry	R90/1, R91/2, R91/3, R92/3	Dust, NO_x, SO_2, mercury, dioxins, fluorides	Hydrocarbons, heavy metals[1], PAH, phenol, cyanide
Non-ferrous metal industry	R98/1; D96/1 *Aluminium industry:* R92/1, R98/2, R02/01	SO_2, mercury, dust *Aluminium industry:* PAH, fluorides	Organohalogen substances *Aluminium industry:* Mercury, PAH
Surface treatment of metals	R92/04	Volatile halogenated hydrocarbons	Trichloroethene, tetrachloroethene, dichloromethane, heavy metals[2], unbound cyanide
Chlor-alkali industry	D90/3	Mercury	Mercury
Textile industry	R97/1		Heavy Metals[3], organohalogen substances (e.g. PCBs), organochlorine pesticides, organophosphorus pesticides
Pharmaceutical industry	R92/5	halogenated and aromatic hydrocarbons	Heavy metals, halogenated and aromatic hydrocarbons, nutrients
Organic chemical industry	R94/4	Hydrocarbons, PAHs, organohalogens, heavy metals	Hydrocarbons, PAHs, organohalogens, heavy metals
Large combustian plants	R97/2	Heavy metals, PAHs, other organic pollutants	
Pulp and paper industry	D92/1, R94/2, R94/3, D95/2, D95/3, D96/2	NO_x, SO_2, gaseous sulphur, organic sulphuric compounds	Organic substances, organohalogen substances (i.a. chlorinated organic substances), ODS
Vinyl chloride Monomer Industry	D98/4, D98/5, R00/3	Vinyl chloride monomer, 1,2-dichlorethane, PCDD/PCDF, hydrogen chloride	Organohalogen substances (i.a. chlorinated hydrocarbons), copper, vinyl chloride monomer
Refineries	R83/1, R89/5		Hydrocarbons

Heavy metals[1] = cadmium (Cd), chromium (Cr), nickel (Ni), zinc (Zn); heavy metals[2] = Cr, copper (Cu), lead (Pb), Ni, gold (Au), tin (Sn), Zn; heavy metals[3] = antimony (Sb), arsenic (As), Cr, Cd, cobalt (Co), Cu, Pb, Ni, Sn, Zn; PAHs: polycyclic aromatic hydrocarbons; ODS = Oxygen depleting substances; PCDD/PCDF: polychlorinated dibenzodioxins/dibenzofurans; PCBs: polychlorinated biphenyls

[a]For detailed Information see OSPAR 2015a

Table 15.5 Pollution reduction from industrial hot spots, Baltic Sea Area 1991–1998 (Huuska and Forsius 2002)

	BOD	COD	AOX	tot N	tot P	HM (l)	HM (g)	SO_x	NO_x	dust
Reduction from all industrial hot spots[a]	70%	54%	83%	58%	52%	62%	61%	56%	46%	58%

BOD Oxygen depleting substances, measured as BOD (Biochemical Oxygen Demand); *COD* Oxygen depleting substances, measured as COD (Chemical Oxygen Demand); *AOX* Adsorbable Organic Halides, *tot N* total nitrogen, *tot P* total phosphorus, *HM (l)* liquid heavy metals, *HM (g)* gaseous heavy metals, SO_x sulphur oxides (e.g. sulphur dioxide), NO_x nitrogen oxides (e.g. nitrogen dioxide)
[a]For individual industrial sectors see Table 15.2

A considerable reduction of pollutants stemming from industrial activities could also be recorded in the Baltic Sea area. Between 1991 and 1998 the emissions and discharges of a number of industrial hot spots, identified by HELCOM as being significant polluters of the Baltic Sea (see Table 15.2), could be reduced substantially. Table 15.5 gives an overview of relevant pollutants that were reported from industrial hot spot sectors between 1991 and 1998 and the overall reduction of discharges and emissions from industrial hot spots during this time. The decrease of pollution load was mainly due to lower production but also due to implemented process and pollution control measures (Huuska and Forsius 2002). The reduction figures show, that from 1991 until 1998 the reported emissions and discharges could be reduced significantly, with reductions ranging from 46 to 83%.

15.5 Outlook

Examples from the North-East Atlantic Region and the Baltic Sea show that substantial reductions can be achieved by regulating industrial releases. However, for many pollutants the quality objectives are still not reached (OSPAR 2008, 2010; HELCOM 2013). This is partly because implementation of BAT and BEP still has to be improved, and partly because for some pollutants, e.g. PAH, total elimination of releases is impossible (OSPAR 2008: 4). Furthermore, as releases from point sources decrease, the relevance of inputs from diffuse sources increases. Example given, inputs of heavy metals and nutrients in the German catchment area of the North Sea and the Baltic sea area, monitored between 2006–2008, show that the relevance of sources has shifted from point to diffuse sources—the latter being for heavy metals urban areas, erosion and groundwater; for nutrients groundwater, erosion and surface run-offs of mainly agricultural land and drainage (BMUB and UBA 2013: 81–83 and 89–90). Looking at PAH, a key diffuse source is the transport sector. Stricter emission limits for cars and trucks are therefore necessary in order to achieve further emission reduction for these pollutants (OSPAR 2008: 61).

In the Mediterranean Sea area pressure from land-based sources remains high, despite important improvements. With regard to industrial sectors, attention needs to be paid to the production of energy, manufacture of refined petroleum products, food packing and manufacture of cement and metals (EEA 2014: 8).

In some maritime regions of the world pollution from land-based industrial sources has to date not been tackled at all, or is just starting to become apparent (UNEP 2014b). Pido et al. (2015) reported that pollution by heavy metals and hazardous substances is increasing in the Northwest Pacific Region. For certain industrial sectors (chemical industry, coal fired power plants) the potential for the impact on the marine environment has shifted from the Atlantic Ocean basin to the Pacific Ocean basin due to rising production figures in Asia and Pacific (UN 2016: 12). In general, regulating land-based industrial sites is a central issue in the protection of the marine environment from hazardous substances.

References

BMUB (Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit) and UBA (Umweltbundesamt) (2013). Water resource management in Germany: Part 2. Water quality. Umweltbundesamt 2013. https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/wawi_teil_02_englisch_barrierefrei.pdf. Retrieved 8 Mar 2016

EC (2003) Integrated pollution prevention and control reference document on best available techniques in common waste water and waste gas treatment/management systems in the chemical sector. February 2003. http://eippcb.jrc.ec.europa.eu/reference/BREF/cww_bref_0203.pdf. Retrieved 11 MAr 2016

EEA (European Environment Agency) (2014) Horizon 2020 Mediterranean report. EEA-UNEP/MAP joint report. EEA technical report no. 6/2014. http://www.eea.europa.eu/publications/horizon-2020-mediterranean-report. Retrieved 4 Mar 2016

HELCOM (Helsinki Commission) (n.d.) HELCOM. Industrial releases. http://www.helcom.fi/action-areas/industrial-releases. Retrieved 4 Mar 2016

HELCOM (2007) HELCOM Baltic Sea action plan. HELCOM Ministerial Meeting Krakow, Poland, 15 Nov 2007. http://www.helcom.fi/Documents/Baltic%20sea%20action%20plan/BSAP_Final.pdf. Retrieved 4 Mar 2016

HELCOM (2013) The Baltic Sea joint comprehensive environmental action programme (JCP). Implementation of hot spots programme, 1992–2013. Final report. Baltic Marine Environment Protection Commission – Helsinki Commission, 2013. http://helcom.fi/Lists/Publications/Final%20report%20on%20JCP%20efficiency.pdf. Retrieved 3 Mar 2016

HELCOM (2016) HELCOM: About Us. http://www.helcom.fi/about-us. Retrieved 30 June 2016

Huuska P, Forsius K (2002) Review of progress at industrial hot spots. The Finnish Environment 576. Finnish Environment Institute. Helsinki, 2002. http://www.helcom.fi/Documents/SYKE%20Industrial%20Hot%20Spot%20Review.pdf. Retrieved 3 Mar 2016

OSPAR (Oslo and Paris Convention for the Protection of the marine environment of the North-East Atlantic) (1992) Convention for the protection of the marine environment of the North-East Atlantic. http://www.ospar.org/site/assets/files/1290/ospar_convention_e_updated_text_in_2007_no_revs.pdf. Retrieved 11 Aug 2016

OSPAR (2008) Towards the cessation target. Emissions, discharges and losses of OSPAR chemicals identified for priority action. Hazardous substances series. OSPAR Commission 2008. http://www.ospar.org/documents?v=7116. Retrieved 4 Mar 2016

OSPAR (2009a) Trends in atmospheric concentrations and deposition of nitrogen and selected hazardous substances to the OSPAR maritime area. OSPAR Commission 2009. http://qsr2010.ospar.org/media/assessments/P00447_Trend_atmospheric_ s.pdf. Retrieved 8 Mar 2016

OSPAR (2009b) Trends in waterborne inputs. Assessment of riverine inputs and direct discharges of nutrients and selected hazardous substances to OSPAR maritime area in 1990–2006. Monitoring and assessment series. OSPAR Commission 2009. http://www.ospar.org/documents?v=7159. Retrieved 8 Mar 2016

OSPAR (2010) Quality status report 2010. Chapter 5: Hazardous substances. OSPAR Commission. London. http://qsr2010.ospar.org/en/ch05_02.html. Retrieved 8 Mar 2016

OSPAR (2013). OSPAR list of chemicals for priority action (revised 2013). Reference number 2004–12. http://www.ospar.org/work-areas/hasec/chemicals/priority-action. Retrieved 4 Mar 2016

OSPAR (2014) Comprehensive atmospheric monitoring programme. Deposition of air pollutants around the North Sea and the North-East Atlantic in 2012. Monitoring and assessment series. 2013. http://www.ospar.org/documents?v=7365. Retrieved 8 Mar 2016

OSPAR (2015a) Decisions, recommendations and other agreements applicable within the framework of the OSPAR convention. update 2015. http://www.ospar.org/convention/agreements. Retrieved 6 Mar 2016

OSPAR (2015b) Mercury losses from the Chlor-alkali industry in 2013. Hazardous substances series. OSPAR Commission 2015. http://www.ospar.org/documents?v=7371. Retrieved 8 Mar 2016

OSPAR (2015c) About OSPAR. http://www.ospar.org/convention. Retrieved 14 July 2016

Pido MD, Xie X, Koshikawa H, Nam J, Arzamastsev IS (2015) Integrated coastal planning and ecosystem-based management in the northwest Pacific region. POMRAC technical report no. 8 – Vladivostok: Dalnauka, 2015, 188p. http://www.pomrac.dvo.ru/Pub/DOC/Integrated_Coastal_Planning.pdf. Retrieved 8 Mar 2016

UN (United Nations) (2016) The first global integrated marine assessment. World Ocean Assessment I. Chapter 20. Coastal riverine and atmospheric inputs from land. http://www.un.org/Depts/los/global_reporting/WOA_RPROC/Chapter_20.pdf. Retrieved 30 June 2016

UNEP (United Nations Environment Programme) (1995) Washington declaration on protection of the marine environment from land-based activities. http://unep.org/gpa/documents/meetings/Washington/WashingtonDeclaration.pdf. Retrieved 4 Mar 2016

UNEP (2014a) United Nations Environment Programme. Mediterranean action plan. MED POL. Plan on reduction of input of BOD by 50% by 2010 from industrial sources for the Mediterranean Region. MAP technical reports series no. 144. UNEP/MAP Athens 2004. http://195.97.36.231/dbases/new_publications/PMS/pdfs/0501a_144E.pdf. Retrieved 25 Aug 2016

UNEP (2014b) The global programme of action for the protection of the marine environment from land-based activities (GPA). http://unep.org/gpa/About/about.asp. Retrieved 9 Mar 2016

Chapter 16
Land-Based Wastewater Management

Stephan Koester

Abstract The marine environment not only receives direct wastewater discharge from marine outfalls and shipping activities but also has to cope with wastewater emissions from land-based wastewater facilities transported via inland waterways. As a general rule, wastewater treatment plants actively contribute to the protection of marine environment by removing organic compounds and nutrients from the wastewater. However, if wastewater is untreated or insufficiently treated, the wastewater management sector definitely contributes to the eutrophication of the marine environment. In addition, the wastewater industry has to face the problem of the pollutants of rising concern and especially those compounds which undeniably originate from wastewater treatment plants such as organic micropollutants, pathogens, microplastics and engineered nanoparticles. It is quite crucial to find convincing responses to these still outstanding issues.

Keywords Marine environment • Land-based wastewater treatment • Nutrients • Micropollutants • Microplastics

16.1 Introduction

Wastewater, as it originates from anthropogenic activities, can be highly heterogenic and sometimes a heavily polluted matrix. In addition, it is also a major source of nutrients. As a general rule, wastewater is discharged from point sources into the aquatic environment. As to the marine environment, it not only receives direct wastewater discharge via submarine outfalls from coastal areas, but also has to cope with the wastewater emissions from non-coastal areas. Self-evidently the municipal and industrial wastewater emissions contribute to the contamination of both the inland surface waters and the marine environment. Especially, untreated and

S. Koester,
Institute of Sanitary Engineering and Waste Management,
Leibniz University Hanover, Hanover, Germany
e-mail: koester@isah.uni-hannover.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_16

insufficiently treated wastewater can cause heavily negative impacts on the aquatic environment such as eutrophication. The last decades show that environmental protection can only be as good as the existing provisions of the associated regulatory framework. The environmental legislation in place has become more stringent and has been constantly in line with the latest technologically and economically feasible solutions. For the field of aquatic environment protection, one can measure the concrete status of enforcement of the relevant legislation by aggregating the relevant urban catchment indicators such as the rates of wastewater collection, types of the prevailing wastewater collection systems and the performance of wastewater treatment. The aquatic pollution control moved a historically important step forward since introducing requirements for an advanced nutrient removal from wastewater—in most cases tied to a larger plant size. Thus, it is widely acknowledged that nowadays wastewater treatment plants actively contribute to the protection of marine environment by removing organic compounds and nutrients from the wastewater before it is discharged to the water cycle. In view of these achievements in point-source pollution control it may be right to label the non-point source emissions as the major long-lasting problem for water pollution. If so, the latter problem would be outside the scope of wastewater industry. However, even within the scope, there are still further noteworthy challenges to overcome regarding wastewater disposal. Explicitly, organic micropollutants, pathogens, microplastics and engineered nanoparticles are of rising concern. This chapter aims at making a realistic appraisal of the impact of land-based wastewater management activities on the marine environment. For that purpose it firstly introduces the state of the art techniques for wastewater disposal and subsequently assesses the emissions from wastewater treatment plants with special emphasis on the pollutants of rising concern.

16.2 State of the Art Techniques for Wastewater Collection and Treatment

16.2.1 Wastewater Collection and Transport

When debating the state-of-the-art techniques for wastewater disposal, the historical context must be considered in the first instance. Originating from the increasing use of water closets, water became a medium for massively diluting and transporting human faeces and urine. It may have been historically a fundamental mistake that sewage and rainwater run-off ended up in the same pipe. The outcome has been the burden of the still existing "combined sewer systems". Thus, we still have to cope with the decisions made more than 100 years ago. From today's perspective, one may even conclude that there could have been a better design and concept for the entire wastewater infrastructure.

Nowadays, a combined sewer system refers to the single pipe system which diverts a mixture of the municipal plus industrial sewage (dry-weather run-off) and the rainwater run-off. The major shortcoming of the combined sewer system occurs in case of heavy rainfall events, when the combined sewer overflow events might take place frequently to avoid overloading the sewer system including the downstream wastewater treatment plant. Thus, the combined sewer overflow events cause undesired but finally inevitable direct discharge of untreated wastewater into the receiving aquatic environment. Due to such drawbacks of the combined sewer system, it is in most cases more preferable to adopt the separate sewer system, namely the sewer system that transports sewage and rainwater run-off separately in different pipes. The separated sewer system thus avoids the discharge of untreated sewage into the natural water cycle (compare Fig. 16.1).

16.2.2 Wastewater Treatment

Wastewater treatment plants are facilities designed for reducing the anthropogenic water pollution to a minimum. As end-of-pipe solution these plants receive a complex wastewater matrix from manifold sources. The wastewater composition varies according its diverse origins. In practice, the wastewater pollution can be traced back to two origins: sewage-borne and surface-borne pollution. Important sewage-borne pollution sources include households, business and industry, public facilities and healthcare institutions like hospitals. Surface-borne pollution originates generally from run-off areas (i.e. sealed land-particularly traffic areas). Wastewater can carry a variety of pollutants, including organic compounds (evaluated with the parameters such as COD chemical oxygen demand, BOD biochemical oxygen demand and TOC total organic carbon), waterborne nutrients (esp. nitrogen and phosphorous), inorganic compounds (e.g. heavy metals) and waterborne pathogens etc.. As for stormwater run-off esp. road run-off, it is featured with some particular pollutants such as tire debris, polycyclic aromatic hydrocarbons (PAH), heavy metals and de-icing salts. During the transportation via sewer system, pollutants concentrated in wastewater can get massively influenced by factors such as the groundwater infiltration, drainage water exfiltration and possible misconnections.

Conventionally, wastewater treatment comprises a mechanical treatment process for the removal of suspended solids and lipids followed by a downstream biological

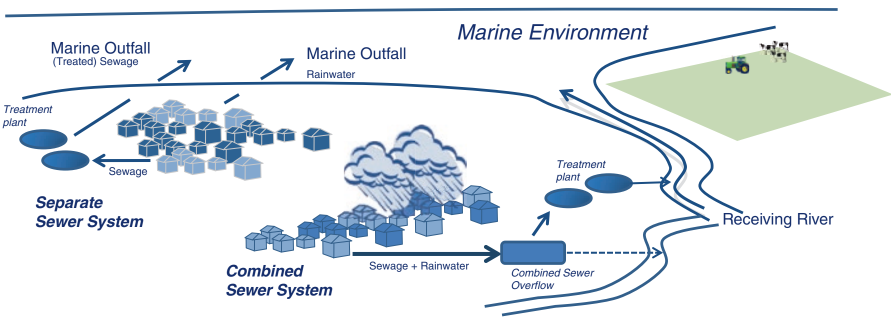


Fig. 16.1 Urban catchments and links to the marine environment

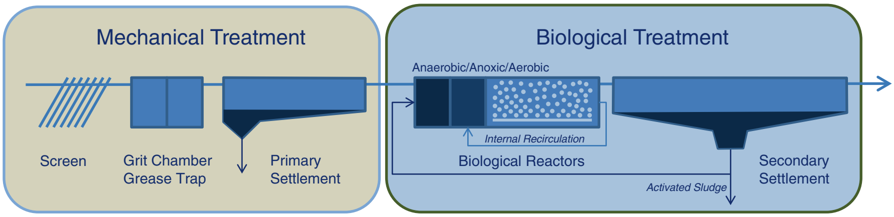


Fig. 16.2 Conventional scheme for wastewater treatment

treatment process for the removal of dissolved compounds, as illustrated in Fig. 16.2. According to the situations, these basic processes occasionally can get expanded by adding some chemical processes. To have a further look into the processes, it is first priority of wastewater treatment to remove pollutants such as suspended solids and lipids with mechanical treatment. For the downstream removal of the critical dissolved pollutants, always a biological or bio-chemical treatment is required. Predominantly in activated sludge systems wastewater treatment plants maintain an ideal environment for specialized bacteria to degrade organic pollutants and for some further specialized bacterial communities to remove nutrients. Inevitably, the biological treatment leads to the formation of suspended solids in the form of biological sludge which has to be removed from the treated wastewater. For reliable sludge retention, the final treatment step is in most instances a sedimentation process which sometimes has to be aided by the use of flocculation and coagulation agents. Nowadays, the standard wastewater treatment process is the *Tertiary Treatment*, comprised of mechanical pretreatment and an advanced multi-stage biochemical treatment. Thus, the latter treatment stage can reliably remove the organics and nutrients (nitrogen and phosphorous) from wastewater.

The state-of-the-art treatment techniques mentioned above are not applied uniformly across the world. In the upcoming years, the wastewater treatment industry still has several significant gaps to fill. But even for the forerunner EU, which already had 75% of its wastewater treatment plants in the big cities adopting tertiary treatment standard by the end of the year 2009 (EEA 2013), it still has thorny wastewater treatment challenges to overcome. Because even if a high standard is achieved, the tertiary treatment is still considered to be insufficient for the removal of the above-mentioned pollutants of rising concern.

16.3 Emissions of Wastewater Treatment Plants

16.3.1 Conventional Pollutants

The last decades witnessed the continuous improvements of the wastewater treatment solutions for minimizing the emissions of wastewater treatment plants. Technically speaking, there is no doubt about the success of the implementation of the tertiary treatment on large wastewater treatment plants. The tremendous 64.3% reduction of nitrogen released from German municipal wastewater treatment plants achieved in the

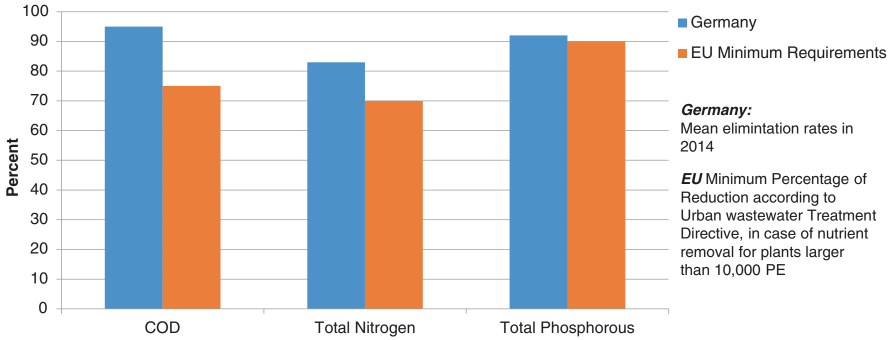


Fig. 16.3 Treatment performance of German wastewater treatment plants compared with EU minimum requirements (DWA 2015; EU 1991)

period from 1985 to 2005 was chiefly due to the extension of wastewater treatment schemes since 1990 (UBA 2010). During the same period the phosphorous loads of wastewater treatment plants could have reduced by 83.3%, thanks to the source control measures of restricting phosphorous-containing detergents (UBA 2010).

In summary, the performance of wastewater treatment is nowadays fairly satisfying in terms of the conventional pollutants. Assuming a proper operation the average reduction rates for carbon and phosphorous is above 90% and for nitrogen above 80%. For example, Fig. 16.3 shows the mean elimination rates of the municipal wastewater treatment plants in Germany based on a benchmark test for the reference year 2014. In 2014 the German wastewater treatment plants achieved significantly better treatment results than the European minimum requirements.

16.3.2 Pollutants of Rising Concern

As stated before, the set of pollutants of rising concern encompasses organic micropollutants (Broeg et al., Chap. 20), macro-, micro- and nanoparticles and also specific pathogens. These emerging pollutants are usually not subject to any limit values and are therefore not included in the governmental oversight. But why should we focus on these emerging pollutants? Because they have been found to exert negative effects on the aquatic ecosystems and, hence, may endanger human beings, meanwhile our current wastewater treatment technologies still cannot remove these emerging pollutants sufficiently.

16.3.2.1 Organic Micropollutants

Organic micropollutants is a general term for plenty of different mostly complex organic pollutants such as pharmaceutical residues, endocrine disruptors, very stable compounds like (X-ray) contrast agents, industrial chemicals as well as personal care products. All these compounds can be found in wastewater treatment plant effluents. Perhaps the best known effect caused by micropollutants in the aquatic environment is feminization of male fish due to sex-changing effects triggered for example by estrogenic pollutants such as residues of birth control pills (Vajdaa et al. 2011 and many others). Besides these degenerative effects, a further study brought worldwide attention to the micropollutants issue. Thus, it is found that dilute concentrations of the psychiatric drug *Oxazepam* can alter the behavior of fish populations (Brodin et al. 2013). These observations stress the importance of a reliable and holistic toxicological risk assessment for organic micropollutants, which, however, is fairly difficult.

Usually, wastewater treatment plants are not designed for removing micropollutants. Plenty of studies show that in conventional treatment plants a certain removal of micropollutants can be reached (compare Table 16.3). However, the actual removal performance still does not reach the target concentrations which are considered to be appropriate. On the contrary, it is observed that certain pharmaceuticals may even increase after biological treatment, due to the fact that substances can get biologically transformed back to their parent compounds during sewage treatment (Luo et al. 2014).

As far as the design of future wastewater treatment schemes is concerned, it can be anticipated that the removal of micropollutants will gain in importance. In order to come to a reliable and robust removal of micropollutants, further downstream treatment is necessary. Advanced removal technologies are already available such as *ozonation* and *adsorption by activated carbon*. However, there still exist some enduring doubts for applying ozonation for micropollutants removal, because of the occurrence of (potentially toxic) by-products. Furthermore, as the currently technically suitable treatments (i.e. removing compounds in extremely low concentrations from large volumes of wastewater) can lead to a significant increase of energy consumption and costs, the decision makers explicitly claim for more economically viable solutions.

16.3.2.2 Microplastics

In the recent past, the issue of pollution by microplastics arose in the environmental debates. Since this particular issue has been discussed beyond the academic world, especially the wastewater treatment industry moved into the spotlight. Microplastics are particles smaller than 5 mm (see Table 16.1) and should therefore not be mixed up with micropollutants.

Undoubtedly, municipal wastewater contains microplastics. Specific personal care products such as peeling creams or tooth pastes (Fig. 16.4), magnification 4x [a] and 10x [b]) as well as plastic fibers from synthetic fabrics (Fig. 16.5 a and b) get into the wastewater from households.

Investigations of wastewater samples from domestic washing machines conducted by Browne et al. demonstrated that a single garment can produce more than 1,900 fibers per wash (Browne et al. 2011).

But here too, wastewater treatment plants are not assigned to remove microplastics. Thus, it is very likely that microplastics escape from wastewater treatment plants. Our state of knowledge still cannot elucidate the fate of the microplastics in the wastewater treatment process, inter alia, due to the detection difficulties in

Table 16.1 Different types of plastics in the environment (UBA 2015)

Diameter	Term	Affected organisms	Industrial application
>25 mm	Macroplastic	Vertebrates, birds	Pre-products and end products
5–25 mm	Mesoplastic	Birds, fish	Pre-products and granules (pellets)
1–5 mm	Large microplastic particles	Fish, crustaceans	Granules (pellets)
<1 mm	Small microplastic	Mussels, plankton	Microparticles in personal care products

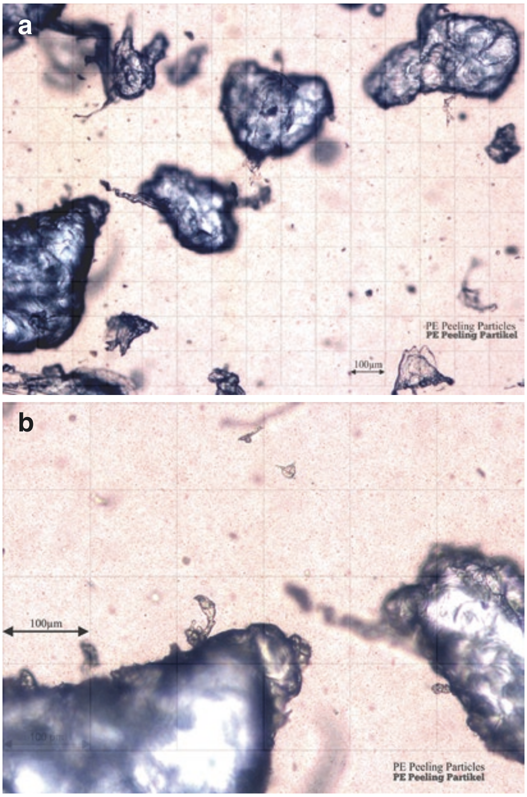


Fig. 16.4 Peeling particles in a personal care product: 4 and 10× magnification, mesh width 100 µm (own pictures)

practice. Some snapshot analyses of primary and secondary effluents showed significant removal of microplastics by the mechanical treatment, namely only a considerably reduced amount of microplastic particles can escape from the wastewater treatment plant. Referring to a HELCOM study the removal rates of the given particles and fibers reached more than 90% (HELCOM 2014). The investigations conducted by Leslie et al. surprisingly suggest that MBR technology does not entail any advantages in terms of MP removal (Leslie et al. 2013). However, the above-mentioned studies lead to first rough indications on the effluent qualities attainable by conventional treatment schemes (Table 16.2).

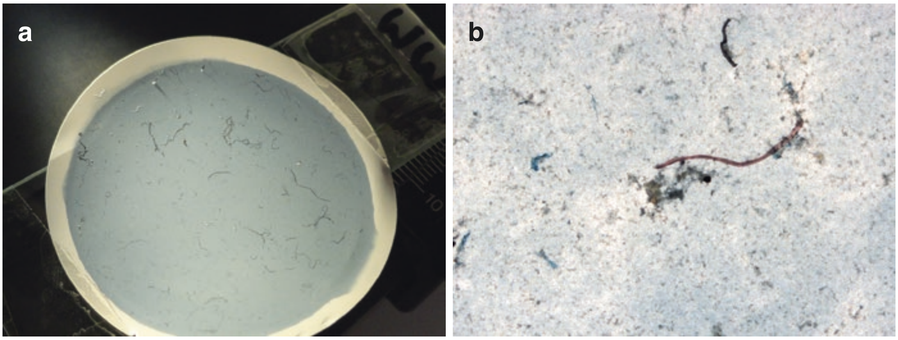


Fig. 16.5 (**a**) Filter paper sample after 0.45 μm-filtration of washing machine wastewater, (**b**) unidentified fibers in washing machine wastewater filtrate (own pictures)

Table 16.2 Microplastic particles and fibers per liter wastewater treatment plant effluent

Study	Microplastic particles per liter effluent
HELCOM (2014)	7 synthetic particles 16 textile fibers 125 black particles
Leslie et al. (2013)	50 particles (average)
Mintenig et al. (2014)	Peak 13.7 microplastics particles

Despite the removal described above, numerous projections indicate wastewater treatment plants as a noteworthy source for microplastics. In fact, effluents from wastewater treatment plants finally play more or less a potentially minor role compared to other sources of microplastics, for example the surface-borne input, especially tire debris (UBA 2015).

16.3.2.3 Engineered Nanoparticles

By size, *Engineered Nanoparticles* (ENPs) are categorized within the limit of less than 100 nm, thus, significantly smaller than the microplastic particles. In terms of environmental awareness, microplastics and ENPs share similarities. For many years ENPs have been widely used for food production, personal care products, textiles, industrial and others purposes (Mouneyrac et al. 2015). The best known and highly used ENPs include Ag, ZnO, Titanium Dioxide and Carbon-based/Carbon Nanotubes (Maurer-Jones et al. 2013; Weir et al. 2012). For instance, one can easily find the applications of silver nanoparticles in personal care products, food packaging materials, disinfectants, cleaning agents and functional clothing with antibacterial effects. Inevitably, wastewater treatment plants become an important emission source for ENPs, which transfers a considerable amount of ENPs into the water cycle (Brar et al. 2010). Conventional biological treatment can remove a significant share of the imported ENP, thanks to the manifold interactions with bacterial sludge (Wang et al. 2012 in OECD 2015). To give an example: nine British wastewater treatment plants' removal performance for colloidal silver (size

2–450 nm including nanosilver) reached about 48% in view of an influent concentration of 12 ng/L set against an effluent concentration of 6.2 ng/L (Johnson et al. 2014). Likewise Li et al. (2013) indicate an average removal of around 35% nanoscale silver particles by municipal wastewater treatment plants. Some further treatment plant onsite measurements (e.g. Kiser et al. 2009) and further modeling and simulations (e.g. Gottschalk et al. 2009) led to supplementary estimations in terms of ENPs concentrations in plant effluents. The available data simply point out that plant effluents show higher ENP-concentrations in comparison to surface waters (Maurer-Jones et al. 2013).

16.3.2.4 Pathogens

Pathogens are biological agents that cause and spread disease. Wastewater treatment plants are a relevant source of pathogens, especially if wastewater is inadequately treated or if appropriate disinfection measures are not applied. Wastewater-borne pathogens such as bacteria, viruses and parasites/pathogenic protozoa commonly exist in treatment plant effluents. Nevertheless, the better the quality of wastewater treatment, the lower is the amount of pathogens in the effluent. The efficiency of disinfection might be also restricted by the actual performance of applied methods (Brettar et al. 2007). From the point of view of hygiene, critical situations are heavy rain periods which can temporarily lead to a less effective wastewater disposal/treatment (Brettar et al. 2007). In case of heavy precipitation, combined sewer overflows become further route of pathogens into rivers and coastal waters. Another aspect is that wastewater treatment plants can be relevant secondary sources of antibiotic resistances, because on these plants the resistances from primary sources can accumulate (Schwartz and Alexander 2014).

16.4 Significance of Land-Based Wastewater Management for Marine Pollution

Self-evidently, almost everything that is released to the aquatic environment will finally have impact on the marine environment. This applies equally for all the compounds addressed above. In the following it is briefly discussed to which extent the considered facets of the land-based wastewater management contribute to the marine pollution.

16.4.1 Conventional Pollutants (COD, BOD, N and P)

In territories where high standards for wastewater emissions properly have been enforced, the impact of emissions of treated wastewater should have only minor importance for the pollution of marine ecosystems—especially compared with non-point source pollution. However, once wastewater treatment significantly lags behind these standards, wastewater treatment facilities are considered to be highly relevant sources for the marine pollution caused by organics and nutrients.

To illustrate the significance of land-based wastewater management for marine pollution caused by organics and nutrients, it is worthwhile to have a look on the Baltic Sea, one of the most sensitive sea areas worldwide. Especially, thanks to the Helsinki Convention and the activities of its contracting parties, the Baltic Sea catchment is one of the best investigated sea areas worldwide. Moreover, there are many organizations carrying out international protection schemes on the Baltic Sea. For instance, the Baltic Sea is the first and to date the only special protection area appointed by MARPOL Annex IV (*MARPOL 2005*). The principal environmental concern for the marine ecosystem of the Baltic Sea is eutrophication (Beusekom et al., Chap. 22). As anywhere in the marine environment, the nutrients discharged to the Baltic Sea are airborne (e.g. airside emission from ships and combustion processes), and waterborne (direct discharge and river-borne) from insufficiently treated wastewater (point sources) and from farmland (non-point sources) (BMUB 2008). Referring to the HELCOM Report 2013, in 2010 the Baltic Sea received a total nitrogen input of 977,000 t and a total phosphorous input of 38,300 t. Direct discharges contributed only a minor proportion of the waterborne input. While the main input came from the catchment and were transported by rivers. In 2010, municipal and industrial wastewater treatment facilities contributed around 30,000 t N and 1,600 t P river-borne input to the Baltic Sea. Thus, the nitrogen input from treatment plants counted for (only) about 3% of the total nitrogen input. For phosphorous it was about 4.2% (HELCOM 2013).

With regard to the impact of wastewater emissions on marine environment, the direct discharge of (treated) wastewater into the marine environment by submarine outfalls is a particular case. By definition, a submarine outfall is a submarine pipeline that directly discharges wastewater of whatever kind in coastal areas. This can have a direct impact on the marine ecosystems. To what extent the marine ecosystems are affected depends on the performance of wastewater treatment. Investigations in terms of "plume tracking and dilution of effluent from the sewage outfalls" show that there can be a significant impact from direct discharge on marine ecosystems (e.g. Caron et al. 2015; Xu et al. 2014).

16.4.2 Organic Micropollutants

Recently, the occurrence and fate of micropollutants has become a key issue within our debates about the status of the marine environment. As for the marine environment, plenty of different sources of micropollutants can potentially affect its water, sediments and biota. Beyond doubt, wastewater treatment plants are a relevant source of micropollutants for marine environment, due to its input by riverine sources or marine outfalls (Ghekiere et al. 2013). The mere presence of human pharmaceuticals and corresponding metabolites explicitly proves that these wastewater-borne compounds reach the marine environment. In fact, one can easily demonstrate the entrance of wastewater-borne micropollutants to the marine environment e.g. by

Table 16.3 Overview of reported ranges of concentrations for selected micropollutants in different environments

Parameter	Raw waste-water (μg/L)	Reported plant removal efficiency(%)	Effluent wastewater treatment plant (μg/L)	Inland surface waters (ng/L)	Marine environment(ng/L)
Carbamazepine (anticonvulsant)	(1) 0.04–3.78 (6) ≤2.9	(1) 0–62.3 (5) ≈ −23–11	(1) 0.005–4.6 (6) ≤1.2	(1) 1–1,194	(2) 0.21–732 (4) 3.1–157
Diclofenac (analgesic)	(1) <0.001–94.2	(1) 0–81.4	(1) <0.001–0.69	(1) 0.5–1,043 (2) 49	(2) 0.02–11.6 (4) 4.6–9.7
Sulfamethoxazole (antibiotic)	(1) <0.003–0.98 (3) 0–1.76	(1) 4–88.9 (3) <0–>93 (5) ≈ 13–72	(1) <0.003–1.15 (3) <30–964	(1) 0.2–60	(2) 0.8–96 (4) 3.6–42
Bisphenol A(org. Syn. Compound)	(1) 0.013–2.14	(1) 62.5–99.6	(1) <0.03–1.1	(1) 2.1–881 (2) 57 (6) ≤776/8,300	(2) <96–694

Figures were taken and aggregated from (1) Luo et al. (2014), (2) Bebianno and Gonzalez-Rey (2015), (3) Michael et al. (2013), (4) Nödler et al. (2014), (5) Gurke et al. (2015) and (6) Jiang et al. (2013). The cited values were not necessarily collected by the cited authors. Readings from/on diagrams can lead to slightly fuzzy values (indicated by ≈)

the presence and detection of explicitly wastewater-borne tracers like caffeine (Claessens et al. 2015). Comparing the micropollutants' concentrations in the marine environment and those in treatment plant effluents or rivers, in most cases the former lie below the latter. However, marine pollution study still remains at a very early stage, particularly regarding the marine environment data acquisition (i.e. micropollutants measurements) and the respective problem or the risk assessment. Table 16.3 gives examples for selected compounds in different environments to illustrate the very wide differences among scientific investigations.

16.4.3 Microplastics

The debate regarding the pollution of aquatic ecosystems by microplastics dates back to the observations in the marine environment (e.g. Andrady 2011). For a little while wastewater treatment plants were considered as a highly relevant source of microplastics. However, recently some other apparently more relevant sources have been identified (e.g. tire debris), so that in a holistic view wastewater industry only represents one among other sources. A further highly interesting finding for marine environment is that the plastic debris tends to sorb certain organic micropollutants from seawater (Hirai et al. 2011).

16.4.4 Engineered Nanoparticles

Engineered nanoparticles (ENP), as in the case of microplastics, recently also have become a reasonable concern regarding its environmental impacts on the marine environment. In this respect, wastewater treatment plants are another important source for ENP apart from anti-fouling agents and paints (Matranga and Corsi 2012). And similar to microplastics "ENPs have been found to be available for uptake both in pelagic and benthic organisms", so that there is really a practical reason for anxiety (Mouneyrac et al. 2015). Despite the selective investigations mentioned above the knowledge about the fate of ENPs in wastewater treatment plants still can be improved notably (Matranga and Corsi 2012). In addition, further efforts are needed to fill the knowledge gaps concerning the environmental risks related to the ENP release and presence in marine ecosystems (Matranga and Corsi 2012; Weinberg et al. 2011).

16.4.5 Pathogens

Unsurprisingly, manifold pathogens exist in the marine environment (Griffin et al. 2003). That applies also to wastewater-borne pathogens. As stated above, the presence of wastewater-borne pathogens in the seas is finally inevitable, despite all the efforts in terms of wastewater treatment and disinfection (Brettar et al. 2007). Pathways to the marine environment include direct wastewater discharges by submarine outfall and the riverine discharges. In this respect, the effectiveness of wastewater treatment finally determines the magnitude of pathogen transfer from wastewater facilities to the marine environment. Evidently, this especially applies to the cases of marine outfalls. Heavy rain periods are considered to be quite problematic, especially when storm events or floods flush the untreated or insufficiently treated sewage into rivers and coastal waters (Brettar et al. 2007). Brettar et al. conclude that there is an increasing "load of pathogenic organisms in coastal water and shellfish during heavy rain periods" (Brettar et al., 2007). A further relevant aspect is that there can be an interdependence between man-made eutrophication and the survival of pathogens in the marine environment because many factors associated with eutrophication can affect or even promote the pathogens spread (Brettar et al. 2007).

16.5 Conclusions

Land-based activities are highly relevant for the marine pollution and can exacerbate the pressure on the marine environment. Provided a proper enforcement of legal regulations, a massive reduction of the negative influence of land-based wastewater management activities on the marine environment can be achieved. In view of wastewater management there is a simple equation: If wastewater is treated according to the state-of-the-art standards, wastewater discharges only play a minor role in terms of the total amount of organic and nutrient loads being released into the marine environment. If wastewater is not or insufficiently treated, the wastewater management sector decisively contributes to the eutrophication of the inland rivers and the marine environment—in addition to the non-point sources which can be held responsible for the largest share of released nutrients. In order to further minimize the remnant pollution from wastewater treatment plants, it would be advisable to upgrade the small-scale wastewater treatment facilities as a priority. Another issue is the fate of sewage sludge and further residues from wastewater treatment plants. Good practices in residue management are indispensable to minimize any adverse side effects on the aquatic environment. Finally, the wastewater industry has to face the problem of the pollutants of rising concern and here especially those compounds which indisputably originate from wastewater treatment plants. As already proved, wastewater treatment plants account for the release of micropollutants, pathogens and gradually for tiny particles like microplastics and engineered nanoparticles. Thus, we have to ask how to act in response to these challenges. In this context wastewater treatment has developed perhaps not as well as it could or should. Thus, we are on the threshold to solve these still outstanding issues.

References

Andrady AL (2011) Microplastics in the marine environment. Mar Pollut Bull 6:1596–1605

Bebianno MJ, Gonzalez-Rey M (2015) Chapter 16: Ecotoxicological risk of personal care products and pharmaceuticals. In: Amiard-Triquet C, Amiard J-C, Mouneyrac C (eds) Aquatic ecotoxicology: advancing tools for dealing with emerging risks. Elsevier, Amsterdam

BMUB (2008) http://www.bmub.bund.de/themen/wasser-abfall-boden/meeresumweltschutz/ergebnisse-helcom/. Retrieved 8 Jan 2016

Brar SK, Verma M, Tyagi RD, Surampalli RY (2010) Engineered nanoparticles in wastewater and wastewater sludge – evidence and impacts. Waste Manage 30(3):504–520

Brettar I, Guzman CA, Höfle MG (2007) Human pathogens in the marine environment – an ecological perspective. CIESM workshop monographs no. 31: marine sciences and public health, Geneva (Switzerland) CIESM 2007, pp 59–68

Brodin T, Fick J, Jonsson M, Klaminder J (2013) Dilute concentrations of a psychiatric drug alter behavior of fish from natural populations. Science 339:814–815

Browne MA, Crump P, Niven SJ, Teuten E, Tonkin A, Galloway T, Thompson R (2011) Accumulation of microplastic on shorelines worldwide: sources and sinks. Environ Sci Technol 2011(45):9175–9179

Caron DA, Gellene AG, Smith J, Seubert EL, Campbell V, Sukhatme GS, Seegers B, Jones BH, Lie AAY, Terrado R, Howard MDA, Kudela RM, Hayashi K, Ryan J, Birch J, Demir-Hilton E, Yamahara K, Scholin C, Mengel M, Robertson G (2015) Response of phytoplankton and bacterial biomass during a wastewater effluent diversion into nearshore coastal waters. Estuar Coast Shelf Sci 186(Part B):223–236

Claessens M, De Laender F, Monteyne E, Roose P, Janssen CR (2015) Modelling the fate of micropollutants in the marine environment using passive sampling. Mar Pollut Bull 96(1–2):103–109

DWA (2015) 27. Leistungsvergleich kommunaler Kläranlagen. https://de.dwa.de/tl_files/_media/content/PDFs/1_Aktuelles/leistungsvergleich_2014.pdf. Retrieved 12 Dec 2015

EU (1991) Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment

European Environment Agency (2013) Urban waste water treatment. Created 26 Mar 2012. Published 31 Jan 2013. Last modified 4 Sep 2015. http://www.eea.europa.eu. Retrieved 22 Dec 2015

Ghekiere A, Verdonck F, Claessens M, Monteyne E, Roose P, Wille K, Goffin A, Rappé K, Janssen CR (2013) Monitoring micropollutants in marine waters, can quality standards be met? Mar Pollut Bull 69(1–2):243–250

Gottschalk F, Sonderer T, Scholz RW, Nowack B (2009) Modeled environmental concentrations of engineered nanomaterials (TiO_2, ZnO, Ag, CNT, fullerenes) for different regions. Environ Sci Technol 43:9216–9222

Griffin DW, Donaldson KA, Paul JH, Rose JB (2003) Pathogenic human viruses in coastal waters. Clin Microbiol Rev 16:129–143

Gurke R, Rößler M, Marx C, Diamond S, Schubert S, Oertel R, Fauler J (2015) Occurrence and removal of frequently prescribed pharmaceuticals and corresponding metabolites in wastewater of a sewage treatment plant. Sci Total Environ 532(2015):762–770

HELCOM (2013). Baltic Sea environment proceedings no. 141 review of the fifth Baltic Sea pollution load. Compilation for the 2013 HELCOM Ministerial Meeting. http://www.helcom.fi/Lists/Publications/BSEP141.pdf. Retrieved 3 Dec 2015

HELCOM (2014). BASE project 2012–2014: preliminary study on synthetic microfibers and particles at a municipal wastewater treatment plant. http://www.helcom.fi/Documents/HELCOM%20at%20work/Projects/BASE/Microplastics%20final%20report%20Base_final.pdf. Retrieved 8 Jan 2015

Hirai H, Takada H, Ogata Y, Yamashita R, Mizukawa K, Saha M, Kwan C, Moore C, Gray H, Laursen D, Zettler ER, Farrington JW, Reddy CM, Peacock EE, Ward MW (2011) Organic micropollutants in marine plastics debris from the open ocean and remote and urban beaches. Mar Pollut Bull 62(8):1683–1692

Jiang J-Q, Zhou Z, Sharma VK (2013) Occurrence, transportation, monitoring and treatment of emerging micro-pollutants in waste water—a review from global views. Microchem J 110(2013):292–300

Johnson AC, Jürgens MD, Lawlor AJ, Cisowska I, Williams RJ (2014) Particulate and colloidal silver in sewage effluent and sludge discharged from British wastewater treatment plants. Chemosphere 112(2014):49–55

Kiser MA, Westerhoff P, Benn T, Wang Y, Pérez-Rivera J, Hristovski K (2009) Titanium nanomaterial removal and release from wastewater treatment plants. Environ Sci Technol 43(17):6757–6763

Leslie, H.A., van Velzen, M.J.M. & Vethaak, A.D. (2013). Microplastic survey of the Dutch environment: novel data set of microplastics in North Sea sediments, treated wastewater effluents and marine biota. IVM Institute for Environmental Studies. Final report R-13/11, 9 September 2013. http://www.ivm.vu.nl/en/Images/IVM_report_Microplastic_in_sediment_STP_Biota_2013_tcm234-409860.pdf. Retrieved 15 Dec 2015

Li L, Hartmann G, Doblinger M, Schuster M (2013) Quantification of nanoscale silver particles removal and release from municipal wastewater treatment plants in Germany. Environ Sci Technol 47:7317–7323

Luo Y, Guoa W, Ngo HH, Nghiem LD, Ibney Hai F, Zhang J, Liang S, Wang XC (2014) A review on the occurrence of micropollutants in the aquatic environment and their fate and removal during wastewater treatment. Sci Total Environ 473–474(2014):619–641

MARPOL (2005) IMO-Resolution A.927(22): Resolution A.982(24) adopted on 1 December 2005 (Agenda item 11) Revised guidelines for the identification and designation of particularly sensitive sea areas – MARPOL – IMO Resolution A.927(22) updated by Resolution A.982(24)

Matranga V, Corsi I (2012) Toxic effects of engineered nanoparticles in the marine environment: model organisms and molecular approaches. Mar Environ Res 76(2012):32–40

Maurer-Jones MA, Gunsolus IL, Murphy CJ, Haynes CL (2013) Toxicity of engineered nanoparticles in the environment. Anal Chem 2013(85):3036–3049

Michael I, Rizzo L, McArdell CS, Manaia CM, Merlin C, Schwartz T, Dagot C, Fatta-Kassinos D (2013) Urban wastewater treatment plants as hotspots for the release of antibiotics in the environment: a review. Water Res 47(2013):957–995

Mintenig, S., Int-Veen, I., Löder, M. & Gerdts, G. (2014). Abschlussbericht: Mikroplastik in ausgewählten Kläranlagen des Oldenburgisch-Ostfriesischen Wasserverbandes (OOWV) in Niedersachsen. Probenanalyse mittels Mikro-FTIR Spektroskopie, Alfred-Wegener-Institut. http://www.oowv.de/uploads/media/Abschlussbericht_Mikroplastik_in_Klaeranlagen-3.pdf. Retrieved 12 Dec 2015

Mouneyrac C, Syberg K, Selck H (2015) Chapter 17: Ecotoxicological risk of nanomaterials. In: Amiard-Triquet C, Amiard J-C, Mouneyrac C (eds) Aquatic ecotoxicology: advancing tools for dealing with emerging risks. Elsevier, Amsterdam

Nödler K, Voutsa D, Licha T (2014) Polar organic micropollutants in the coastal environment of different marine systems. Mar Pollut Bull 85(1):50–59

OECD (2015) The fate of engineered nanomaterials in sewage treatment plants and agricultural applications. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/EPOC/WPRPW%282013%294/FINAL&docLanguage=En. Retrieved 10 Mar 2016

Schwartz T, Alexander J (2014) Antibiotikaresistenzen in Abwasser – Nachweis und Vermeidung der Verbreitung. KA Korrespondenz Abwasser, Abfall 61(3):183–185

UBA (2010) Berechnung von Stoffeinträgen in die Fließgewässer Deutschlands mit dem Modell MONERIS: Nährstoffe, Schwermetalle und Polyzyklische aromatische Kohlenwasserstoffe. UBA-Texte 45/2010

UBA (2015) Sources of microplastics relevant to marine protection in Germany, Texte 64/2015, Publisher Umweltbundesamt/Federal Environment Agency, authors: R Essel, L Engel, M Carus, RH Ahrens

Vajdaa AM, Barber LB, Gray JL, Lopez EM, Bolden AM, Schoenfuss HL, Norris DO (2011) Demasculinization of male fish by wastewater treatment plant effluent. Aquat Toxicol 103(2011):213–221

Wang Y, Westerhoff P, Hristovski KD (2012) Fate and biological effects of silver, titanium dioxide, and C60 (fullerene) nanomaterials during simulated wastewater treatment processes. J Hazard Mater 201–202(2012):16–22

Weinberg H, Galyean A, Leopold M (2011) Evaluating engineered nanoparticles in natural waters. Trends Anal Chem 30(1):72–83

Weir A, Westerhoff P, Fabricius L, Hristovski K, von Goetz N (2012) Titanium dioxide nanoparticles in food and personal care products. Environ Sci Technol 2012(46):2242–2250

Xu EGB, Liu S, Ying G-G, Zheng GJS, Lee JHW, Leung KMY (2014) The occurrence and ecological risks of endocrine disrupting chemicals in sewage effluents from three different sewage treatment plants, and in natural seawater from a marine reserve of Hong Kong. Mar Pollut Bull 85(2):352–362

Chapter 17
Tourism

Alan Simcock

Abstract With the coming of mass passenger transport, tourism has become an important part of the economies of many States. The scale of this is discussed. Concentrations of tourist activity can create pollution problems from sewage. Tourism makes many demands for infrastructure, which can change coastal zones, and adversely impact on coastal biodiversity. The activities of tourists can affect sites of importance to coastal wildlife, and in some forms can interfere with its reproductive success. With proper management, however, a sustainable balance can be achieved. Such management systems need to address all the aspects concerned, and to win the support of all stakeholders. The chapter finally discusses the main elements needed for such systems.

Keywords Beach • Boat • Coral • Dolphin • GDP • Hotel • ICZM • Infrastructure • Marinas • MSP • Recreation • Seabird • Seal • Shark • Tourism • Tourists • Turtle • Whale

17.1 Structure and State of the Tourism Sector

17.1.1 Introduction

Seaside tourism has a long history. During the Roman Republic and the early Roman Empire, the Roman élite enjoyed themselves around the Bay of Naples and adjoining coasts and islands: swimming, boating and fishing were prized leisure activities (Balsdon 1969: 199 ff). Recreational visits to the seaside developed again in the later eighteenth century, as a result of medical experts recommending the health benefits of sea-bathing (Russell 1755), and the consequent examples of the British royal family at Weymouth and Brighton. After the Napoleonic wars, similar

A. Simcock
Joint Coordinator, United Nations' World Ocean Assessment 1, Richmond, Surrey, England
e-mail: ajcsimcock@aol.com

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_17

developments took place on the European continent—for example at Puttbus on the German island of Rügen (Lichtnau 1996).

With the arrival of steamboats and the railways, large numbers of people became able to make visits to the seaside: the rich travelled long distances to destinations such as the French Riviera, while industrial workers made shorter journeys to the nearest sea coasts. Whole towns grew up to service this traffic, such as Blankenberge and Knokke-Heist in Belgium, Blackpool and Southend in England and Deauville and Trouville in France (Walton 1983).

The introduction of mass long-distance air travel from the mid 1960s brought about a further revolution in tourism, allowing long trips for short period. The consequent growth in tourism can only be described as phenomenal.

17.1.2 Scale of Tourism

In 1965, the number of international tourist arrivals worldwide was estimated at 112.9 million. Thirty-five years later, in 2000, this figure had grown to 687.3 million—an increase of 509%, equivalent to an average annual compound growth rate of 5.3%. By 2013, this had grown further to 1.06 billion—a further growth of 54%, equivalent to an annual growth rate of 3.4% (WTO 2014).

Although these figures give a general impression of the growth in tourism globally, they can be misleading, since they deal only with international tourism, and do not cover domestic tourism traffic—that within a single country. International tourism statistics show a higher proportion of the total traffic in regions with relatively large numbers of States, but do not reflect the large amounts of tourist traffic within large States: a relatively short journey in Europe can easily cross three or more States (and thus count as international) while a journey twice or three times as long in China or the United States of America will not appear in international tourism statistics. It is not easy to obtain statistics on total tourism (both international and domestic) because the absence of border crossings removes the most obvious point of statistical capture. However, it is clear that in large States domestic tourism is often many times larger than international tourism. In Brazil, in 2011, national tourism was estimated to be nearly 10 times larger than international tourism (FIPE 2012; AET 2012). In 2013, national tourism in mainland China was estimated to involve 20 times more tourists than international tourism. In the USA, in 2013, domestic tourism was estimated to be involve 22 times more travel than international tourism (USA Travel 2014).

Such overall tourism statistics on their own do not, however, give a clear picture of the impact of tourism on the coasts and ocean, since they include tourism of all kinds, whether in cities, forests, mountains or the coast. In small coastal and island States, total tourism will be close to the number of tourists who may affect the ocean, since everyone will be in the coastal zone. Even where other forms of tourism are a substantial part of the market, it is nevertheless clear that coastal tourism is a very significant component of total tourism. In 2012, a study showed that for 28

European countries, 599 million tourist person/nights (42%) were spent in coastal regions out of the total of 1416 million tourist person/nights in those countries (Eurostat 2014). This is consistent with Europeans' expressed preferences for coastal holidays where 46% wished for seaside holidays (EC 2014). Likewise, in Brazil in 2011, 78% of domestic tourism destinations were in the coastal Federal Units (FIPE 2012). In the USA, in 2008, it was noted that Miami Beach attracted more than twice as many visitors as the Grand Canyon, Yellowstone National Park and Yosemite National Park combined, and that California beaches attract more visitors than all 388 National Park Service properties combined (Houston 2008). Coastal tourism is therefore a dominant form of tourism generally.

17.1.3 Regional Spread

Although a large part of this increase in tourism has occurred in Africa and Asia, Europe continues to dominate the destinations of international tourism, with 51% of all international tourist arrivals in 2012. Tourist arrivals in Asia and the Pacific more than doubled. This represented an increase in the share of world traffic by 6% points, from 17 to 23% of the global total. Likewise, tourist numbers in Africa have risen both in absolute terms and as a proportion, although from a much lower base: tourist arrivals in Sub-Saharan Africa rose by over a quarter between 2007 and 2012, from 3.5 to 5% of the global total (WTO 2014).

European tourists equally form the bulk of the international tourism market: 53% of international arrivals are from Europe; the numbers of Asian and Pacific tourists are growing strongly, and the number of African tourists is also growing significantly, although from a low base (WTO 2014). This is not surprising since the majority of tourists tend to visit countries in their own region (Orams 2003). It is for small States that the growth in long-distance tourism is most important: taking, for example, the 25 States and territories that cooperate in the Caribbean Tourist Organization, 35% of their 24 million arrivals in 2012 were from the USA, 14% from Europe and 12% from Canada, meaning that at least 61% of arrivals were from outside their immediate area (CTO 2013).

17.1.4 Economic Aspects

The large numbers of people taking holidays away from home require a large amount of resources in the form of transportation, accommodation, feeding and recreation. As a study of foreign direct investment in tourism by the United Nations Conference on Trade and Development (UNCTAD) puts it: "A significant part of tourism's development potential stems from the fact that it links together a series of cross-cutting activities involving the provision of goods and services such as accommodation, transport, entertainment, construction, and agricultural and fisheries production"

(UNCTAD 2007). Tourism has therefore become a major economic activity. (Since it is often difficult to distinguish travel for business purposes from travel for recreational purposes, it is often necessary to describe this economic activity as "tourism and travel"; in the rest of this section, tourism must be understood in this wider sense.)

The World Bank publishes data on tourism for 114 States and territories. These data show that, tourism globally accounts for about 6% of total exports (in the sense of purchases in a country's economy by people from outside that country). However, some regions of the world (particularly the Caribbean) are economically very dependent on international tourism. It also shows that most small coastal States and territories are more dependent on such earnings than larger countries with more diversified and larger industries or resources of raw materials—although it is not unimportant even in countries such as Australia (11%) or the United States (9%). The results of an analysis of this data are summarized in Table 17.1.

Expenditure by international tourists, however, is only part of the economic aspects of coastal tourism. Domestic tourism can be many times more significant, particularly in larger States. Although there are no global estimates of the total expenditure solely in coastal regions by domestic and foreign tourists combined, it

Table 17.1 International tourism expenditure by visitors, analysed by global region, ranked by regional average percentage of total exports

Region (and number of States and territories covered)	Inbound tourism expenditure (million US$) 2012	Regional average % of total exports 2012	State or territory with highest % of total exports in region in 2012	State or territory with lowest % of total exports in region in 2012
Caribbean Islands (11)	12,008	44.2	Aruba (Netherlands) (65.7%)	Haïti (16.3%)
Oceania (7)	41,108	11.3	Fiji (61.1%)	Solomon Islands (10.5%)
North America (3)	234,108	7.4	USA (9.0%)	Mexico (3.4%)
Western and Central Europe (inc. Cyprus and Turkey) (18)	440,661	6.1	Cyprus (27.8%)	Germany (3.0%)
Middle East & North Africa (12)	53,889	5.3	Jordan (33.0%)	Algeria (0.4%)
Central and South America (17)	36,606	4.5	Belize (28.9%)	Brazil (2.4%)
East Asia (12)	273,708	4.7	Macau, China (94.2%)	Japan (1.8%)
South Asia (5)	23,093	4.4	Maldives (79.9%)	Bangladesh (0.4%)
Eastern Europe (13)	28,624	3.7	Albania (45.9%)	Russian Federation (3.0%)

Source: Compiled from World Bank 2014

is helpful to look at estimates of total tourism expenditure as a whole, given the evidence (see above) that coastal tourism can be nearly as much as a half or more of total tourism.

In assessing the importance of tourism for a country, it is also important to consider not only the direct expenditure on that activity, but also the "indirect" expenditure on that activity and the resulting "induced" economic activity. The indirect expenditure is that which those active in the economic activity have to spend to buy assets and supplies that they need to carry it out. In the case of tourism, this includes the construction of hotels and other necessary buildings and the purchase of food, power and services, etc. The induced economic activity (sometimes called the multiplier effect) of tourism is the economic activity generated by people who are earning from tourists. The World Travel and Tourism Council (an industry body) has commissioned research to estimate the scale of the contribution of the tourism sector (in the wider sense explained above) to national economies. Table 17.2 summarizes

Table 17.2 Estimated contribution of tourism to GDP and employment 2013, analysed by global regions and ranked by share of total contribution to total GDP

Region	Direct contribution to GDP 2013 US$ million	% share of total GDP	Total contribution to GDP, including the multiplier effect 2013 US$ million	% share of total GDP	% share of direct employment	% share of total employment, including multiplier effect
World	2,155,500	2.9	6,990,540	9.5	3.3	8.9
Caribbean	15,299	4.3	48,994	13.9	3.6	11.3
South East Asia	121,166	5.0	294,376	12.3	3.7	9.7
North Africa	34,951	5.6	74,998	12.1	5.2	11.6
Oceania	49,606	2.8	188,018	10.8	4.4	12.4
European Union (27)	552,148	3.2	1,512,360	9.0	4.0	9.9
Central and South America	142,476	3.2	387,609	8.8	2.8	7.9
North East Asia	431,742	2.6	1,389,330	8.5	2.9	8.2
North America	544,342	2.7	1,665,850	8.3	4.2	10.4
Remainder of Europe and Central Asia	111,596	2.3	362,120	7.2	NA	NA
Sub-Saharan Africa	36,623	2.6	95,713	6.9	2.3	5.8
Middle East	63,988	2.4	167,598	6.4	2.5	6.4
South Asia	NA	NA	NA	NA	NA	NA

Source: Compiled from WTTC 2014

the conclusions of this research (unlike Table 17.1, information on land-locked States cannot be separated out from that for coastal States). The Table also shows estimates of the proportion of employment in the different regions supported directly and in total.

Tourism is thus a significant component of many economies. It has also provided much of the economic growth needed in many countries to alleviate poverty. As a result, many governments and international organizations promote tourism development to improve national economies. Nevertheless, a substantial part of the earnings will accrue outside the country concerned, because of imports of necessary goods, remittance of earnings by expatriate staff and foreign companies operating tourism and the payments of commission to travel agents. This "leakage" is usually a higher proportion of earnings in developing countries than in developed countries, although it is not easy to quantify (Yu 2012).

Apart from tourism's significance in economies as a whole, there are also social effects. The creation of tourist resorts can in many cases result in those already living in the area losing access to public facilities like beaches, finding it impossible to obtain housing because of increases in land values, and seeing sites to which they attach cultural or religious values being profaned. On the other hand, careful planning and collaboration with the local people have produced successful tourist resorts with substantial benefits for local people (Bartolo et al. 2008; Cater 1995; Wilson 2008).

17.2 Impacts of Tourism on the Marine Environment

17.2.1 Pollution

The influx of tourists to coastal resorts inevitably results in problems in the treatment and disposal of waste, both solid and liquid. Large amounts of solid waste are generated, and inadequate handling of this often means that it escapes to the marine environment, thus adding to the problem of marine debris. In addition, litter dropped on beaches by tourists is itself a significant source of marine debris (Werner, Chap. 23). Adequate treatment of the urban waste water created by tourist developments is a further problem. If this sewage is not managed effectively, health problems can be suffered by tourists bathing or boating in the sea. This is likely to undermine the success of a tourist development should awareness of such threats spread. At the same time, even urban waste water that is collected and given proper primary and secondary treatment can contribute to elevated levels of nutrients in the sea, thus leading to eutrophication and the consequent problems of algal blooms, green tides (*marées vertes*) and, in some cases, outbreaks of paralytic shellfish poisoning (Simcock et al. 2016).

A special case of these problems of waste and sewage is presented by cruise ships, particularly in the Caribbean (a major cruising region), where large cruise ships put into relatively small ports which have limited facilities for handling waste and sewage. Islands with populations in the range of 20,000–100,000 are faced with handling the waste and/or sewage from ships with combined passengers and crew of up to 7000 people or more. This is the equivalent of a moderately sized town being added to such an island overnight (ECLAC 2005).

The yachts and small boats used by tourists present separate potential pollution problems. Inevitably, such vessels present an impact from oil escapes from motor engines. More seriously, there are significant residual problems from anti-fouling paints (especially tributyltin (TBT)). The use of TBT has been banned since the 1980s for small vessels (under 25 m) in many parts of the world and, more generally, under the International Convention on Control of Harmful Anti-Fouling Systems on Ships since 2003 for new applications and from 2008 for vessels already treated with TBT (Chap. 6). However, some States have still not accepted this prohibition: 16% of the tonnage of the world's shipping is registered in States that have not become parties to this Convention (IMO, 2014). Even where States are parties to the Convention, areas still remain where TBT is being found in small-boat harbours and associated areas—for example, in Brazil, the Ilha Grande Bay, Rio de Janeiro (described as one of the most heavily protected tourist areas in the country) was shown in 2009 to be still heavily affected by TBT (Pessoa et al. 2009).

17.2.2 Physical Structures

Coastal tourism needs coastal infrastructure. In the first place, transport is needed to get the tourists to the coast. This requires airports, roads, car-parks and (in some cases) railways. All this tends to change the coastal landscape. In addition, tourism demands accommodation. Hotels and restaurants are therefore built in large numbers, with many completely new resorts being developed. These commonly include marine promenades, bathing places and other hard landscape features, which completely change the shoreline (Davenport and Davenport 2006).

Globally, there are few statistics on the extent to which coastal areas have been built up to meet tourism needs. Many studies of specific areas are available, most using satellite-based photographs or sensing, but a comprehensive overview is lacking. Particular efforts, however, have been made in Europe, making a more general overview possible. Studies by the European Environment Agency have shown that, for the coastal zone up to 1 km from the shoreline, more than 10% was built up in Bulgaria, Germany, Latvia, Lithuania, the Netherlands, Poland, Portugal and Romania, more than 20% in France, Italy, Spain, more than 30% in Slovenia and nearly 50% in Belgium (the last two countries having very short coastlines). The proportion of the area close to the shoreline covered with urban development has also been growing rapidly: between 1990 and 2000, nearly 8% of the area within 10 km of the shoreline in the States mentioned (together with Denmark, Estonia, Finland, Greece and Ireland) was changed from agricultural or natural uses to artificial land cover (EEA 2006). Some regional studies in the United States have shown a similar picture: more than 10% of the estuarine coastlines of Delaware, Maryland, Virginia, and North Carolina now have artificial shorelines (Currin 2013).

Built development for tourism is often linked to more general urban development. In many parts of the world (for example, Cyprus, Rousillon in France, southern Spain, Costa Rica, the Algarve in Portugal, and California and Florida in the United States), tourist development has been linked to the development of residential property for people retiring from colder, industrialised areas. Both types of development lead to a variety of land-use demands—in particular golf courses. These bring pressures from high levels of fertilizer, pesticide and water use and the consequent run-off (Honey and Krantz 2007).

This change from agricultural or natural uses to hard, artificial land cover is an inevitable companion of coastal tourism. These alterations in the nature of the immediate coastal zone have significant implications for coastal ecosystems. Species that use both land and sea, such as seabirds, marine reptiles and some marine mammals, and habitats such as mangroves and salt marshes which combine both land and sea are particularly affected. The alterations usually introduce a barrier of artificial land cover between the sea and the natural or agricultural land cover in the hinterland, thus making it more difficult for animals to move between one and the other, and affecting the plant cover in the marginal zone. The changes also usually introduce night-time illumination, which also affects the way in which animals (particularly nocturnal animals such as bats) can use the terrain.

The impact of such changes is most obvious for sea turtles, which need to come ashore onto sandy beaches to lay their eggs. Their eggs are usually deposited near the vegetation fringe at the top of the beach. Such areas are obviously most affected by coastal development. In the Mediterranean, at the beginning of the nineteenth century, there were significant breeding populations of green turtles (*Chelonia mydas*), loggerhead turtles (*Caretta caretta*) and leather-back turtles (*Dermochelys coriacea*). Because of the transformation of so many Mediterranean sandy beaches into tourist resorts, these breeding areas are now reduced to Cyprus (for the green turtle) and small areas of Greece and Turkey (for loggerhead turtles); breeding by leather-back turtles is now virtually unknown in the Mediterranean, except for occasional reports from Israel and Syria (Davenport 1998). Night-time lighting of tourist areas is also a significant problem at turtle-hatching time: turtle hatchlings, which emerge at night, are programmed to make for the lightest part of the horizon, which in natural conditions will be the sea; they are confused by street lighting and fail to reach the sea (Tuxbury and Salmon 2005; Arianoutsou 1988).

Changes from natural to artificial shorelines also affect purely marine species. The difference between a naturally sloping beach and a more vertical seawall produces a significantly different environment. There is growing evidence that the biota living on breakwaters, seawall, groynes and similar structures, and the fish assemblages associated with them, differ from those on natural shorelines. Even where the natural shoreline is rocky, the replacement artificial shoreline will have different effects; for example, replacing natural rock with concrete may provide a different acid/alkali balance as a result of leaching (Bulleri and Chapman 2010).

The introduction of artificial hard coastal constructions can also affect the movement along the coastline of sediments, changing the patterns of sand transport and sedimentation. This can result in changes to beaches. The exact pattern will depend on local circumstances: for example, at Nouakchott, Mauritania, the construction of port facilities is resulting in erosion of dune systems, with increased risks of sea flooding of coastal settlements, reduction of beach area and threats of siltation of the harbour (Elmoustaphat et al. 2007). Even though sophisticated computer modelling of the possible effects of coastal constructions can be used to reduce the risks, cases where this has been carried out have resulted in significantly different results in practice (Klein and Zviely 2001).

17.2.3 Beach and Shore Usage

For many people, the main point of a seaside holiday is the use of a sandy beach for a mixture of sun-bathing, lounging, swimming and surfing. In general, such usage does not require any change to the natural state of the beach. In many places, however, steps have been taken to try to improve the beach, either by structures to prevent movement of sand along the shore or to supplement sand from dredging ("beach feeding"). Such measures have often had unwelcome consequences elsewhere. In addition, more recently, artificial reefs have been constructed to improve the size of waves, and thus the attractiveness of beaches to surfers. An Australian example using rock has been judged successful. Other attempts, using large sand-filled containers, have been less successful (Mossman 2003; CCT 2008; Rendle and Davidson 2012; Rendle and Rodwell 2014; Bailey 2012).

Protection of bathers from attacks by sharks has been seen as necessary in some parts of the world, notably Australia and the United States. This has had some adverse effects on local populations of rays, dolphins and turtles, because they have become entangled in this netting (Davenport and Davenport 2006).

The need to keep beaches attractive to tourists often leads the local beach managers to clean up the debris left by the beach users. However, such clean-up operations usually also include the removal of the natural deposits along the high-tide line of seaweed and other marine material (including dead seabirds and other biota). Such removal of natural material has been shown to reduce substantially the biodiversity of sandy shore shorelines, especially seabirds (Llewellyn and Shackley 1996; Mann 2000). Nevertheless, such beach cleaning may often be necessary to maintain tourism, especially where large amounts of seaweed are brought up onto beaches by the sea.

Biodiversity impacts can also be found on rocky shores, where even 200 visitors a day can reduce coverage by seaweed and barnacles to such an extent that recovery takes a year or more (Schiel and Taylor 1999; Milazzo et al. 2002; Pinn and Rodgers 1996). Similar impacts also occur on dunes by reducing the vegetation on which stability depends (Hylgaard and Liddle 1981; Lemauviel and Rose 2003).

Use of the near shore for anchoring ships can also result in damage to the seabed. This is particularly important for shores where the immediate underwater habitat is coral reefs or seagrass beds. Damage has been noted from small pleasure vessels, which often anchor over coral areas so that those on board can dive to see the corals. But more serious damage is caused by cruise ships anchoring in such areas.

Destruction of corals of up to 300 m^2 has been observed from one anchoring of one cruise ship. Recovery from such damage can take a long time (Allen 1992).

17.2.4 Interaction with Wildlife

Over the past half-century, coastal tourism has led to significant increases in the interaction between tourists and the local wildlife. Many businesses have grown up to enable tourists to come closer to the local wildlife. Six major categories of business are involved, though others do occur. Five are non-consumptive (general marine diving, viewing corals, watching seabirds, watching whales and other marine mammals and watching sharks), and one of longer standing (recreational fishing and hunting) has a direct impact on the marine biota.

17.2.4.1 Marine Diving

All around the world, tourists (both domestic and international) engage in diving (usually using self-contained underwater breathing apparatus (SCUBA)). The necessary equipment was developed during the Second World War and its use in tourism has developed since then, with rapid growth as the equipment has become more reliable and cheaper. The scale of this tourist activity can be judged from the activities of the Professional Association of Diving Instructors: between 2000 and 2013, the number of firms in its membership grew by 24% to 6,197, and the number of individual trainers by 26% to 135,615. The annual number of people trained in this period has been around 900,000 (PADI 2014).

At low levels of usage, diving sites do not appear to be adversely affected by recreational diving. There are, however, thresholds above which both the divers' experience is affected (by over-crowding) and the marine environment is adversely affected (by physical damage and disturbance of fish and other biota). The problem lies in establishing where those thresholds lie, particularly in the absence of long-term monitoring (Davis and Tisdell 1996).

To enhance the experience of recreational divers, artificial reefs have been created in several locations. Many of these used former naval ships cleaned of potentially polluting material and then sunk at the desired location. These have brought substantial economic benefits from increased visits by tourists for the experience of diving around them (SWEC 2003; Morgan et al. 2009).

17.2.4.2 Coral Viewing

The sheer splendour and variety of tropical and sub-tropical coral reefs has made them a very popular tourist attraction: people are prepared to travel great distances and pay substantial costs to see coral reefs in their native state. This has therefore generated a large component of the tourist trade in areas which have coral reefs.

The specific pressures on corals generated by such viewing can be seen from an assessment of the tourism pressures on the Great Barrier Reef of Australia. These cover:

(a) Damage (particularly to branching corals) by untrained scuba divers;
(b) Damage by trampling at landing points where large concentrations of tourists were landed from boats to walk on the reef;
(c) Some reduction in growth caused by shading from pontoons moored to provide facilities (lecture theatres, restaurants, etc.) for tourists;
(d) Fish feeding by tourists: inappropriate types of food can adversely affect the health of fish, and frequent feeding can disturb the balance of species;
(e) Shell collecting;
(f) Glass-bottomed boats and semi-submersible vessels can causing damage through collisions with corals.

All these pressures were seen as capable of being controlled by proper management. The overall conclusion was that, with proper management, coral viewing was compatible with sustaining the reef in a good condition (Dinesen and Oliver 1995).

Other studies, however, suggest that:

(a) Diving can, through abrasion, make large massive coral communities more susceptible to other pressures;
(b) Damage is virtually impossible to avoid (based on studies in St Lucia and the Cayman Islands);
(c) Substantial damage can still occur even when restrictive and highly-policed management is in place;
(d) Camera-users do more damage than divers not undertaking photography (Hawkins et al. 1999; Rouphael and Inglis 2001; Tratalos and Austin 2001; Barker and Robert 2004).

17.2.4.3 Bird-Watching

There are no global statistics to show the extent of coastal tourism based on bird-watching (Balmford et al. 2009). This is largely due to two facts. First, it is not easy to identify bird-watching tourism as a distinct activity: many people may spend a day or two bird-watching out of a longer holiday, although many others will go to destinations with large bird populations (such as migration areas) and spend much of their time bird-watching. Secondly, the resource demand is not easy to capture: much bird-watching is done in the open with no more equipment than binoculars. Nevertheless, bird-watching is a substantial and growing part of the tourism market: in the USA, 19.9 million tourist journeys in 2012 were primarily for bird-watching (NSRE 2012).

The adverse impact of bird-watching arises from the interaction of the tourist and bird populations. On land, tourists entering nesting areas during the breeding season can disturb breeding birds, potentially leading to the abandonment of nests. On water, boats carrying bird-watchers can disrupt seabird feeding. This is particularly significant at staging-post sites where migrant birds congregate, since the energy balance of migrating birds is often delicate. Such sites are particularly attractive to bird-watchers because of the numbers of birds (often of many different species) passing through them. On both land and water, bird-watchers can cause birds to flush into the air, making them use energy which (particularly during migration) can be in a tight balance. Careful management of bird-watching sites can minimize this kind of problem (Green and Darryl 2010; Parsons and Mavor 2006).

17.2.4.4 Whale, Seal and Dolphin Watching

As a tourist activity, whale watching dates back to about 1950, when part of Point Loma in San Diego, California, United States, was declared a public venue for observing grey whales and the spectacle attracted 10,000 visitors in its first year. Within a few years, the practice spread to other areas and countries. By 2008, whale-watching was taking place in 119 countries, with about 13 million people per year taking part. This supported about 13,000 jobs and generated expenditure by tourists of about US$ 2.1 billion (IFAW 2009). Other marine mammals also support tourism based on watching them. Dolphin-watching has developed as a tourism activity since the 1980s, and is now practised around the world (Constantin and Bejder 1996). Seal-watching has also developed within the ranges of the various species of seals and other pinnipeds (Newsom and Rodger 1996; Bosetti and Pearce 2002; Hoyt 2009).

Whale-watching involves risks to both humans and the animals. For humans, the risks come from their presence, often in relatively small boats, in the vicinity of large marine animals. The risks are enhanced where the activity involves being in the water—"swimming with dolphins". The threats to the animals are various. The most obvious are those of collisions between whale-watching boats and cetaceans. With quite large boats, often travelling at high speeds (in order to minimize the "blank" time to get from the shore to where the cetaceans are), such collisions can often be fatal to whales (IWC 2007). Many behavioural responses by cetaceans have been observed to less extreme pressures (Senigaglia et al. 2012; Parsons 2012). The difficult issue to resolve is whether such behavioural changes are having long-term harmful effects: one study at least suggests that, in the long term, such pressures may lead to reduced reproductive rates (Bejder et al. 2006). The cumulative effect of the various pressures from whale-watching the whale-watching subcommittee of the International Whaling Commission to state in 2006 that "… there is new compelling evidence that the fitness of individual odontocetes [that is, the toothed whales (such as the sperm whale (*Physeter macrocephalus*), the killer whale (*Orcinus orca*), beaked whales (*Ziphiidae*) and dolphins (*Delphinidae*)] repeatedly exposed to whale-watching vessel traffic can be compromised and that this can lead to population-level effects" (IWC 2007). As a result, the International Whaling Commission has instituted a 5-year strategic plan (2011–2016) on whale-watching to provide a framework for research, monitoring, capacity-building, development and management by national authorities (IWCSC 2013; IWC 2014).

17.2.4.5 Shark Watching

Shark watching and shark diving has developed into an industry that, on one estimate, exceeds US$ 300 million per year. The activity in many cases involves placing tourists wearing scuba gear in metal cages and lowering them into the water, and then attracting sharks by throwing "chum" (fish waste and offal) into the water. It therefore has considerable potential both for injury to the tourists and for disturbing the local ecology. On the other hand, strong arguments are made that the potential economic gains for developing economies are large and the environmental risks are low and can be kept within acceptable bounds by suitable management and monitoring (Martin and Abdul Hakeem 2006).

17.2.4.6 Recreational Fishing and Hunting

In most countries, marine recreational fishing is less significant than inland recreational fishing. Nevertheless, estimates suggest that recreational fishing is important in 76% of the world's exclusive economic zones (Mora et al. 2009). Some coastal marine stocks in more industrialized nations are exclusively exploited for recreation, or intensive co-exploitation for commercial and recreational purposes occurs. Overall, there is a growing recognition of the immense economic, socio-cultural and ecological importance of recreational fishing as a significant component of global capture fisheries (FAO 2012). One estimate puts the global level of expenditure in 2003 on recreational fishing at US$ 40 billion per year, supporting 954,000 jobs (Cisneros-Montemayor and Sumaila 2010). This includes fishing by people in the localities around their homes, and the proportion that is attributable to tourists (whether international or domestic) is uncertain.

Recreational fisheries are most developed in economically developed countries, but they are emerging as a social and economic factor in many other economies (for example, Argentina, Brazil, China, India) and some other developing countries. Where statistics are available, some 4% to 16% of the populations engage in recreational fishing (FAO 2012).

The environmental impact of this recreational fishing activity is twofold. First, it is a driver increasing the demand for small boats in coastal waters. This demand is one of the factors underlying the development of coastal marinas. Secondly, the catch from recreational fishing is a component of the total fishing mortality caused by capture fisheries. Traditionally, it has been regarded as of marginal importance. However, figures are beginning to emerge that show that it can be a significant component and needs to be taken into account in the general management of fish stocks, but there is doubt whether this is being done sufficiently (Mora et al. 2009).

Waste discarded from recreational fishing boats can cause problems. For example, discarded monofilament fishing lines have been found on 65% of coral colonies at Oahu, Hawaii, United States, apparently causing substantial mortality by abrading polyps when moved by wave surge (Yoshikawa and Asoh 2004).

Recreational hunting for seabirds and some marine mammals and reptiles also takes place. In many countries, such hunting is prohibited or strictly controlled, especially for species regarded as threatened or endangered. Nevertheless, such recreational hunting can be of some economic significance for local communities: in Canada (the only one of the five jurisdictions in which polar bears are found that allows recreational (trophy) hunting for them), licences and support services bring an income of about US$ 1.3 million per year (2010 prices) to the 30 or so communities concerned (Écoressources Consultants 2010).

17.2.4.7 Boating and Personal Leisure Transport

In North America and Europe a massive growth has occurred over the last 50 years in the numbers of small vessels used for pleasure boating. For example, in the United States (including the Great Lakes and internal waterways), in 2013 just under 12 million such craft were notified to the authorities (USCG 2014), a slight reduction on the previous year, suggesting that the market may be becoming saturated. A high proportion (82%) of these vessels is motorized, with consequent pollution problems from oil and noise. This activity is economically significant, with the turnover in the United States estimated at US$ 121.5 billion per year. It is estimated that 36% of the adult population take part in recreational boating at least once a year (NMMA 2013). Such widespread activities are not without their risks; global figures are not available but, for example, in the United States in 2013 4,062 boating accidents occurred, involving 560 deaths. Safety measures and instruction can be effective, because the 2013 figures represent reductions of 50% (accidents) and 31% (deaths) over the last 15 years (USCG 2014). Although the current level of participation in the rest of the world is much lower, it is expected to grow rapidly over the next few years in the fast-growing economies: in Brazil, sales of leisure boats have been growing at a rate of over 10% per year since 2005 (except in 2009) (FT 2011); in China, it is forecast that the number of pleasure yachts will increase to over 100,000 by 2020 (CCYIA 2013).

All these boats require moorings when they are not being used for recreational sailing. There has therefore been a parallel growth in marinas and specialized harbours for small boats. These installations form a significant part of the hard coastal constructions discussed above, and therefore present the problems analyzed there.

As concern has grown over the transport of non-indigenous organisms by ships, the role of small boats as vectors of such biota has been shown to be significant (Chap. 25).

Recreational boat anchors can cause damage to coral reefs. Their anchors can likewise cause problems to seagrass beds (Backhurst and Cole 2000). Recreational motor boats can cause further damage to seagrass beds from the action of their propellers in shallow water; re-growth after such damage can take up to 4 years (Sargent et al. 1994; Dawes et al. 1997). Powerboats (high-speed motor-boats) cause disturbance through noise and wake to seabirds, marine mammals and sea turtles, particularly to slower-swimming species that are unable to get away, and by disturbing foraging. They can also affect the enjoyment of beaches and inshore waters by other human users. Other devices can cause similar disturbances (Davenport and Davenport 2006).

17.2.5 Cumulative Effects

The basic driver of impacts from coastal tourism on the marine environment is the number of tourists and the disposal income available to them. As tourist numbers increase, more infrastructure is needed to service them, and they impose larger demands on the natural environment. The larger the disposable income that the tourists have, the greater will be the demand for services involving capital resources such as leisure boats, marinas and services such as whale watching. The basic issue is the carrying capacity of the local natural environment: low levels of demand for all these kinds of services may well be able to be accommodated with little or no adverse impact on the natural environment. Depending on local circumstances, there will in many cases be thresholds where, if the demands for services exceed them, the adverse effects on the environment will increase non-linearly: a 25% increase in tourist numbers from 1,000 bed-places in a locality may be acceptable; a 25% increase from 20,000 bed-places may be disastrous, because the extra resources may be well beyond the carrying capacity of the locality and the increased pressures may be intolerable for the local wildlife.

There is also an interrelationship between the overall levels of activity and the economic benefits from tourism. At lower levels of tourist activity, it can be possible to win larger economic benefits, because some tourists are prepared to pay higher charges for facilities that are not crowded. As tourist resorts become more crowded, the market will become more of a mass market, with lower margins. In some areas, crowding has been allowed to such an extent that the market has been depressed, and returns have become very low.

17.2.6 Costs of Environmental Degradation

Most tourist resorts have developed incrementally over a number of decades. No baseline material is usually available, and information on developments is usually partial. It is therefore not often possible to work out the scale of adverse change even for one tourist resort. Data for larger areas permitting comparisons over time—for national coastal zones or global regions—are even less available.

17.3 Management Requirements

17.3.1 Key Requirements and Challenges

As can be seen from the above descriptions of the pressures on the marine environment and the related social and economic aspects, the problem of achieving sustainability in tourist resorts is usually a question of balance. Even in a fragile ecosystem, sustainable tourism will nearly always be possible, but only if the pressures generated are kept well within the carrying capacity of that ecosystem. In some cases, achieving that may require a very low level of tourist activity. In most cases, however, careful balancing, planning and design may enable a much higher level of tourist activity, with consequent economic and social benefits, without undermining the sustainability of the marine ecosystem.

Three main groups of issues need to be considered in the creation or expansion of any coastal tourist area or resort:

(a) ***The nature of the intended tourism.*** Tourism is a highly competitive business. There thus needs to be a clear general understanding on what type of tourism it is intended to develop. Without this basis, there is a risk that the development of the necessary infrastructure will fail to deliver what is needed, and that investment will consequently not achieve the desired results, and that the management approaches adopted will not deliver the appropriate balance between the various interests. A strategy acceptable to all stakeholders is therefore a desirable foundation for the development of sustainable tourism;

(b) ***The development of the necessary infrastructure.*** This includes the means of access (airports, roads, railways), the buildings necessary for housing, feeding and entertaining the tourists and the supporting personnel, the means of delivering the necessary food and the necessary support services (power supply, water supply, waste water management, waste disposal). It will also include the provision of harbours and marinas and other facilities for boats;

(c) ***The management of the sea/land interface.*** This covers the extent to which the natural state of the coast is adapted to allow the development of the necessary tourism infrastructure as well as the ways in which the natural and the developed areas of the coast are then managed. The latter aspect will include the questions of granting concessions to allow commercial undertaking to have exclusive use of particular areas or to provide specific services, and the conditions on which they can do so, the provision of other services by public authorities and the basis for any charges for them and controls over access to, and use of, specific areas to safeguard ecosystems.

These issues must be addressed within national frameworks of property ownership and spatial planning. The law on the ownership of coastal space varies considerably between the different legal traditions. In the civil law tradition, beaches, harbours, ports and the foreshore are usually considered part of the public domain and cannot be owned by individuals or commercial enterprises—see, for example, article 538 of the French Code Civil or article 339 of the Spanish Código Civil. In federal States, such as Germany, control of such public property may be divided between the Federation and the federal states (Niedersächsischer Landtag 2012). In the common law tradition, the situation is somewhat different. For example, in England, the Crown (that is, in effect the State) is the *prima facie* owner of foreshore (that is, the land between mean high water and mean low water). The same applies to seabed, being land below mean low water. Beaches (above mean high water), however, belong to the owner of the coastal land. Nevertheless, nearly half of the foreshore has been granted to local authorities, commercial undertakings or private individuals (Halsbury 1998). In some Scandinavian traditions, in contrast, private ownership of coastal land extends into the sea as far as the point at which the seabed drops away significantly (the *marbakke*) (Falkanger 1997). These different frameworks will therefore require significantly different approaches to the development of a strategy for managing coastal tourism.

17.3.2 Instruments for Sustainable Management

The sustainable management of tourism has to be seen as part of the overall approach of Integrated Coastal Zone Management (ICZM), sometimes called Integrated Coastal Area Management. ICZM is fundamentally based on a comprehensive understanding of the relationships between coastal resources, their users, uses, and the mutual impacts of development on the economy, society and the environment. It is therefore necessary to understand how all the stakeholders interact with the coastal environment and with each other. Coastal resources are used simultaneously by a wide range of people and undertakings. Integrated management must rest on a clear understanding of all these uses, users and relationships are clearly known (UNEP 1995; UNEP 2009).

In the past, ICZM has usually been confined to the land and sea areas relatively close to the coastline. Increasingly, it has become necessary to bring the coastal sea into consideration. This has often been addressed by introducing Marine Spatial Planning (MSP), as an equivalent to land-use planning, which in some parts of the world has been practised for the best part of a century. It is essential that ICZM and MSP are conducted in close cooperation, even though separate processes may be necessary because the stakeholders in the two areas may be significantly different (OSPAR 2009; EC 2011).

Within ICZM and MSP, the instruments that are particularly important for delivering sustainable tourism include:

(a) ***Allocation of space:*** The ways that coastal land and coastal waters are permitted to be used will determine much of the way in which coastal tourism develops. It is therefore fundamental that decisions on these basic issues are taken in accordance with an agreed public strategy;

(b) ***Enforcement of planning conditions:*** Decisions on the allocation of space will often need to be accompanied by conditions (such as concerning the times of day when activities are permitted). The whole purpose of achieving sustainable tourism will be negated if the allocation decisions and the conditions to which they are subject are not enforced;
(c) ***Construction standards and their enforcement:*** Delivering their health and safety of tourists is an important factor in making tourists welcome. This means that sound approaches are needed to ensuring that infrastructure is built to appropriate standards. Since the appearance of a tourist area can play an important role in attracting tourists, construction standards may also need to address the appearance of buildings and other features;
(d) ***Management of beach areas:*** Since many tourists visit coastal resorts to enjoy the beaches, it is important that these are maintained in a way that is attractive to them. The nature of what is wanted will vary from place to place. Provision of facilities may be made directly by public authorities or through contracts with commercial undertakings (which may in some cases grant them exclusive use of beach areas). Consideration will need to be given to the appropriate basis of charging for the provision of facilities, including (where they are provided by commercial undertakings) whether market conditions will adequately control pricing. Beach cleaning may be necessary in some areas, but the effects of this on marine biodiversity (see above in Sect. 17.2.3) need to be considered;
(e) ***Marine protected areas:*** Where coastal and marine wildlife are a significant attraction of an area, it will be necessary to consider whether protected areas need to be instituted in order to ensure the sustainability of the areas in the face of tourist pressures. Protection of these areas and their wildlife may require restrictions on access, either absolutely or by limiting numbers in specific periods or particular parts of such areas. General guidance on the designation of marine protected areas (such as OSPAR 2003) will be relevant;
(f) ***Control of pollution and solid waste management:*** The health and safety of tourists, as well as the conservation of the coastal wildlife, can only be guaranteed if there are adequate controls to prevent pollution of the coastal area. In this context, appropriate treatment of urban waste water will be most important, both to prevent water-borne disease and to guard against eutrophication problems. The adequate management of solid waste will also be crucial, both for health reasons and to preserve the appearance of a resort;
(g) ***Control of recreational fishing:*** In areas where recreational fishing is a major attraction, it will be desirable to consider the impact of recreational catches on local fish stocks, particularly of the top predators such as sharks and billfish. In many areas, recreational fishing is not considered in fisheries management decisions, although it can have serious impacts on some of the rarer fish stocks;
(h) ***Control of boating and similar activities:*** The use of boats and other personal leisure transport can have serious impacts on coastal biodiversity (see Sect. 17.2.4 above). It may therefore be necessary to consider controls over the speed of boats and other devices, both in the interests of wildlife and of other tourists, over the areas where they are allowed to go, and over where they may anchor. Noise levels from boats and other devices may also need to be considered;
(i) ***Monitoring:*** A tourism strategy for an area will need to be monitored in all its aspects. Without a knowledge of how local ecosystems are responding to the

pressures from tourism, and how the tourist businesses are developing, sensible decisions are impossible on the approaches to adopt and changes to make in existing arrangements;

(j) ***Stakeholder agreements:*** In any tourist area there will be a wide range of stakeholders. These will include the local authorities, the various components of the tourist trade (both local and those engaged in brining tourists to the area), organizations interested in the conservation of wildlife, local history and social practices, the local populations (especially those not involved in the tourist trade) and civil society generally. Some of the measures discussed in the foregoing indents may need legislative or administrative action. Others may be capable of being delivered by voluntary agreements. Methods need to be devised to bring together the views of all these interests and to seek the most effective and efficient way of delivering the various measures needed to achieve sustainable tourism. These methods will vary widely according to local circumstances and traditions.

17.4 Conclusions

Tourism is nowadays a very important feature of the global economy. It introduces many pressures and can result in the degradation of important ecosystems. With proper management, however, it can be an important factor in enabling communities that would otherwise be impoverished to achieve a good standard of living. The challenge is to find methods to balance the many factors involved in order to deliver sustainable tourism.

References

AET (2012) Secretaria Nacional de Políticas de Turismo, Anuário Estatístico de Turismo—2012. http://www.dadosefatos.turismo.gov.br/export/sites/default/dadosefatos/a nuario/downloads_anuario/Anuxrio_Estatxstico_de_Turismo_2012_-_Ano_base_2011.pdf. Accessed 15 Aug 2014

Allen WH (1992) Increased dangers to caribbean marine ecosystems. Bioscience 42(5):330–335

Arianoutsou M (1988) Assessing the impacts of human activities on nesting of loggerhead sea-turtles (*Caretta caretta L.*) on Zakynthos Island, Western Greece. Environ Conserv 15:327–334

Backhurst MK, Cole RG (2000) Biological impacts of boating at Kawau Island, north-eastern New Zealand. J Environ Manag 60:2000

Bailey S (2012) Closed—but Boscombe bodyboarders still love the surf reef, Bournmouth Daily Echo, 2 April

Balmford A, Beresford J, Green J, Naidoo R, Walpole M, Manica A (2009) A global perspective on trends in nature-based tourism. PLoS Biol 7(6):e1000144. doi:10.1371/journal.pbio.1000144

Balsdon JPVD (1969) Life and Leisure in Ancient Rome. Bodley Head, London

Barker HHL, Robert CM (2004) Scuba diver behaviour and the management of diving impacts on coral reefs. Biol Conserv 120:481–489

Bartolo R, Delamaro M, Bursztyn I, Hallewell L (2008) Tourism for whom? different paths to development and alternative experiments in Brazil. Lat Am Perspect 35(3):103–119

Bejder L, Samuels A, Whitehead H, Gales N (2006) Interpreting short-term behavioural responses to disturbance within a longitudinal perspective. Anim Behav 72(5):1149–1158

Bosetti V, Pearce D (2002) A study of environmental conflict: the economic value of grey seals in South West England. Centre for Social and Economic Research on the Global Environment Working Paper GEC 01-02 (ISSN 0967-8875)
Bulleri F, Chapman MG (2010) The introduction of coastal infrastructure as a driver of change in marine environments. J Appl Ecol 47:26–35
Cater E (1995) Environmental contradictions in sustainable tourism. Geogr J 161(1):21–28
CCT (Contra Costa Times) (2008) Surf's not up, so reef's coming out, 29 September. http://www.contracostatimes.com/california/ci_10586139. Accessed 10 Oct 2014
CCYIA (China Cruise and Yacht Industry Association) (2013) Report 2012/13, Beijing
Cisneros-Montemayor AM, Sumaila UR (2010) A global estimate of benefits from ecosystem-based marine recreation: potential impacts and implications for management. J Bioecon 12(3):245–268
Constantin R, Bejder L (1996) Managing the whale- and dolphin-watching industry. In: Higham ES, Lück M (eds) Marine wildlife and tourism management: insights from the natural and social sciences. CABI, Wallingford
CTO (Caribbean Tourist Organization) (2013) Latest Statistics 2012. http://www.onecaribbean.org/content/files/13MARCH2013Lattab12.pdf. Accessed 14 Aug 2014
Currin C (2013) Carolyn Currin in Living Shoreline Summit Committee, 2013 Mid-Atlantic Living Shorelines Summit Proceedings. http://www.dnr.maryland.gov/ccs/pdfs/ls/2013summit/SummitProceedings.pdf. Accessed 17 Oct 2014
Davenport J (1998) Temperature and the life history strategies of sea-turtles. J Therm Biol 22:479–488
Davenport J, Davenport JL (2006) The impact of tourism and personal leisure transport on coastal environments. Estuar Coast Shelf Sci 67:280–292
Davis D, Tisdell C (1996) Economic management of recreational scuba diving and the environment. J Environ Manag 48:229–248
Dawes CJ, Andorfer J, Rose C, Uranowski C, Ehringer N (1997) Regrowth of the seagrass *Thalassia testudinum* into propeller scars. Aquat Bot 59:139–155
Dinesen Z, Oliver J (1995) Tourism impact, in State of the Great Barrier Reef world heritage area workshop. In: Wachenfeld DR, Oliver J, Davis K (eds). Great Barrier Reef marine park authority, Townsville
EC (2011) European Commission maritime spatial planning in the EU—achievements and future development. Publications Office of the European Union, Luxembourg
EC (European Commission) (2014) Flash Eurobarometer 392, Preferences of Europeans Towards Tourism. http://ec.europa.eu/public_opinion/flash/fl_392_en.pdf. Accessed 12 Dec 2014
ECLAC (United Nations Economic Commission for Latin America and the Caribbean) (2005) Issues and challenges in Caribbean cruise ship tourism, Santiago, Chile, 2005 (Document LC/CAR/L.75)
Écoressources Consultants (2010) Evidence of the socio-economic importance of polar bears for Canada. ISBN: 978-1-100-18970-3
EEA (European Environment Agency) (2006) The changing faces of Europe's coastal areas, Copenhagen
Elmoustaphat AO, Levoy F, Monfort O, Koutitonsky VG (2007) A numerical forecast of shoreline evolution after Harbour construction in Nouakchott, Mauritania. J Coast Res 23(6):1409–1417
Eurostat (Directorate-General for Statistics of the European Commission) (2014) Coastal regional statistics. http://ec.europa.eu/eurostat/statistics-explained/index.php/Coastal_region_statistics. Accessed 15 Aug 2014
Falkanger T (1997) Fast Eiendoms Retsforhold, Oslo
FAO (Food and Agriculture Organization) (2012) FAO technical guidelines for responsible fisheries 13: recreational fisheries. FAO, Rome
FIPE (Fundação Instituto de Pesquisas Econômicas) (2012) Caracterização e Dimensionamento do Turismo Doméstico no Brasil—2010/2011. http://www.dadosefatos.turismo.gov.br/export/sites/default/dadosefatos/demanda_turistica/domestica/downloads_domestica/Demanda_domestica_-_2012_-_Relatorio_Executivo_nov.pdf. Accessed 17 Aug 2014

FT (2011, September 20) Boatbuilders ride wave of economic prosperity. Financial Times, Brazil
Green R, Darryl NJ (2010) Practices, needs and attitudes of bird-watching tourists in Australia. Cooperative Research Centre for Sustainable Tourism, Gold Coast
Halsbury (1998) Halsbury's laws of England 12(1), 1998 Reissue, para 242
Hawkins JP, Roberts CM, Van't Hof T, De Meyer K, Tratalos J, Aldam C (1999) Effects of recreational scuba diving on Caribbean coral and fish communities. Conserv Biol 13(4):888–897
Honey M, Krantz D (2007) Global trends in coastal tourism. Centre on Ecotourism and Sustainable Development, Stanford
Houston JR (2008) The economic value of beaches—a 2008 update. Shore Beach 76(3):22–26
Hoyt E (2009) Whale watching. In: Perrinan WF, Würsig B, Thewissen JGM (eds) Encyclopedia of marine mammals. Academic, San Diego
Hylgaard T, Liddle MJ (1981) The effect of human trampling on a sand dune ecosystem dominated by *Empetrum nigrum*. J Appl Ecol 18:559–569
IFAW (International Fund for Animal Welfare) (2009) Whale watching worldwide—tourism numbers, expenditures and expanding economic benefits. IFAW, Yarmouth Port
IMO (International Maritime Organization) (2014) Status of Multilateral Conventions. (http://www.imo.org/About/Conventions/StatusOfConventions/Documents/Status%20-%202014.pdf)
IWC (International Whaling Commission) (2007) Report of the scientific committee. J Cetacean Res Manag 9, supplement
IWC (International Whaling Commission) (2014) Five year strategic plan for whalewatching 2011–2016. http://iwc.int/private/downloads/61pp7v1qdn4sss40ow88kgso4/AC-002s3%20IWC%20Whale%20Booklet_HR.pdf. Accessed 12 Oct 2014
IWCSC (International Whaling Commission) (2013) Report of the Scientific Committee Annual Meeting 2013. https://archive.iwc.int/pages/view.php?ref=3285&search=%21collection73&order_by=relevance&sort=DESC&offset=0&archive=0&k=&curpos=1. Accessed 12 Oct 2014
Klein M, Zviely D (2001) The environmental impact of marina development on adjacent beaches: a case study of the Herzliya marina, Israel. Appl Geogr 21:145–156
Lemauviel S, Rose F (2003) Response of three plant communities to trampling in a sand dune system in Brittany (France). Environ Manag 31:227–235
Lichtnau B (1996) Architektur in Mecklenburg und Vorpommern, 1800–1950, Steinbecker Verlag, Ernst-Moritz-Arndt-Universität Greifswald
Llewellyn PJ, Shackley SE (1996) The effects of mechanical beachcleaning on invertebrate populations. Br Wildl 7:147–155
Mann KH (2000) Ecology of coastal waters: with implications for management. Blackwell Science, Boston
Martin R, Abdul Hakeem AA (2006) Development of a sustainable shark diving ecotourism industry in the Maldives: challenges and opportunities. Maldives Mar Res Bull 8:2–36
Milazzo M, Chemello R, Badalementi F, Riggio S (2002) Short-term effect of human trampling on the upper infralittoral macroalgae of Ustica Island MPA (western Mediterranean, Italy). J Mar Biol Assoc U K 82:745–748
Mora C, Myers RA, Coll M, Libralato S, Pitcher TJ, Sumaila RU, Zeller D, Watson R, Gaston KJ, Worm B (2009) Management Effectiveness of the World's Marine Fisheries. PLoS Biol 7(6):e1000131
Morgan OA, Massey DM, Huth W (2009) Diving demand for large ship artificial reefs. Mar Resour Econ 24(1):43–59
Mossman (2003) Town of Mossman Park, Mossman Beach Management Plan, adopted 26 August 2003. www.mosmanpark.wa.gov.au/council/public-documents/download/28/
Newsom D, Rodger K (1996) Impact of tourism on Pinnipeds and implications for toursim management. In: Higham ES, Lück M (eds) Marine wildlife and tourism management: insights from the natural and social sciences. CABI, Wallingford
Niedersächsischer Landtag (2012) 16. Wahlperiode Drucksache 16/0000, Hannover
NMMA (National Marine Manufacturers Association) (2013) 2013 U.S. Recreational Boating Statistical Abstract, Chicago

NSRE (2012) National Survey on Recreation and the Environment (NSRE) 2013 The Interagency National Survey Consortium, Coordinated by the USDA Forest Service, Recreation, Wilderness, and Demographics Trends Research Group, Athens, GA and the Human Dimensions Research Laboratory, University of Tennessee, Knoxville
Orams MB (2003) Sandy beaches as a tourism attraction: a management challenge for the 21st century, J Coast Res, Special Issue No. 35
OSPAR (2009) OSPAR Commission—overview of national spatial planning and control systems relevant to the OSPAR Maritime Area (Publication Number: 444/2009), London
PADI (Professional Association of Diving Instructors) (2014) Statistics. http://www.padi.com/scuba-diving/about-padi/. Accessed 10 Oct 2014
Parsons ECM (2012) The negative impacts of whale-watching. J Mar Biol 2012:807294
Parsons M, Mavor RA, Mitchell PI (2006) The UK seabird monitoring programme. In: Boere GC, Galbraith CA, Stroud DA (eds) Waterbirds around the world. The Stationery Office, Edinburgh
Pessoa I, Fernandez M, Toste R, Dore M, Parahyba M (2009) Imposex in a touristic area in Southeastern Brazilian coast. J Coast Res, Special Issue 56
Pinn EH, Rodgers M (1996) The influence of visitors on intertidal biodiversity. J Mar Biol Assoc UK 85:263–268
Rendle E, Davidson M (2012) An evaluation of the physical impact and structural integrity of a geotextile surf reef. Coast Eng 1(33):21
Rendle E, Rodwell L (2014) Artificial surf reefs: a preliminary assessment of the potential to enhance a coastal economy. Mar Policy 45:349–358
Rouphael AB, Inglis GJ (2001) "Take only photographs and leave only footprints"? An experimental study of the impacts of underwater photographers on coral reef dive sites. Biol Conserv 100(3):281–287
Russell R (1755) De tabe glandulari sive de usu aquae marinae (Oeconomia naturalis in morbis acutis et chronicis glandularum), London
Sargent FJ, Leary TJ, Crewz DW, Kruer CR (1994) Scarring of Florida's seagrasses: assessment and management options. Technical Report FMRI 1/94, Florida Marine Research Institute, St Petersburg
Schiel DR, Taylor DI (1999) Effects of trampling on a rocky intertidal assemblage in southern New Zealand. J Exp Mar Biol Ecol 235:213–235
Senigaglia, V., Bejder, L., Christiansen, F., Gendron, D., Lundquist, D., Noren, D., Schaffar, A., Smith, J.C., Williams, R. and Lusseau, D. (2012) Meta-analyses of whalewatching impact studies: differences and similarities in disturbance responses among species. International Whaling Commission Scientific Committee Paper SC/64/WW6. http://iwc.int/private/downloads/burvztaqbdsg8sk8gwoc4g4o0/SC-64-WW6.pdf
Simcock A, Halpern B, Kirubagaran R, Hossain MMM, Polette M, Smith E, Wang J (2016) Chapter 20—Coastal, riverine and atmospheric inputs from land. In: Simcock A, Innes L (Coordinators) World Ocean Assessment I. United Nations
SWEC (South-West Economy Centre, University of Plymouth) (2003) An assessment of the socio-economic impact of the sinking of HMS Scylla, Plymouth. http://www.wrecktoreef.co.uk/wp-content/uploads/2012/12/scylla-eco-soc.pdf. Accessed 10 Oct 2014
Tratalos JA, Austin TJ (2001) Impacts of recreational SCUBA diving on coral communities of the Caribbean island of Grand Cayman. Biol Conserv 102:67–75
Tuxbury SM, Salmon M (2005) Competitive interactions between artificial lighting and natural cues during seafinding by hatchling marine turtles. Biol Conserv 121:311–316
UNCTAD (United Nations Conference on Trade and Development) (2007) FDI and tourism, the development dimension. UNCTAD, Geneva
UNEP (1995) Guidelines for integrated management of coastal and marine areas—with special reference to the Mediteranean basin, United Nations Environment Programme Regional Seas Reports and Studies No. 161, Priority Actions Programme Regional Activity Centre (PAP/RAC) of the Mediterranean Action Plan (MAP—UNEP), Split

UNEP (2009) Sustainable coastal tourism, an integrated planning and management, United Nations Envrionment Programme Manuals on Sustainable Tourism, Priority Actions Programme Regional Activity Centre (PAP/RAC) of the Mediterranean Action Plan (MAP—UNEP), Split

USA Travel (US Travel Association) (2014) US travel answer sheet June 2014. https://www.ustravel.org/sites/default/files/page/2009/09/US_Travel_Answ erSheet_June_2014.pdf. Accessed 15 Aug 2014

USCG (United States Coast Guard) (2014) Recreational boating statistics 2013. USCG, Washington, DC

Walton J (1983) Leisure in Britain (1780–1939). Palgrave Macmillan, Basingstoke

Wilson TD (2008) Economic and Social Impacts of Tourism in Mexico, Latin American Perspectives, Vol. 35(3)

World Bank (2014) World development indicator 6.14. http://wdi.worldbank.org/table/6.14. Accessed 10 Oct 2014

WTO (World Tourism Organization) (2014) Compendium of tourist statistics. WTO, Madrid

WTTC (World Travel and Tourism Council) (2014) Economic data. http://www.wttc.org/focus/research-for-action/economic-data-search-tool/. Accessed 18 Sept 2014

Yoshikawa T, Asoh K (2004) Entanglement of monofilament fishing lines and coral death. Biol Conserv 117(5):557–560

Yu L (2012) The International hospitality business: management and operations. Routledge, London

Part IV
Pollution from Diffuse Sources

Chapter 18
Climate Change: Warming Impacts on Marine Biodiversity

Helmut Hillebrand, Thomas Brey, Julian Gutt, Wilhelm Hagen, Katja Metfies, Bettina Meyer, and Aleksandra Lewandowska

Abstract In this chapter, the effects of temperature change—as a main aspect of climate change—on marine biodiversity are assessed. Starting from a general discussion of species responses to temperature, the chapter presents how species respond to warming. These responses comprise adaptation and phenotypic plasticity as well as

H. Hillebrand (✉)
Institute for Chemistry and Biology of the Marine Environment (ICBM), Carl-von-Ossietzky University of Oldenburg, Wilhelmshaven, Germany

Helmholtz Institute for Functional Marine Biodiversity (HIFMB), Oldenburg, Germany
e-mail: helmut.hillebrand@uni-oldenburg.de

T. Brey • K. Metfies
Alfred Wegener Institute, Helmholtz Centre for Marine and Polar Research, Bremerhaven, Germany

Helmholtz Institute for Functional Marine Biodiversity (HIFMB), Oldenburg, Germany
e-mail: thomas.brey@awi.de; katja.metfies@awi.de

J. Gutt
Alfred Wegener Institute, Helmholtz Centre for Marine and Polar Research, Bremerhaven, Germany
e-mail: julian.gutt@awi.de

W. Hagen
BreMarE Bremen Marine Ecology, University of Bremen, Bremen, Germany
e-mail: whagen@uni-bremen.de

B. Meyer
Institute for Chemistry and Biology of the Marine Environment (ICBM), Carl-von-Ossietzky University of Oldenburg, Wilhelmshaven, Germany

Alfred Wegener Institute, Helmholtz Centre for Marine and Polar Research, Bremerhaven, Germany

Helmholtz Institute for Functional Marine Biodiversity (HIFMB), Oldenburg, Germany
e-mail: bettina.meyer@awi.de

A. Lewandowska
Institute for Chemistry and Biology of the Marine Environment (ICBM), Carl-von-Ossietzky University of Oldenburg, Wilhelmshaven, Germany
e-mail: aleksandra.lewandowska@uni-oldenburg.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_18

range shifts. The observed range shifts show more rapid shifts at the poleward range edge than at the equator-near edge, which probably reflects more rapid immigration than extinction in a warming world. A third avenue of changing biodiversity is change in species interactions, which can be altered by temporal and spatial shifts in interacting species. We then compare the potential changes in biodiversity to actual trends recently addressed in empirical synthesis work on local marine biodiversity, which lead to conceptual issues in quantifying the degree of biodiversity change. Finally we assess how climate change impacts the protection of marine environments.

Keywords Climate change • Adaptation • Marine conservation • Phenology • Range shift • Warming

18.1 Introduction

Climate change impacts on marine ecosystems are multifaceted, with strongly interdependent changes in CO_2 concentrations, temperature, mixing regimes, and biogeochemical cycles of elements and organic compounds. The response of marine communities to these non-point pressures requires dealing with the synergies of these changes. However, for marine biodiversity we still need to understand the basic mechanisms driving the responses to any single of these factors of which most are non-linear. Therefore, in this section, we address the different stressors in separate chapters, but interlink these closely. The present chapter focuses on the temperature aspect of climate change and its consequences on marine ecosystems and biodiversity. Acidification-related aspects are dealt with in Chap. 19 (Thor et al.), eutrophication in Chap. 22 (von Beusekom et al.).

In this chapter we mainly address the question of human-mediated changes in climate, disentangling it from climate change on geological time frame, which have less connection to marine environment protection. The anthropogenic causation of climate warming has been globally summarized by the latest report of the Intergovernmental panel on Climate Change (IPCC 2013). Initiated by human-induced increases in CO_2-emissions, the global atmospheric temperature increased by 0.85 °C in the period 1880 to 2012, whereas the global ocean warmed by 0.44 °C at the surface between 1971 and 2010. A warming of similar magnitude in the first 70 years of the twentieth century is discernible as well (Fig. 18.1, down right). Moreover, the ocean absorbed most of the energy stored in the climate system. It is predicted that the global ocean will continue to warm during the current century, predictions for global averages in the upper 100 m ranging between 0.6 and 2.0 °C. It is very likely that this heat will penetrate from the surface to the deep ocean and affect global ocean circulation (Balmaseda et al. 2013; Llovel et al. 2014; Roemmich et al. 2015).

This general pattern showed—and will continue to show—strong regional variation, e.g., IPCC predicts the strongest ocean warming for the surface in tropical and Northern Hemisphere subtropical regions and for greater depth in the Southern Ocean (IPCC 2013). At the same time, in addition to the overall warming trend,

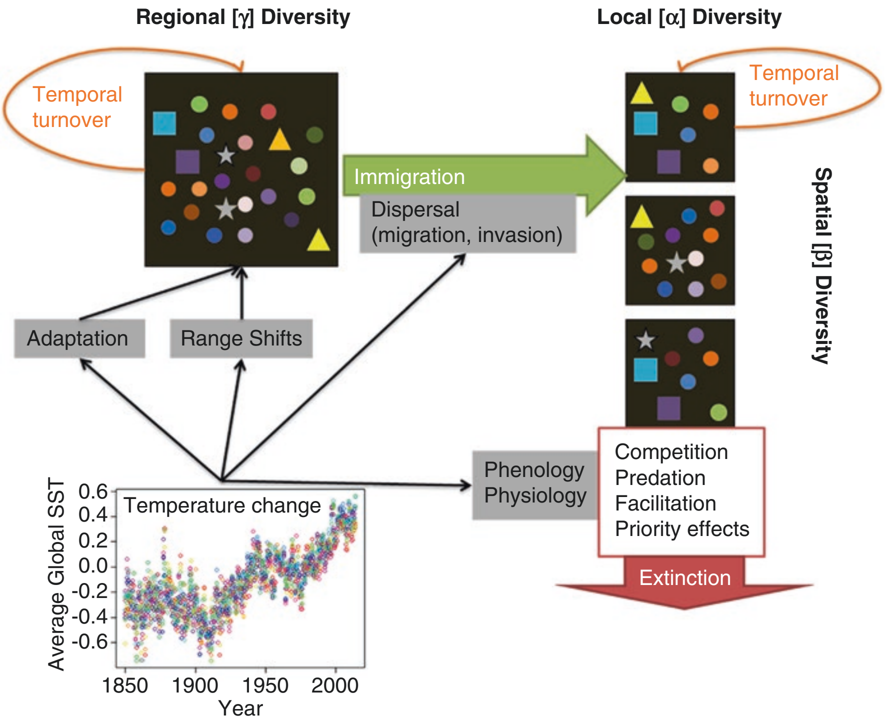


Fig. 18.1 Potential responses of marine communities under altered temperature regimes. Temperature change is presented as global average sea surface temperature (standardized to the period 1951–1980 as anomaly in °C), *different colours* are different month such that the degree of variation for each year gives an estimate of the seasonal variation in warming. Regional consequences of temperature change on biodiversity are mediated by species distribution shifts (see Sect. 18.4) and adaptation to altered temperature (see Sect. 18.3). These processes will also alter the patterns of immigration at the local scale. Interactions between species (such as competition, facilitation, and predation) and stochastic processes (such as priority effects) at the local scale constrain which species survive or go extinct in the assemblage (Sect. 18.5). These constraints of local biodiversity are affected by temperature through altered timing (phenology) and fitness (physiology) of the organisms (Sect. 18.2)

changes in the variability in temperature between years and with seasons is observable (Fig. 18.1). Thus, any marine region is affected by overlaying temporal patterns, comprising trends in mean temperature, altered variation around this trend in time and space, and extreme events, especially consisting of extraordinary heat waves. Each of these aspects of climate warming (trend, variation, and extreme events) can separately or jointly alter the composition, diversity and productivity of marine communities. Additionally, indirect effects from the warming driven changes in ocean circulation might alter, amplify or counteract the direct consequences of temperature change. Potential regional aspects include, e.g., the weakening of the Atlantic current (Rahmsdorf et al. 2015) and deep-water formation (Fahrbach et al. 2011), the amplification of the marine effects of the El-Nino Southern Oscillation (ENSO) phenomenon (Cai et al. 2014) or shifts in oceanic fronts, e.g. of the Polar Frontal System to the South (Sokolov and Rintoul 2009), shrinking and regionally advancing of polar ice caps (Arrigo and Thomas 2004; Cook et al. 2005; Comiso 2010; Turner et al. 2009) and the thinning and stabilizing of surface water layers (Sarmiento et al. 2004).

Temperature change thus is multi-layered in time and space, comprising global trends with regional patterns and variance as well as local heat-waves. Consequently, climate change impacts on biodiversity can only be understood, if processes affecting biodiversity are also analysed across different scales of space, time and organisation (Fig. 18.1). Therefore, it is useful to address consequences of climate change across different scales of biodiversity,[1] which have been introduced to classical ecology by Whittaker (1960): The smallest component of biodiversity is called α-diversity, which describes species composition, species richness and dominance in local assemblages of potentially interacting species. It can be characterized as within-habitat diversity, whereas the difference in species composition of local habitats within a region is called β-diversity or spatial species turnover. The composition and richness of all habitats in a region is called γ-diversity, which encompasses the entire regional species pool potentially colonizing a certain habitat.

In the following sections, we analyse different pathways of biodiversity change with special emphasis on temperature changes (see Chaps. 19 and 22), such as adaptation (see Sect. 18.3), range shifts (see Sect. 18.4), or the change in local interactions (see Sect. 18.5). We then compare the potential changes in biodiversity to actual trends recently addressed in empirical synthesis work on local marine biodiversity (see Sect. 18.6), which lead to conceptual issues in quantifying the degree of biodiversity change. Finally we assess how climate change impacts the protection of marine environments (see Sect. 18.7). Before doing so, however, we will present a short primer on species responses to temperature as a basis for potential changes in biodiversity. Obviously, a full accounting of the ecophysiology of temperature is beyond the scope of this Handbook, but section Sect. 18.2 clarifies some basics to help understand the biodiversity consequences of temperature change.

[1] The term "biodiversity" comprises different aspects of biological differentiation. We explicitly use this term sensu lato, crossing scales from "diversity within species" (e.g, genotypic differences in a population) over "diversity between species" (e.g., number of species in a food web) to diversity at higher organisational scales (e.g., functional groups). At all these levels, biodiversity can be characterized by richness (number of entities, such as genotypes or species or functional groups), evenness (dominance structure, high evenness reflecting equal contribution of all entities to the community), and identity (taxonomic or functional characteristics [traits] of the entities).

18.2 Organismal Response to Temperature

Organisms physiologically respond to environmental gradients such as temperature with an optimum curve (Fig. 18.2a), where performance (e.g., a metabolic rate such as photosynthesis rate, growth rate) is maximized under optimum conditions (O in Fig. 18.2a), and survival is only possible in a certain range of temperature (between the pessima P in Fig. 18.2a). This is also the broadest ecological niche of this species for temperature, where niche is a set of conditions an organism can tolerate. Often, conditions sufficient not only for survival but for somatic growth or reproduction are narrower subsets of this niche. This type of niche is called fundamental, as it relies completely on the physiological capacity of the species. This contrasts to realized niches, which take other species into account, e.g. competitors, prey species or predator species, which may limit the occurrence of a species along the temperature gradient to an even narrower range of conditions (Fig. 18.2a).

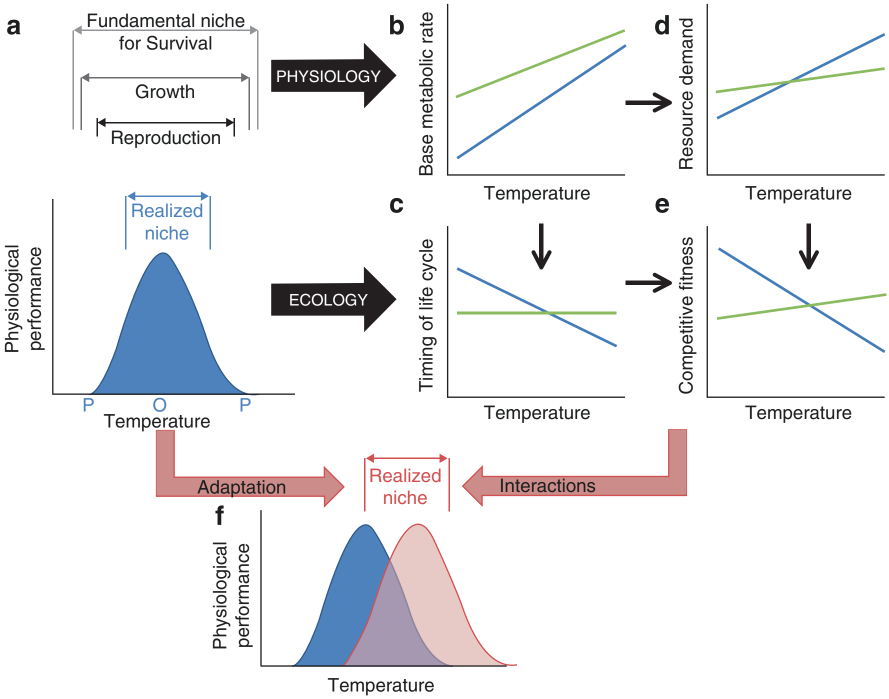


Fig. 18.2 Conceptual summary of species responses to temperature. (**a**) Optimum curve of a focal species to a temperature gradient with optimum and a fundamental niche constrained by pessima (P), and a realized niche. (**b**–**e**) Physiological and ecological processes to a small shift in temperature below the optimum of a focal species (*blue*) and an interacting species (*green*), which could be a consumer (panel **c**) or a competitor (panel **e**). (**f**) Adaptation (change in the fundamental niche) and altered interactions lead to a new realized niche in a warmed climate (depicted in *red*). More details see text

When addressing the warming effects on biodiversity, effects on fundamental and realized niches are possible. Warming might enhance temperature to an extent that minimum temperature requirements are met (entering the fundamental niche) or that maximum temperatures are exceeded (leaving the fundamental niche). It has been discussed how likely it is that warming (a global increase of ca. 1 °C) is sufficient to exceed the physiological tolerance of a species given that many species experience large temperature ranges in temporal (seasonal, tidal, upwelling) or spatial (depth) dimensions of their habitat. However, if temperature changes induce additional stressors, e.g. reducing the oxygen content of water, the fundamental niche in fact may be too small (Pörtner and Farrell 2008). Moreover, changes in biodiversity might occur at much more subtle changes of temperature given the temperature-dependence of species interactions and thus the realized niche. To understand this, the physiological and ecological responses to temperature ranges within the niche (or even below the optimum) have to be addressed (Fig. 18.2b-e).

Below the optimum, an increase in temperature leads to increased metabolic rates (Fig. 18.2b, for details, see e.g. the metabolic theory of ecology, Brown et al. 2004). Thus, physiological rates (enzyme kinetics, respiration, uptake of resources, development, or growth) increase, with the slope of the increase differing between species. This physiological response will also alter the phenology of a species (Fig. 18.2c), whereby the term phenology includes all temporal life-cycle events such as larval fall, end of hibernation, migration to winter or summer habitats, etc.. This are often triggered by physiological responses, and consequently differ between organisms. If interacting species show different phenological responses, temporal mismatches might occur (see Sect. 18.5).

The changed metabolic rates are closely related to altered resource requirements as well (Fig. 18.2c), such that some species need to take up more nutrients or prey in order to meet the higher energetic demands (Fig. 18.2d). Consequently, competitive dominance might shift along a small temperature gradient, if competing species show different shifts in competitive fitness along a temperature gradient (Fig. 18.2e). A species winning in a competitive situation at low temperature might lose at slightly higher temperatures, if the change is sufficient to alter resource requirements or is beyond the optimum of one of the species. Additionally, changes in phenology might alter competition as well, if e.g. an earlier larval fall allows one species to occupy space (pre-emption of a limiting resource).

These changes in interactions will impact the realized niche, which might be compressed or expanded and shifted along the temperature axis in a warmed world depending on the actual change in the interactions (see Sect. 18.5). However, the realized niche might also change by adaptation (see Sect. 18.3), which can shift the fundamental niche by, e.g. physiological acclimatization, selection from standing genetic variation (favouring genotypes with higher optimal temperature) or novel mutations. The biogeographic consequence of a shifted realized niche then often is a range shift (see Sect. 18.4).

18.3 Adaptation to Altered Temperature Regimes

Thermal adaptation to a shifting climate—as well as acclimatization between seasons—requires shifting thermal niches and adjusting niche widths (Pörtner 2010, see also Fig. 18.2). Irrespective whether we deal with adaptation within species (changing allele frequencies in a population) or between species (changing species frequencies in a community), adaptation can comprise novel mutations or—normally on a much shorter time scale—selection from standing genetic (or species) variation. The latter is called phenotypic plasticity. Hence, depending on environmental conditions the genotype may adjust phenotypic characteristics of an organism according to the requirements in a habitat. Reusch (2013) differentiates between phenotypic plasticity and phenotypic buffering. This definition refers to classical plasticity as response within the usual performance range of an individual selecting for enhanced opportunity under novel conditions. In contrast, phenotypic buffering represents a special case and implies maintenance of a functional phenotype under conditions of increasing stress close to the tolerance limits of an organism.

Phenotypic plasticity includes modifications in e.g., life-history traits, behaviour and physiological performance and is a key mechanism allowing organisms to adapt rapidly to changing environmental conditions (acclimation). Developmental plasticity in behavioural and life-history traits is a common phenomenon in marine animals and climatic stimuli during early ontogeny may be an essential trigger to express plasticity (O'Connor et al. 2007, Munday et al. 2013). Eurythermal organisms from temperate regions or coastal systems exhibit a more pronounced plasticity than rather stenothermal organisms from tropical or polar regions (Somero 2005; Reusch 2013; Storch et al. 2014). However, plasticity is not limited to individuals. Climatic effects, e.g. elevated temperatures, experienced by the parents may result in a better performance of the offspring, e.g. juvenile damselfish fully coping with increased temperatures (Donelson et al. 2012). Evidence of such accelerated transgenerational plasticity effects is accumulating in marine systems. These non-genetic mechanisms open a new avenue of experimental research and need to be considered, when predicting climate change implications (Munday et al. 2013).

The greatest risk of extinction is experienced by species with longer generation cycles, small population size as well as ecological specialists and overexploited species (Dulvy et al. 2003). Especially more complex species (but also larger species) have to "buy time" to persist in a climate change scenario (Chevin et al. 2010; Storch et al. 2014), as their genetic modifications usually require more extended time scales for DNA-fixed adaptive changes. Munday et al. (2013) point out that even in long-lived species genetic adaptation should not be dismissed as an adaptive option during times of rapid environmental changes, based on advances in theoretical understanding of phenotypic plasticity and genetic evolution (Chevin et al. 2010). Thus, both phenotypic plasticity and evolutionary potential of organisms must be considered, when predicting the consequences of climate change for marine organisms. However, few data are available on evolutionary responses from marine systems, due to a "weak tradition" of marine biology in this field, fewer model organisms and difficulties with multi-generational experimental studies. Reusch (2013) argues that fisheries data on recruitment, maturity, reproductive effort and growth of individuals may provide the best evidence of plastic versus adaptive responses, with harvesting inducing evolutionary change (Olsen et al. 2004), although possibly selecting for different life-history traits than climate change (Munday et al. 2013).

Phenotypic plasticity, trans-generational plasticity, genetic adaptation, and species sorting will all play a role in the alteration of biodiversity under climate change, but the relative importance and the time-frame for these different response mechanisms is not easily addressed (Litchman et al. 2012). Litchman et al. (2012) conclude that assessing these issues requires a combination of experimentally derived data on major functional traits (and their plasticity) with data on species distributions along temperature gradients to better characterize thermal niches. At the same time, molecular approaches, quantitative genetics and (long-term) evolution experiments need to address temperature effects on selection and mutation in isolation and in combination with other stressors (e.g., acidification). The potential in predicting species occurrence and performance by combining ecological and evolutionary constraints has already been shown in model approaches (Follows et al. 2007; Thomas et al. 2012).

18.4 Range Shifts Alter Regional Marine Diversity under Altered Temperature Regimes

Biogeographic studies on climate change effects focused on the observation and prediction of range shifts with latitude or other spatial gradient correlated to temperature (Wilson et al. 2004; Hampe and Petit 2005; Jump and Penuelas 2005; Parmesan et al. 2005; Thuiller et al. 2005; Wilson et al. 2005). Also in marine organisms, substantial shifts in spatial distribution ranges have been observed in organism groups from passively transported plankton to mobile top-predators (Beaugrand et al. 2002; Atkinson et al. 2008, Beaugrand et al. 2009; Montes-Hugo et al. 2009, Block et al. 2011; Hazen et al. 2013). In an unprecedented meta-analysis across locations and marine organism groups, Poloczanska et al. (2013) summarized 360 studies on distributional shifts and found an average shift of 30.6 [±5.2] km decennium^{-1}, with the leading edge of the range moving faster (72.0 [±13.5] km dec^{-1}) than the trailing edge (15.4 [±8.7] km dec^{-1}). These results have two major implications: First, this shift is substantially faster than comparable estimates for the leading edge across terrestrial organisms (6.1 [±2.4] km dec^{-1}) or terrestrial plus freshwater organisms (19.7 [±3.7] km dec^{-1}) (Parmesan and Yohe 2003; Chen et al. 2011). Second, there is a huge discrepancy between the shifts of leading and trailing edges of the ranges, which partly can be explained by different warming scenarios in the different data sets used for these edge estimates (Poloczanska et al. 2013). However, differences in the lower and upper margin of climate-induced range shifts are also congruent with observations of a time-lag between immigration and extinction at the regional scale. Comparisons within single animal groups such as marine fish and invertebrates shows that projected immigration rates (species arriving per area) were an order of magnitude higher than local extinction rates (Cheung et al. 2008a). This discrepancy reflects the time needed for immigration and extinction: Moving forward in space entering a new regional pool (i.e., moving the leading edge) is fast as it is an immediate consequence of successful colonization. Local extinction of poleward-moving species at the trailing edge, however, requires time, as displacement by immigrating species is not instantaneous. This phenomenon has been called "extinction debt" and is well described in terrestrial ecology (Tilman et al. 1994; Wearn et al. 2012). The impact of immigrations such as bioinvasions (see Chap. 25 by Kuhlenkamp ànd Kind) on native biodiversity cannot be observed in short time, which has led to the conclusion that the time since invasion in many parts of the world is insufficient to record regional extinctions (Gilbert and Levine 2013). In the context of climate change impacts on biodiversity, this means that we are prone to observe increases in species richness in a warming climate for a long period of time (see Sect. 18.6) before decreases in biodiversity are to be expected.

Predictions on future regional biodiversity under a warming climate are often inferred from fundamental or realized temperature niches of species. This assumes that species are able to track the changing geographic location of their "climate envelopes", which are calculated from their present-day distribution. Potential shifts in regional biodiversity are then derived from calculating the area change within a certain climate envelope and using species-area relationships to predict the change in regional diversity (Thomas et al. 2004; Araujo et al. 2005; Xenopoulos et al. 2005; Lewis 2006). This approach has been mainly used—and critically discussed—in terrestrial assessments of climate change effects on biodiversity. Critics of this approach point to the extinction debt discussed above and the absence of temporal dynamics of dispersal and migration (He and Hubbell 2011) as well as the lack of acknowledging the non-uniformity of species-are relationships (Drakare et al. 2006; Gutt et al. 2012). More fundamentally, climate envelope modelling in its most basic form does not include adaptation and species-co-dependencies. An example for a marine model, which considers some of these biological processes, is that of Cheung et al. (2008b).

Most indirect effects of thermal change, which is mostly but not exclusively temperature increase, result in range shifts, which can be much faster than those affected by the heating of the oceans through the atmospheric warming. In case of changing current dynamics, transportation vectors for pelagic organisms and pelagic larvae of benthic sedentary species are changed. Such changes in hydrodynamic pattern result in sudden changes in environmental conditions and, thus, potentially affect diversity patterns considerably. A temperature-driven increase in the stability of pelagic stratification and thinning of surface waters leads to changes in the nutrient and food supply and in the underwater light environment, resulting in altered species interactions (see Sect. 18.5). In some marine ecosystems a shift from larger to smaller phyto- and zooplankton organisms (Moline et al. 2004; Hays et al. 2005) with cascading effects on higher trophic levels (Montes-Hugo et al. 2009) and even on the abyssal benthos is observed or expected (Smith et al. 2008). In polar areas, warming might shift species composition and functional biodiversity (e.g., via reduced ventilation of the deep-sea or melting of sea-ice alter), which potentially alters primary production as well as particle flux to the sea-bed, and thereby destructs essentially important habitats (Boetius et al. 2013; Gutt et al. 2015).

18.5 Species Interactions in Altered Temperature Regimes

Local assemblage biodiversity can respond to changing temperature regimes especially through altered species interactions (Fig. 18.1). Local biodiversity increases if species disperse into the community, either as new immigrants (see Sect. 18.4 on range shifts and Chap. 25 on invasions) or from the regional species pool via colonization from neighbouring habitats. Immigration might be inhibited if previously arrived species occupy space or ecological niches (so-called priority effects). When established in a local habitat, species can go extinct based on competitive exclusion, predator-prey dynamics or the lack of facilitating/mutualistic interactions. All of these (priority effects as well as competitive, predator-prey-, and mutualistic interactions) are sensitive to temperature changes as the organisms' fitness in these interactions depend on the one hand on potentially temperature-dependent physiological traits, on the other hand on their phenology, i.e., their seasonal appearance (Fig. 18.1).

The majority of spring and summer events, such as spring phytoplankton bloom, have advanced in response to climate change (Thackeray et al. 2010; Poloczanska et al. 2013). Poloczanska et al. (2013) summarized 50 data sets on marine phenology shifts in spring and in summer, and found on average an earlier onset of phenological aspects by 4.4 [± 0.7] days decennium^{-1}. As a result of differences in thermal physiology (e.g. between ectotherms and endotherms or autotrophs and heterotrophs) organisms vary in phenological responses to climate warming. This variation can disorder the synchrony of ecological interactions among species, functional groups and trophic levels (Fig. 18.3), potentially disrupting ecosystem resilience. For example, the dominance of small phytoplankton species increases with warming, because smaller cells have a competitive advantage at higher temperatures through high nutrient uptake and growth rates (Reuman et al. 2014). Such dominance shift results in changes in food chain length and hence reduced energy transfer to higher trophic levels. Furthermore, temperature-driven shifts in species composition might lead to the dominance of toxic species or species having low nutritional value with potentially negative consequences for upper trophic levels. Depending on physiological traits, increasing temperature can also dampen or enhance oscillations in predator-prey interactions (Amarasekare 2015). Warming enhances the negative impact of a keystone predator on prey communities if higher temperatures increase predator occurrence (Harley 2011) or consumption rates (Isla et al. 2008; O'Connor 2009). Differential phenological shifts of prey and predator in response to temperature change might induce temporal mismatches in the occurrence (Fig. 18.3), leading to altered marine trophodynamics (Philippart et al.

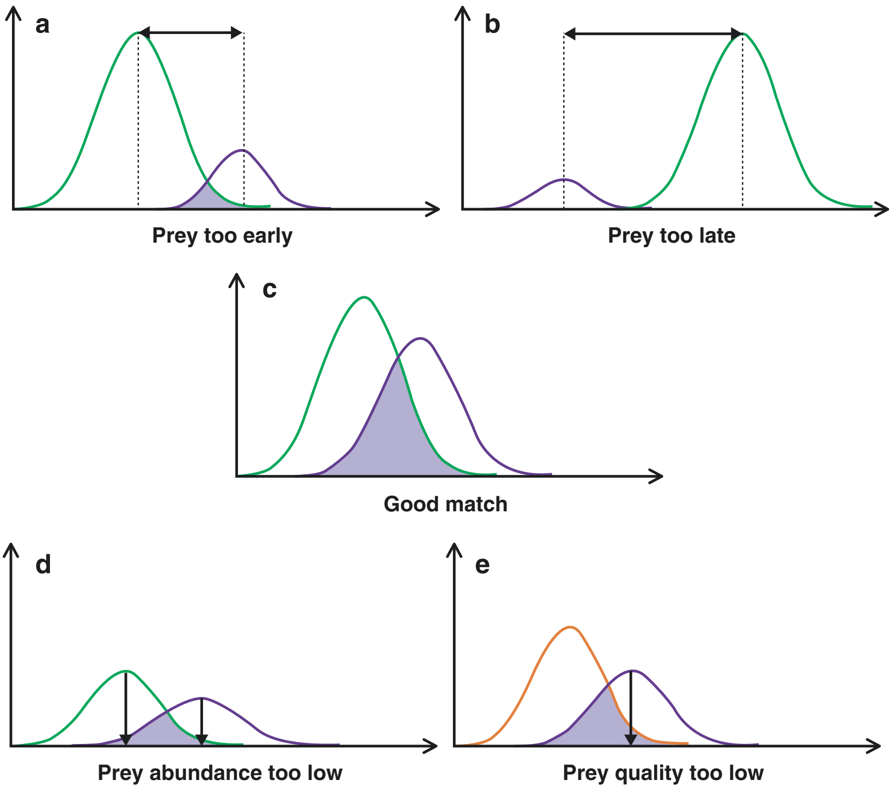


Fig. 18.3 Match (**c**) and mismatch (**a**, **b**, **d**, **e**) in trophic interactions in response to climate warming. Too early (**a**) or too late (**b**) prey development (*green* and *orange curves*) can lead to trophic mismatch resulting in a decrease of consumer biomass (*violet curves*). Similarly, lower prey abundance (**d**) or low food quality (e.g. low nutritional value, toxic species; **e**) can limit consumer growth. Combined mismatch scenarios (e.g. earlier development and low abundance of the prey) can occur as well

2003; Edwards and Richardson 2004; Durant et al. 2005; Burthe et al. 2012; Sommer et al. 2012) and consequent declines in commercially important fish stocks such as cod (Beaugrand et al. 2003).

An important aspect of mismatch occurs when temperature-induced changes in phenology meet endogenous rhythms which are stimulated by other variables such as day-length. A wide range of organism from cyanobacteria to humans have developed a circadian rhythm with an endogenous timing system, for which day length (photoperiod) is the most widely used environmental stimulus. In marine organisms in general, little is known about the principles of endogenous clocks and how these clocks interact with environmental cycles and this is particularly true for high latitude pelagic organisms. The polar pelagic environment is particularly characterized by extreme seasonal changes in environmental factors such as day length, light intensity, sea ice extent and food availability and a rapid change in these conditions in the face of climate warming (Atkinson et al. 2004; Pörtner et al. 2009; Schofield 2010). Not surprisingly, many polar pelagic organisms have evolved endogenous rhythmic physiological and behavioral functions, which are synchronized with these cyclic changes (e.g. Kawaguchi et al. 1986; Marcus and Scheef 2010; Meyer 2012; Jørgensen and Johnsen 2014).

Unfortunately, the range of conditions in which the clocks are operating in polar pelagic key organisms, such as krill, is not well understood. It is also not known which physiological and behavioral consequences might emerge when the daily and seasonal timing systems in these animals exceed their normal limits, protected from changes in temperature and pH. Increasing sea water temperature and changing sea ice dynamics may cause a change in the seasonal pattern of food availability in the environment leading to an earlier onset of biological production such as plankton spring blooms (Jørgensen and Johnsen 2014). The ovary of female krill begins to mature at this time, and the spring bloom is an important fuel for this process. However, whereas the phenology of environmental conditions to which the life cycle of key organisms is synchronized may change, the dominant stimulus (photoperiod) of endogenous driven cycles will not. The ongoing environmental alterations might desynchronize previously matched interactions between the endogenous seasonal rhythms of key species such as krill (e.g. metabolic regulation, sexual maturation, and lipid accumulation) and its environment (e.g. seasonal sea ice dynamic, spring diatom blooms), which have evolved over millions of years.

Climate change driven modifications of organism performance, population size and species inventory add up to the overall changes in biodiversity observed at the community/ecosystem level. Assuming that the emergent behaviour of an ecosystem depends on the properties and behaviour of the species it is composed of, such change in biodiversity should cause responses at the ecosystem level. To understand these causal relationships and their implications for ecosystem functioning, goods and services, the response of the entire ecological network has to be analyzed (Woodward et al. 2010). Feeding relationships constitute the dominant type of organism-to-organism interaction in ecosystems, and hence the network approaches focus on food webs. Generally, environmental variability is buffered by system resilience, which is provided by organism adaptive capacity, functional biodiversity and functional redundancy, i.e. the networks' capacity for functional compensation (Bellwood et al. 2003; Fonseca and Ganade 2001; Johnson 2000; Naeem 1998). Hence, a system's capacity to buffer stress is likely to be correlated with biodiversity, because the more species a network is composed of, the greater trophic variety as well as redundancy among species might become (McCann 2000; Hooper et al. 2005).

Among the multitude of functional traits, species vulnerability to food web-mediated alterations seems to play a particularly important role (Petchey et al. 2008). Vulnerability of a species is expected to increase with predator diversity and to decrease with prey diversity (e.g. Jacob et al. 2011; Memmott et al. 2000; Mintenbeck et al. 2012). Hence, trophic network analysis facilitates the identification of species that may be particularly sensitive to food web alterations such as the Antarctic silverfish *Pleuragramma antarctica* in the Antarcic Ocean fish community (Mintenbeck et al. 2012). Furthermore, we have to consider whether such secondary effects are isolated events or, through feedback and cascading mechanisms, may ripple through the whole network. Jacob et al. (2011) studied network robustness in relation to species functional traits in a 489 species marine food web from the Antarctic Weddell Sea. Their modeling approaches indicate that the initial, e.g., temperature induced loss of a few species may cause a cascade of secondary extinctions up to a network collapse to half its initial size. The severity of this secondary loss of biodiversity depends to a large extent on the functional traits of the primary extinctions, and effects are most severe when the most vulnerable species are lost initially. Jacob et al. (2011) hence reinforce the view that highly connected species are essential for network robustness (e.g., Dunne et al. 2002; Petchey et al. 2008) and thus for maintaining biodiversity under environmental change.

18.6 Expected and Observed Trends in Local Diversity Under Changing Climate

The net change in marine biodiversity at the local scale is a product of these counteracting temperature-dependent changes in immigration, phenology, physiology and interactions- and consequently extinctions. This net change comprises the change in local composition (temporal turnover) and the change in emergent biodiversity properties such as species richness. Recently, two major meta-analyses have analysed long-term trends in local marine species richness across ecosystems and organisms. Across 100 times series from terrestrial, freshwater and marine systems, no systematic loss of local species richness (α-diversity) was observed (Dornelas et al. 2014). Most data sets showed no net change in richness, however, the change in biotic composition (the shift in the identity of species present) was faster than predicted from null models in their data set (see Sect. 18.4). In an analysis of 471 time series, exclusively from coastal marine ecosystems, species richness showed predominantly positive trends (Elahi et al. 2015). Only for habitats for which locally an adverse human impact was reported (ca 3% of the studies), a clear negative trend in richness was observed. By contrast, time series from locations where positive effects were performed (e.g. via protection) showed a strong positive trend in richness. The habitats with equivocal or no information on environmental trends showed a weaker but on average positive richness trend.

A different picture arises from warming experiments: here, most experiments showed a decrease in species richness with increasing temperature across all three major realms, but especially pronounced in marine ecosystems (Gruner et al. 2017). The loss of species scaled directly to the degree of warming, i.e., higher warming resulted in more pronounced species loss. The difference between these experimental results and the observational time series warrants an explanation. Whereas methodological issues might contribute to these differences (duration of experiments versus time series, the latter also being affected by other environmental changes beyond warming), the major discrepancy is immigration: most experiments precluded or inhibited dispersal, thus measured temperature effects on coexistence via competition, facilitation and predation (see Fig. 18.1). The conclusion from these experiments thus is that local loss of species via these interactions is accelerated at higher temperature. This net negative effect of warming becomes visible if analysed in isolation, but not in natural time series, because there (re-) immigration counteracts species loss. As discussed for regional biodiversity, immigration effects are immediate, whereas extinction takes time, precluding the observation of richness decline in natural systems even if there is ample evidence that a warmer climate accelerates metabolic rates as well as population dynamics and consequently leads to faster effects of species interactions (Hillebrand et al. 2012).

In addition to the discrepancy between immediate immigration and delayed extinction, our current knowledge on biodiversity trends also suffers from a strong focus on species richness. The measured species richness in a habitat strongly depends on sampling effort (sample size and the completeness of the census), the size of the species pool (γ-diversity), and the dominance distribution in the community. Chase and Knight (2013) provide an excellent analysis of these issues and suggest that conclusions based on the relative change in species richness alone are prone to suffer from large uncertainties even if sampling effort is standardized. Consequently, species richness estimates have to be amended by other measures of biodiversity to reflect biodiversity change. Evenness, a measure of the relative dominance structure, has been proposed as a useful—and statistically more or less independent—measure of biodiversity (Hillebrand et al. 2008). The advantage of evenness is that it has a closed scale from 0 to 1, allowing easy comparison between sites. The disadvantage, however, is that species identity is not reflected - a shift to different species (e.g. from large long-lived to small short-lived) does not necessarily shift evenness even if the ecological consequences can be dramatic. Integrative indices combining information on dominance and number of taxa (e.g., Shannon, Simpson) are useful if complete knowledge of rare species is lacking, especially in extremely species-rich systems like coral reefs and the deep-sea. These indices as well as cumulative dominance plots are driven by dominance patterns with a focus on abundant species and down-weighted rare species. Still, these indices are crude simplifications of biodiversity and by definition do not address the role of rare species, which might have disproportionate impacts on ecosystem functions (Bracken and Low 2012).

Therefore, ecologists seek to get more complete information including shifts in taxon identity (e.g., species replacing each other), richness (number of taxa) and dominance into measures of temporal turnover (Fig. 18.1). While the meta-analysis by Dornelas et al. (2014) failed to show an overarching trend in species richness, a simultaneous analysis of temporal turnover showed a significant increase in species replacements over time. Another example, more closely related to climate change, is the analysis of the thermal effluent of a nuclear power plant in the Baltic Sea: along the gradient of >9 °C above ambient temperature, species richness was unaffected, but temporal turnover significantly accelerated with increasing temperature (Hillebrand et al. 2010). Thus, the number of species remained constant, but species were replaced faster (see also Guinder et al. 2010; Widdicombe et al. 2010). In a recent article, Hillebrand et al. (2017) used marine, freshwater and terrestrial time series data to show that zero change in richness could be related to anything from none to full exchange of species composition. They argue strongly to base assessments of biodiversity change on multiple measures of composition.

The pitfalls of estimating biodiversity change have potentially dramatic consequences for ecosystem evaluation and management. The Marine Strategy Framework Directive by the European Union lists biodiversity as first descriptor of ecosystem status. Any substantial conclusion on biodiversity change, however, needs well-resolved and long-term continuous observation. Such a comprehensive overview of marine biodiversity and how it responds to natural and anthropogenic stressors is critical in our quest to understand the consequences of climate change for marine ecosystems and to develop management strategies. This requires the development and implementation of new multidisciplinary observation strategies that allow year-round long term observation of marine biodiversity with adequate spatial and temporal resolution, in parallel to physical and biogeochemical measurements. Here special emphasis should be put on integrating observations of marine microbial biodiversity, which has been understudied in the past due to technological constraints. Marine microbes account for 90% of ocean biomass, form the basis of marine food webs and regulate important biogeochemical cycles. Expected climate change related perturbation of marine microbial communities will have important consequences for higher trophic level productivity. Developing an observational framework to establish a baseline for the spatial and temporal variability of microbial biodiversity and community composition is therefore critical to understand consequences of climate change in the marine environment. During the past decades numerous publications successfully demonstrated the potential of molecular methods for refined high resolution assessment of marine microbial biodiversity (e.g. De Vargas et al., 2015; Sunagawa et al., 2015). It is expected that these methods will become progressively more integrated into the day-to-day repertoire of marine long term monitoring sites. Furthermore, combination of molecular biodiversity assessments with cutting edge automated underway sampling on-board ships, and moored sampling technology such as sediment traps or automated water samplers allows year round collection of marine microbes from the surface to the depths, even in remote marine environments. In the long run, molecular-based observation methods have strong potential to be part of multidisciplinary marine long term observation strategies in order to generate information on marine microbial biodiversity with adequate high spatio-temporal resolution (biodiversity and biogeography).

18.7 Protection

It is beyond doubt that marine biodiversity will change in the future. Temperature driven shifts in geographic distribution of species will probably lead to increase of biodiversity in high latitudes and decrease of biodiversity in tropics (Beaugrand et al. 2015; Thomas et al. 2012) with consequences for marine ecosystem productivity. Decrease of the number of cold water species and increasing dominance of warm water species might lead to homogenisation of communities among the globe. Furthermore, disproportionally higher proportion of extinctions at the top of the trophic cascade together with spreading invasions at the bottom of the trophic cascade (Lotze et al. 2006) will potentially change functioning and structure of marine food webs.

The only way to avoid degradation of ecosystems in the face of climate change is reduction of anthropogenic pressure. It becomes clear that we need to radically reduce greenhouse gases emissions and avoid irreversible losses of biodiversity. However, it is not yet clear how to avoid biodiversity loss and whether we only should protect hot spots of an exceptionally high diversity or also places with unique species composition, which contribute considerably to the maintenance of co-existence of species and the ecosystem services and goods they could sustainably provide.

There is strong evidence that marine protected areas and fisheries closures improve biodiversity. In areas where negative impacts were alleviated or positive measures taken, species richness increased in the global analysis of coastal marine biodiversity time series (Worm et al. 2006; Elahi et al. 2015). Moreover, increased diversity enhanced ecosystem functions and had a positive impact on ecosystem recovery after climatic extremes (Worm et al. 2006). Increasing coastal vegetation by restoration of mangroves, salt marshes and seagrass meadows is another promising approach to improve local ecosystem health. Coastal vegetation does not only provide habitat for many aquatic and terrestrial organisms, but it also reduces soil erosion and has a great capacity to sequester atmospheric CO_2 (Bruno et al. 2014).

To understand adaptive capacity of species to climate warming and to identify ecosystem attributes that promote ecosystem resilience, we need effective long-term monitoring programs which would provide practical information for conservation and ecosystem-based management. Management strategies should focus on dominant anthropogenic stressors such as eutrophication and overfishing accompanying climate warming (Sale 2008) and should assess cumulative impact of both natural and human-driven perturbations (Halpern et al. 2007). Unfortunately, governance and decision processes are often organized around single-sectors (e.g. fisheries, tourism), challenging holistic approaches to ecosystem-based management (see Chaps. 5, 6 and 7).

References

Amarasekare P (2015) Effects of temperature on consumer-resource interactions. J Anim Ecol 84:665–679

Araujo MB, Pearson RG, Thuiller W, Erhard M (2005) Validation of species-climate impact models under climate change. Glob Chang Biol 11:1504–1513

Arrigo KR, Thomas DN (2004) Large scale importance of sea ice biology in the Southern Ocean. Antarct Sci 16:471–486

Atkinson A, Siegel V, Pakhomov EA, Rothery P (2004) Long-term decline in krill stock and increase in salps within the Southern Ocean. Nature 432:100–103

Atkinson A, Siegel V, Pakhomov EA, Rothery P, Loeb V, Ross RM, Quentin LB, Schmidt K, Fretwell P, Murphy EJ, Tarling GA, Fleming AH (2008) Oceanic circumpolar habitats of Antarctic krill. Mar Ecol Prog Ser 362:1–23

Balmaseda MA, Trenberth KE, Källén E (2013) Distinctive climate signals in reanalysis of global ocean heat content. Geophys Res Lett 40:1754–1759

Beaugrand G, Edwards M, Raybaud V, Goberville E, Kirby RR (2015) Future vulnerability of marine biodiversity compared with contemporary and past changes. Nat Clim Change 5:695–701

Beaugrand G, Luczak C, Edwards M (2009) Rapid biogeographical plankton shifts in the North Atlantic Ocean. Glob Chang Biol 15:1790–1803

Beaugrand G, Reid PC, Ibanez F, Lindley JA, Edwards M (2002) Reorganization of North Atlantic marine copepod biodiversity and climate. Science 296:1692–1694

Beaugrand G, Brander KM, Lindley JA, Souissi S, Reid PC (2003) Plankton effect on cod recruitment in the North Sea. Nature 426:661–664

Bellwood DR, Hoey AS, Choat JH (2003) Limited functional redundancy in high diversity systems: resilience and ecosystem function on coral reefs. Ecol Lett 6:281–285. doi:10.1046/j.1461-0248.2003.00432.x

Block BA et al (2011) Tracking apex marine predator movements in a dynamic ocean. Nature 475:86–90

Boetius A, Albrecht S, Bakker K, Bienhold C, Felden J, Fernández-Méndez M, Hendricks S, Katlein C, Lalande C, Krumpen T, Nicolaus M, Peeken I, Rabe B, Rogacheva A, Rybakova E, Somavilla R, Wenzhöfer F, RV Polarstern ARK27-3-Shipboard Science Party (2013) Export of algal biomass from the melting Arctic sea ice. Science 339:1430–1432

Bracken MES, Low NHN (2012) Realistic losses of rare species disproportionately impact higher trophic levels. Ecol Lett 15:461–467

Brown JH, Gillooly JF, Allen AP, Savage VM, West GB (2004) Toward a metabolic theory of ecology. Ecology 85:1771–1789

Bruno JF, Harley CDG, Burrows MT (2014) Climate change and marine communities. In: Bertness MD, Bruno JF, Silliman BR, Stachowicz JJ, Bertness MD, Bruno JF, Silliman BR, Stachowicz JJ (eds) Marine community ecology and conservation. Sinauer Associates, Inc., Sunderland, MA

Burthe S et al (2012) Phenological trends and trophic mismatch across multiple levels of a North Sea pelagic food web. Mar Ecol Prog Ser 454:119–133

Cai W, Borlace S, Lengaigne M, van Rensch P, Collins M, Vecchi G, Timmermann A, Santoso A, McPhaden MJ, Wu L, England MH, Wang G, Guilyardi E, Jin F-F (2014) Increasing frequency of extreme el nino events due to greenhouse warming. Nature Clim. Change 4:111–116.

Comiso JC (2010) Variability and trends of the global sea ice cover. In: Thomas DN, Dieckmann GS (eds) Sea ice, 2nd edn. Wiley-Blackwell, Oxford, UK, pp 205–246

Chase JM, Knight TM (2013) Scale-dependent effect sizes of ecological drivers on biodiversity: why standardised sampling is not enough. Ecol Lett 16:17–26

Chen IC, Hill JK, Ohlemuller R, Roy DB, Thomas CD (2011) Rapid range shifts of species associated with high levels of climate warming. Science 333:1024–1026

Cheung WWL, Lam VWY, Sarmiento JL, Kearny K, Watson R, Pauly D (2008a) Projecting global marine biodiversity impacts under climate change scenarios. Fish Fish 10:235–251

Cheung WWL, Lam VWY, Pauly D (2008b) Dynamic bioclimate envelope model to predict climate-induced changes in distribution of marine fishes and invertebrates. Fish Centre Res Rep 16:5–50

Chevin LM, Lande R, Mace GM (2010) Adaptation, plasticity, and extinction in a changing enviroment: towards a predictive theory. PLoS Biol 8:e1000357

Cook AJ, Fox AJ, Vaughan DG, Ferrigno JG (2005) Retreating glacial fronts on the Antarctic Peninsula over the past half-century. Science 308:541–544

Donelson JM, Munday PL, McCormick MI, Pitcher CR (2012) Rapid transgenerational acclimation of a tropical reef fish to climate change. Nat Clim Chang 2:30–32

Dornelas M et al (2014) Assemblage time series reveal biodiversity change but not systematic loss. Science 344:296–299

Drakare S, Lennon JJ, Hillebrand H (2006) The imprint of the geographical, evolutionary and ecological context on species-area relationships. Ecol Lett 9:215–227

Dulvy NK, Sadovy Y, Reynolds JD (2003) Extinction vulnerability in marine populations. Fish Fish 9:261–285

Dunne JA, Williams RJ, Martinez ND (2002) Network structure and biodiversity loss in food webs: robustness increases with connectance. Ecol Lett 5:558–567
Durant JM et al (2005) Timing and abundance as key mechanisms affecting trophic interactions in variable environments. Ecol Lett 8:952–958
Edwards M, Richardson AJ (2004) Impact of climate change on marine pelagic phenology and trophic mismatch. Nature 430:881–883
Elahi R et al (2015) Recent trends in local-scale marine biodiversity reflect community structure and human impacts. Curr Biol 25:1938–1943
Fahrbach E, Hoppema M, Rohardt G, Boebel O, Klatt O, Wisotzki A (2011) Warming of deep and abyssal water masses along the Greenwich meridian on decadal time scales: the Weddell gyre as a heat buffer. Deep-Sea Res II 58:2509–2523
Follows MJ, Dutkiewicz S, Grant S, Chisholm SW (2007) Emergent biogeography of microbial communities in a model ocean. Science 315:1843–1846
Fonseca CR, Ganade G (2001) Species functional redundancy, random extinctions and the stability of ecosystems. J Ecol 89:118–125. doi:10.1046/j.1365-2745.2001.00528.x
Gilbert B, Levine JM (2013) Plant invasions and extinction debts. Proc Natl Acad Sci U S A 110:1744–1749
Gruner DS, Bracken MES, Berger SA, Eriksson BK, Gamfeldt L, Matthiessen B, Moorthi S, Sommer U, Hillebrand H (2017) Effects of experimental warming on biodiversity depend on ecosystem type and local species composition. Oikos 126:8–17
Guinder VA et al (2010) Long-term changes in phytoplankton phenology and community structure in the Bahia Blanca Estuary, Argentina. Mar Biol 157:2703–2716
Gutt J, Zurell D, Bracegridle TJ, Cheung W, Clarke MS, Convey P, Danis B, David B, De Broyer C, di Prisco G, Griffiths H, Laffont R, Peck L, Pierrat B, Riddle MJ, Saucede T, Turner J, Verde C, Wang Z, Grimm V (2012) Correlative and dynamic species distribution modelling for ecological predictions in the Antarctic: a cross-disciplinary concept. Polar Res 31:11091. doi:10.3402/polar.v31i0.11091
Gutt J, Bertler N, Bracegirdle TJ, Buschmann A, Comiso J, Hosie G, Isla E, Schloss IR, Smith CR, Tournadre J, Xavier JC (2015) The Southern Ocean ecosystem under multiple climate stresses – an integrated circumpolar assessment. Glob Chang Biol 21:1434–1453. doi:10.1111/geb.12794
Halpern BS, Selkoe KA, Micheli F, Kappel CV (2007) Evaluating and ranking the vulnerability of global marine ecosystems to anthropogenic threats. Conserv Biol 12:1301–1315
Hampe A, Petit RJ (2005) Conserving biodiversity under climate change: the rear edge matters. Ecol Lett 8:461–467
Harley CDG (2011) Climate change, keystone predation, and biodiversity loss. Science 334:1124–1127
Hays GC, Richardson AJ, Robinson C (2005) Climate change and marine plankton. Trends Ecol Evol 20(6):337–344
Hazen EL et al (2013) Predicted habitat shifts of Pacific top predators in a changing climate. Nat Clim Chang 3:234–238
He FL, Hubbell SP (2011) Species-area relationships always overestimate extinction rates from habitat loss. Nature 473:368–371
Hillebrand H, Blasius B, Borer ET, Chase JM, Downing JA, Eriksson BK, Filstrup CT, Harpole WS, Hodapp D, Larsen S, Lewandowska AM, Seabloom EW, Van de Waal DB, Ryabov AB (2017) Biodiversity change is uncoupled from species richness trends: Consequences for conservation and monitoring. Journal of Applied Ecology, online early. doi:10.1111/1365-2664.12959
Hillebrand H, Bennett DM, Cadotte MW (2008) Consequences of dominance: a review of evenness effects on local and regional ecosystem processes. Ecology 89:1510–1520
Hillebrand H, Burgmer T, Biermann E (2012) Running to stand still: temperature effects on species richness, species turnover, and functional community dynamics. Mar Biol 159:2415–2422
Hillebrand H, Soininen J, Snoeijs P (2010) Warming leads to higher species turnover in a coastal ecosystem. Glob Chang Biol 16:1181–1193
Hooper DU, Chapin Iii F, Ewel J, Hector A, Inchausti P, Lavorel S, Lawton J, Lodge D, Loreau M, Naeem S (2005) Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecol Monogr 75:3–35

Jacob U, Thierry A, Brose U, Arntz WE, Berg S, Brey T, Fetzer I, Jonsson T, Mintenbeck K, Möllmann C, Petchey O, Riede JO, Dunne JA (2011) The role of body size in complex food webs: a cold case. Adv Ecol Res 45:182–223. doi:10.1016/B978-0-12-386475-8.00005-8
IPCC (2013) Summary for policymakers. In: Stocker TF et al (eds) Climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge and New York, pp 1–18
Isla JA, Lengfellner K, Sommer U (2008) Physiological response of the copepod Pseudocalanus sp. in the Baltic Sea at different thermal scenarios. Glob Chang Biol 14:895–906
Johnson KH (2000) Trophic-dynamic considerations in relating species diversity to ecosystem resilience. Biol Rev Camb Philos Soc 75:347–376
Jørgensen EH, Johnsen HK (2014) Rhythmic life of the Arctic charr: adaptations to life at the edge. Mar Genomics 14:71–81
Jump AS, Penuelas J (2005) Running to stand still: adaptation and the response of plants to rapid climate change. Ecol Lett 8:1010–1020
Kawaguchi K, Ishikawa S, Matsuda O (1986) The overwintering strategy of Antarctic krill (*Euphausia superba* Dana) under the coastal fast ice off the Ongul Islands in Lützow-Holm Bay, Antarctica. Mem Nat Inst Polar Res Spec Iss 44:67–85
Lewis OT (2006) Climate change, species–area curves and the extinction crisis. Philos Trans R Soc B Biol Sci 361:163–171
Litchman E, Edwards KF, Klausmeier CA, Thomas MK (2012) Phytoplankton niches, traits and eco-evolutionary responses to global environmental change. Mar Ecol Prog Ser 470:235–248
Llovel W, Willis JK, Landerer FW, Fukumori I (2014) Deep-ocean contribution to sea level and energy budget not detectable over the past decade. Nat Clim Chang 4:1031–1035
Lotze HK, Lenihan HS, Bourque BJ, Bradbury RH, Cooke RG, Kay MC, Kidwell SM, Kirby MX, Peterson CH, Jackson JBC (2006) Depletion, degradation, and recovery potential of estuaries and coastal seas. Science 312:1806–1809
Marcus NH, Scheef LP (2010) Photoperiodism in copepods. In: Nelson RJ, Denlinger DL, Somers DE (eds) Photoperiods – the biological calendar. Oxford University Press, New York, pp 193–217
McCann KS (2000) The diversity–stability debate. Nature 405:228–233
Memmott J, Martinez ND, Cohen JE (2000) Predators, parasitoids and pathogens: species richness, trophic generality and body sizes in a natural food web. J Anim Ecol 69:1–15
Meyer B (2012) The overwintering of Antarctic krill *Euphausia superba*, from an ecophysiological perspective − a review. Polar Biol 35:15–37
Mintenbeck K, Barrera-Oro ER, Brey T, Jacob U, Knust R, Mark FC, Moreira E, Strobel A, Arntz WE (2012) Impact of climate change on fishes in complex Antarctic ecosystems. Adv Ecol Res 46:351–426. doi:10.1016/B978-0-12-396992-7.00006-X
Moline MA, Claustre H, Frazer TK, Schofield O, Vernet M (2004) Alternation of the food web along the Antarctic Peninsula in response to a regional warming trend. Glob Chang Biol 10:1973–1980
Montes-Hugo M, Doney SC, Ducklow HW, Fraser W, Martinson D, Stammerjohn SE, Schofield O (2009) Recent changes in phytoplankton communities associated with rapid regional climate change along the Western Antarctic Peninsula. Science 323:1470–1473
Munday P, Warner RR, Monro K, Pandolfi JM, Marshall DJ (2013) Predicting evolutionary responses to climate change in the sea. Ecol Lett 16:1488–1500
Naeem S (1998) Species redundancy and ecosystem reliability. Conserv Biol 12:39–45
O'Connor MI (2009) Warming strengthens an herbivory-plant interaction. Ecology 90:388–398
O'Connor MI, Bruno JF, Gaines SD, Halpern BS, Lester SE, Kinlan BP et al (2007) Temperature control of larval dispersal and the implications for marine ecology, evolution, and conservation. Proc Natl Acad Sci U S A 104:1266–1271
Olsen EM, Heino M, Lilly GR, Morgan MJ, Brattey J, Ernande B, Dieckmann U (2004) Maturation trends indicative of rapid evolution preceded the collapse of northern cod. Nature 428:932–935
Parmesan C et al (2005) Empirical perspectives on species borders: from traditional biogeography to global change. Oikos 108:58–75
Parmesan C, Yohe G (2003) A globally coherent fingerprint of climate change impacts across natural systems. Nature 421:37–42

Petchey OL, Eklöf A, Borrvall C, Ebenman B (2008) Trophically unique species are vulnerable to cascading extinction. Am Nat 171:568–579

Philippart CJM, van Aken HM, Beukema JJ, Bos OG, Cadee GC, Dekker R (2003) Climate-related changes in recruitment of the bivalve Macoma balthica. Limnol Oceanogr 48:2171–2185

Poloczanska ES et al (2013) Global imprint of climate change on marine life. Nat Clim Chang 3:919–925

Pörtner HO, Farrell AP (2008) Physiology and climate change. Science 322:690–692

Pörtner H, Farrell A, Knust R et al (2009) Adapting to climate change – response. Science 323:876–877

Pörtner HO (2010) Oxygen- and capacity-limitation of thermal tolerance: a matrix for integrating climate-related stressor effects in marine ecosystems. J Exp Biol 213:881–893

Rahmsdorf S, Box JE, Feulner G, Mann ME, Robinson A, Rutherford S, Schaffernicht EJ (2015) Exceptional twentyth-century slowdown in Atlantic Ocean overturning circulation. Nat Clim Chang 5:475–480

Reuman DC, Holt RD, Yvon-Durocher G (2014) A metabolic perspective on competition and body size reductions with warming. J Anim Ecol 83:59–69

Reusch TBH (2013) Climate change in the oceans: evolutionary versus phenotypically plastic responses of marine animals and plants. Evol Appl 7:104–122

Roemmich D, Church J, Gilson J, Monselesan D, Sutton P, Wihffels S (2015) Unabated planetary warming and its ocean structure since 2006. Nat Clim Chang 5:240–245

Sale PF (2008) Management of coral reefs: where we have gone wrong and what we can do about it. Mar Pollut Bull 56:805–809

Sarmiento JL, Slater R, Barber R, Bopp L, Doney SC, Hirst AC, Kleypas J, Matear R, Mikolajewicz U, Monfray P, Soldatov V, Spall SA, Stouffer R (2004) Response of coean ecosystem to climate change. Glob Biogeochem Cycles 18:GB3003. doi:10.1029/2003GB002134

Schofield O (2010) How do polar marine ecosystems respond to rapid climate? Science 328:1520–1523

Smith GR, De Leo FC, Bernardino AF, Sweetman AK, Martinez Arbizu P (2008) Abyssal food limitation, ecosystem strcuture and climate change. Trends Ecol Evol 23:518–528

Sokolov S, Rintoul SR (2009) Circumpolar structure and distribution of the Antarctic circumpolar current fronts: 2. Variability and relationship to sea surface height. J Geophys Res Oceans 114. doi:10.1029/2008JC005248

Somero GN (2005) Linking biogeography to physiology: evolutionary and acclimatory adjustments of thermal limits. Front Zool 2:1. doi:10.1186/1742-9994-2-1

Sommer U, Aberle N, Lengfellner K, Lewandowska A (2012) The Baltic Sea spring phytoplankton bloom in a changing climate: an experimental approach. Mar Biol 159:2479–2490

Storch D, Menzel L, Frickenhaus S, Pörtner HO (2014) Climate sensitivity across marine domains of life: limits to evolutionary adaptation shape species interactions. Glob Chang Biol 20(10):3059–3067

Sunagawa S et al (2015) Structure and function of the global ocean microbiome. Science 348:6237

Thackeray SJ et al (2010) Trophic level synchrony in rates of phenological change for marine, freshwater and terrestrial environments. Glob Chang Biol 16:3304–3313

Thomas CD et al (2004) Extinction risk from climate change. Nature 427:145–148

Thomas MK, Kremer CT, Klausmeier CA, Litchman E (2012) A global pattern of thermal adaptation in marine phytoplankton. Science 338:1085–1088

Thuiller W, Lavorel S, Araujo MB, Sykes MT, Prentice IC (2005) Climate change threats to plant diversity in Europe. Proc Natl Acad Sci U S A 102:8245–8250

Tilman D, May RM, Lehman CL, Nowak MA (1994) Habitat destruction and the extinction debt. Nature 371:65–66

Turner J, Bindschadler R, Convey P, di Prisco G, Fahrbach E, Gutt J, Hodgson D, Mayewsky P, Summerhayes C (2009) Antarctic climate change and the environment. SCAR, Scott Polar Research Institute, Cambridge. 526p

Vargas D et al (2015) Eukaryotic plankton diversity in the sunlit ocean. Science:348. doi:10.1126/science.1261605

Wearn OR, Reuman DC, Ewers RM (2012) Extinction debt and windows of conservation opportunity in the Brazilian Amazon. Science 337:228–232

Whittaker RH (1960) Vegetation of the Siskiyou Mountains, Oregon and California. Ecol Monogr 30:279–338

Widdicombe C et al (2010) Long-term phytoplankton community dynamics in the Western English Channel. J Plankton Res 32:643–655

Wilson RJ, Gutierrez D, Gutierrez J, Martinez D, Agudo R, Monserrat VJ (2005) Changes to the elevational limits and extent of species ranges associated with climate change. Ecol Lett 8:1138–1146

Wilson RJ, Thomas CD, Fox R, Roy DB, Kunin WE (2004) Spatial patterns in species distributions reveal biodiversity change. Nature 432:393–396

Woodward G, Benstead JP, Beveridge OS, Blanchard J, Brey T, Brown L, Cross WF, Friberg N, Ings TC, Jacob U, Jennings S, Ledger ME, Milner AM, Montoya JM, Pichler DE, O'Gorman E, Petchey OL, Olesen JM, Reuman DC, Thompson MS, Van Veen FJF, Yvon-Durocher G (2010) Ecological networks in a changing climate. Adv Ecol Res 42:71–138. doi:10.1016/S0065-2504(10)42002-4

Worm B et al (2006) Impacts of biodiversity loss on ocean ecosystem services. Science 314:787–790

Xenopoulos MA, Lodge DM, Alcamo J, Marker M, Schulze K, Van Vuuren DP (2005) Scenarios of freshwater fish extinctions from climate change and water withdrawal. Glob Chang Biol 11:1557–1564

Chapter 19
Ocean Acidification

Peter Thor and Sam Dupont

Abstract Roughly one third of anthropogenically emitted CO_2 has been taken up by the oceans. When this CO_2 combines with water to form H_2CO_3, a weak acid, water acidity increases in a process referred to as ocean acidification (OA). From the preindustrial era until present time the average pH has decreased by 0.08 units on average and it is projected to decrease a further 0.15 to 0.50 until year 2100 (IPCC RCP2.6 and RCP8.5 projections). Increased acidity hampers calcification in shell forming invertebrates, but OA also acts on a wider range of physiological processes, especially those related to cellular ion regulation, and most often non-calcifying species are equally affected. Meta-analyses show severe effects on many species of corals, echinoderms, molluscs, crustaceans, and fish at levels predicted for year 2100. Nevertheless, generalizations are presently hampered by our lack of knowledge on the variability of effects among life cycle stages, variability among taxa, how evolutionary adaptation and transgenerational effects may alleviate OA effects, and effects of OA on entire communities. Even closely related species react differently, and differences among populations of the same species separated geographically have been recorded. Also, specific life cycle stages seem to be more sensitive. In general, planktonic larvae and juveniles seem more affected than adults. Knowledge on evolutionary adaptation to OA is scarce, but the few studies that do exist indicate possible fast adaptation and buffering of OA effects by transgenerational exposure. Studies show that future OA may shift the biodiversity of entire communities. Two marine communities are of particular concern. Model studies indicate that coral reefs could be pushed beyond sustainability be the end of the century, and OA is progressing fast in the Arctic where many species are physiologically lesser capable of countering OA. OA works in concert with many other environmental stressors and knowledge on OA should be incorporated into decisions on

P. Thor (✉)
Norwegian Polar Institute, Tromsø, Norway
e-mail: Peter.Thor@npolar.no

S. Dupont
Department of Biological and Environmental Sciences, University of Gothenburg, Gothenburg, Sweden
e-mail: sam.dupont@bioenv.gu.se

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_19

suitable areas to protect so as to minimise effects of other stressors in habitats most vulnerable to OA.

Keywords Acidification • Taxon specific variability • Evolutionary adaptation • Community effects • Arctic ecosystem • Coral reefs

19.1 Introduction

In this chapter we first describe the phenomenon ocean acidification (OA), its spatial variability, and the predictions for the near future. We then discuss its biological effects. As for temperature, most biochemical processes display optimal pH ranges outside which their rates decline. The mode of action of OA on organisms, populations, and communities related to niche shifts, changes to phenology, adaptation, acclimatisation (phenotypic plasticity), and loss of biodiversity are therefore similar to those of climate change and are well described in Chap. 18. However, while the effects of temperature is known for virtually all biological processes, our knowledge on effects of changes in pH and carbonate chemistry on complex biological systems lacks behind. Common mechanistic relationships between OA and its effects have therefore yet to be defined. Observed OA effects vary considerably among taxa or groups of taxa, and in this chapter we describe attempts to generalize effects and discuss what factors make such generalizations difficult. Rather than supplying a complete review of present knowledge, which would be outside the scope of this book, we present specific examples highlighting differences and variation in effects. Organisms are intricately linked through trophic connections in any natural community and effects, even on keystone species, may not reflect the community response as a whole. In the last part of the chapter we therefore give a few examples of effects on the community and ecosystem levels before highlighting two specific ecosystems believed to be particularly sensitive; coral reefs and the Arctic. Finally we touch briefly on the possibility of mitigating OA and its effects.

19.2 Present State and Predicted Future of Ocean Acidification

Anthropogenic emission of CO_2 carries with it another important consequence besides increasing temperature. The ocean is in gas equilibrium with the atmosphere, and increasing atmospheric CO_2 partial pressures causes a net uptake of CO_2 into the ocean's interior. This has significant consequences for the ocean chemistry, of which an increase in hydrogen ion concentration (measured as a decrease in pH) is prominent. OA is the term used for observed and predicted decreases in ocean pH. While the oceans may not become acidic in its literal sense—the pH of the present day open ocean ranges from 7.8 to 8.4 (Orr et al. 2005b)—the term is used to describe the increasing acidity. Anthropogenic ocean acidification refers to the component of pH reduction that is caused by human activity.

Absorption of CO_2 by seawater changes the equilibrium of the carbonate system so that carbonic acid, H_2CO_3, is formed:

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-}$$

Carbonic acid dissociates into bicarbonate and hydrogen ions. The result is an increase in hydrogen ions, and counterintuitively also a decrease in carbonate ions, CO_3^{2-}. This is because the increase in hydrogen ion concentration shift the equilibrium of the rightmost reaction to the left.

The oceans are acidifying now, and are doing so at accelerating rates. In total the global ocean is estimated to have absorbed 155 PgC of anthropogenic carbon from 1750 to 2010, corresponding to roughly one third of CO_2 emitted by human activity in this period (Khatiwala et al. 2013). Of these, as much as 37 PgC (24%) has been taken up during the two decades from 1980 to 1999 (Sabine et al. 2004). The meteorological time series at Mauna Loa (Hawaii), which shows an accelerating increase in atmospheric CO_2, has been complemented with measurements of pCO_2 and pH at the Aloha station NW of Hawaii, and this shows a continuation of the trend with a significant decrease in average pH (Fig. 19.1). On average anthropogenic CO_2 emission has given rise to an average decrease of 0.08 pH units of the surface ocean from 1765 to 1994 (Sabine et al. 2004). This decrease will continue due to continued

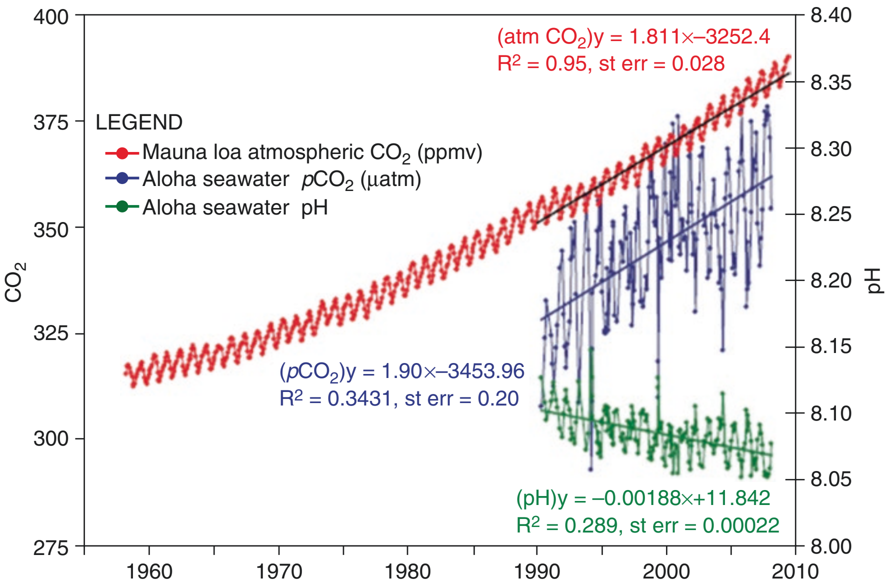


Fig. 19.1 Atmospheric pCO_2 at the Mauna Loa meteorological station and seawater pCO_2 and pH at Station Aloha near Hawaii (Doney et al. 2009)

uptake of anthropogenic CO_2 with the predicted increased atmospheric pCO_2. The global ocean storage capacity for CO_2 is predicted to be three times as high as the present inventory.

In the fifth assessment report (AR5) the IPCC employ four Representative Concentration Pathway (RCP) scenarios based on the change in radiative forcing (difference in solar energy absorbed by the Earth and energy radiated back to space in W/m^2) from the pre-industrial era until year 2100. Four different future scenarios are considered, RCP2.6, RCP4.5, RCP6, and RCP8.5, of which the first three rely on emissions peaking in 2010–2020, 2040, and 2080, respectively. RCP8.5 assumes continued increased throughout the twenty-first century (Collins et al. 2014). Using these scenarios, the IPCC has predicted average sea surface pH changes on the scale of 0.15 pH units for RCP2.6 to 0.5 pH units for RCP8.5 by the year 2100 (Fig. 19.2).

19.2.1 Variability of Ocean Acidification

Sea water pH varies temporally and spatially. Many factors affect the uptake of CO_2 and the formation of carbonic acid. For example, the equilibrium in the equation above is shifted to the right with decreasing temperature and decreasing salinity (Zeebe and Wolf-Gladrow 2001), and the rate of OA is higher towards the poles and in fresh water influenced estuaries and coastal seas. While the North Atlantic and Arctic Ocean contains the largest inventory of anthropogenic carbon (Sabine et al. 2004; Khatiwala et al. 2013), these are also the regions that have experienced the most severe pH decrease since the onset of the industrial revolution. Current estimates put the largest reduction (−0.10 pH units) in the northern North Atlantic and the smallest reduction (−0.05 pH units) in the subtropical South Pacific (Rhein et al. 2013).

The Arctic is recognised as the region where the earliest and strongest impacts of OA is expected (Fabry et al. 2009; AMAP 2013). Contributing only 1% of the global ocean volume, the Arctic Ocean receives 11% of the global fresh water input, and it is already heavily impacted at freshwater influenced shelves along the Canadian and Siberian coasts (Chierici and Fransson 2009). Sea ice melt has very low H^+ buffering capacity and presently increasing ice melt makes Arctic waters, including the central Arctic Ocean, increasingly susceptible to OA (AMAP 2013). Moreover, increasing Atlantic water inflow through the Fram Strait carries large amounts of anthropogenic CO_2 to the Arctic Ocean (Fransson et al. 2001).

Sea water pH also differ among biomes both in terms of average pH but also short term temporal variability (Hofmann et al. 2011). This is because of changes to the chemical composition of the water induced by a range of biological processes, foremost photosynthesis, which takes up CO_2, and respiration, which produces CO_2. Such variability may significantly exacerbate effects of OA by increasing the severity of extremes. On the other hand, it may also render organisms living in these environments better adapted to variations in pH. While the open ocean shows very little variation in pH, nearshore environments and upwelling areas experience rapid variations (Fig. 19.3).

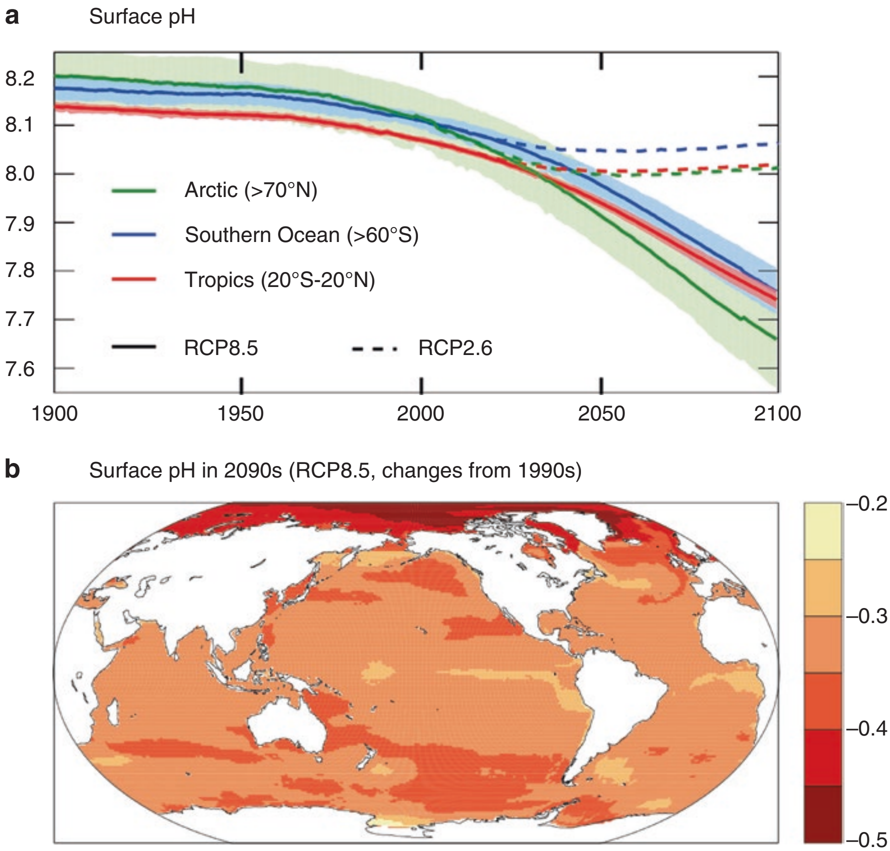


Fig. 19.2 (**a**) Medians (*lines*) and ranges (*shaded area*) of projected ocean acidification from 11 Coupled Model Inter-comparison Project Phase 5 (CMIP5) Earth System models under RCP8.5 and RCP2.6 (representative concentration pathways) scenarios. (**b**) Map of the RCP8.5 median model's change in surface pH from 1990s (IPCC 2013)

19.3 Impacts of Ocean Acidification

19.3.1 Biological Challenges of Decreasing Ocean pH

While the effects of increased temperature are well known for almost any biological process, key processes on the underlying mechanisms governing OA responses are still poorly understood (Browman 2016), and present knowledge is not sufficient to establish any general rules of effects of decreased pH among taxa. Since the process of calcification varies with pH within the range expected under OA—calcification have been seen to change the structure of the exoskeleton in shrimps, for example (Taylor et al. 2015)—much attention has been directed at understanding the processes of dissolution of shells and modifications to the calcification process itself

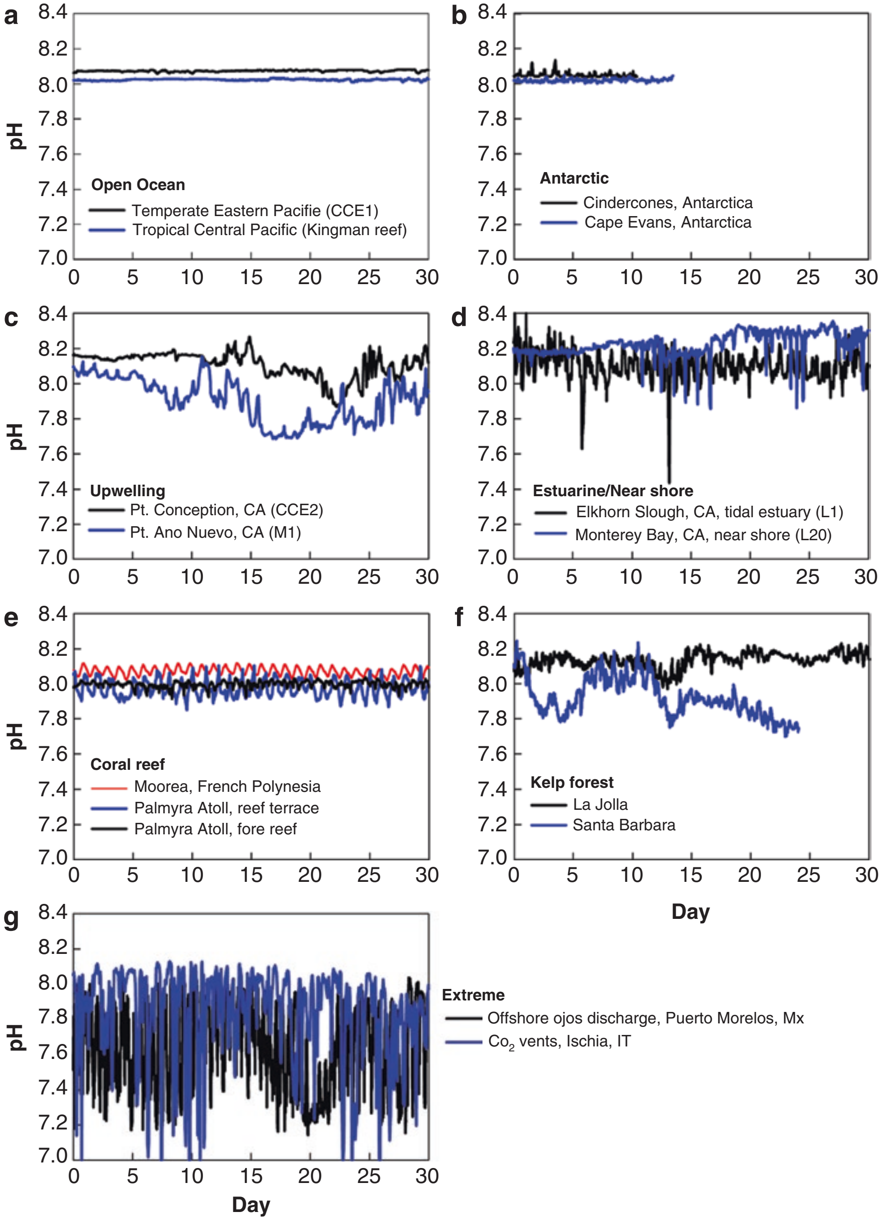


Fig. 19.3 Short term variability in pH among different marine biomes (Hofmann et al. 2011)

(Orr et al. 2005a). But OA acts on a wider range of physiological processes, especially those related to cellular ion regulation, and most often non-calcifying species are equally affected (Pörtner et al. 2004; Pörtner 2008). Thus, the capacity for acid-base regulation has been suggested as an over-arching principle that shapes sensitivity to ocean acidification (Melzner et al. 2009). OA acts especially on marine invertebrates, which are characterized by a low capacity to compensate for disturbances in extracellular ion and acid–base status and sensitivity of metabolism to such disturbances (Pörtner 2008), but studies have shown that also many fish species are affected. Most prominently, studies have shown a loss predator avoidance in fish. Fish use olfactory cues to detect predators and one particular case shows that Clown fish (*Amphiprion percula*) loses the ability to differentiate between the chemical cues of predatory and non-predatory species (Dixson et al. 2010). Settlement-stage larvae changed from complete avoidance of the olfactory cues from predators to complete attraction to these cues at 1000 μatm CO_2 corresponding to pH 7.8. Needless to say, this will incur severe effects in this important coral reef species. On the other hand, behaviour of larval Herring (*Clupea harengus*) seems unaffected (Maneja et al. 2015).

While the scientific field of OA studies is slowly maturing, the general picture of OA effects is unfortunately very complicated. First of all, OA effects vary much among taxa. Even closely related species react differently, and differences among populations of the same species separated geographically have been recorded. One method for generating an overview of the outcome of existing studies is meta-analysis. In such analysis, taxon mean effect sizes (s) are calculated as the ratio between the size of the variable in question at the experimental condition and a control condition. One such analysis of OA effects included 372 responses in 44 different species (Hendriks et al. 2010). This study showed severe overall effects in coral and bivalve calcification (s values of 0.70 ± 0.07 and 0.57 ± 0.07, respectively), copepod and sea urchin fertility (s values of 0.60 ± 0.10 and 0.66 ± 0.06), sea urchin adults and embryos and gastropod growth (s values of 0.38 ± 0.23, 0.77 ± 0.04, and 0.68 ± 0.16), and sea urchin, gastropod, and copepod survival (s values of 0.88 ± 0.06, 0.93 ± 0.03, and 0.81 ± 0.04). Interestingly, the authors of this study concluded that marine species are probably not as sensitive to OA as first believed. However, this conclusion was based on the average effect size among all tested taxa including mostly positive effects on cyanobacteria, phytoplankton, and sea grasses ($s = 1.01 \pm 0.10$). A meta-analysis of effects among phytoplankton shows significant positive effects on growth rate in diatoms (s value 1.042 ± 0.150), other large phytoplankters (s value 1.093 ± 0.172) and nitrogen fixing cyanobacteria (s value 1.248 ± 0.269) (Dutkiewicz et al. 2015). Another study investigated in more detail effects of OA in a wider range of animal taxa and included information of effects direction (positive, negative, or neutral) at several different levels of pCO_2 (Wittmann and Pörtner 2013). This study, which is probably the most comprehensive overview of OA effects to date, showed that many species of corals, echinoderms, molluscs, crustaceans, and fish will be negatively affected by OA at levels predicted for year 2100 (Fig. 19.4). Specifically, the study showed that 50% of coral species will be negatively affected at a pCO_2 of 1003 μatm, 50% of echinoderms will be negatively affected at 870 μatm, 50% of mollusc species will be negatively affected at 781 μatm, 50% of crustaceans will be negatively affected at 2086 μatm, and 50% of fish species will be negatively affected already at 632 μatm (Wittmann and Pörtner 2013).

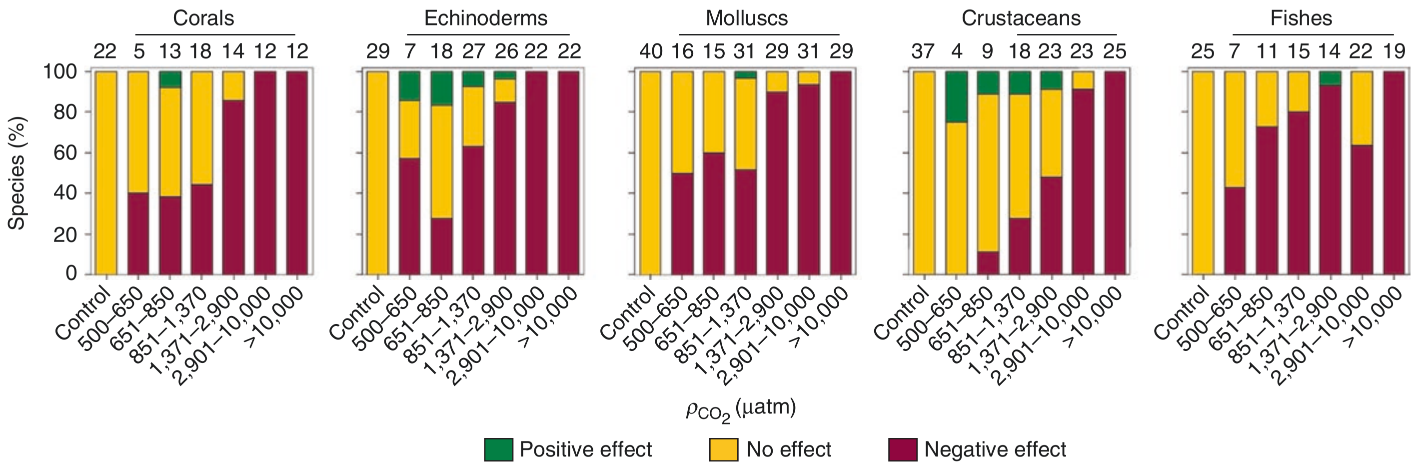


Fig. 19.4 Sensitivities of animal taxa to ocean acidification. Fractions (%) of coral, echinoderm, mollusc, crustacean and fish species exhibiting negative, no or positive effects on performance indicators reflecting individual fitness in response to the respective pCO_2 ranges (μatm). Bars above columns denote count ratios significantly associated with pCO_2 (Fisher's exact test, $p < 0.05$) (Wittmann and Pörtner 2013)

But meta-analysis carries in it an inherent oversimplification of effects. To thoroughly asses any species' response to environmental change one will have to evaluate effects at several different levels (Dupont et al. 2010). (1) Effects may vary tremendously through life cycle stages like embryos, larvae, juveniles, and adults. This is especially true for many benthic marine invertebrates that develop by means of a free-living dispersive planktonic larval stage. These larvae are physiologically and morphologically distinct from the adult and may thus experience very different sensitivities to environmental stressors. Effects should therefore be measured over the whole reproductive cycle. (2) Effects may be counteracted through time by processes related to acclimatisation and transgenerational effects such as adaptation and parental effects, (3) they may vary among sub-populations adapted to different environments in different regions and (4) effects on one (or a group of) particular key species may reverberate through the community in an ecosystem to affects other species on other trophic levels.

19.3.1.1 Life Cycle Differences in OA Effects

Effects of OA have been studied in all life cycle stages in many invertebrates. Echinoderms are among the most studied of all. In 2010 Dupont and co-workers published a meta-analysis of effects among different life stages of echinoderms including brittle stars, sea stars, sea urchins and sea cucumbers (Dupont et al. 2010). In general planktonic larvae experienced negative effects on growth ($s = 0.90 \pm 0.02$, $n = 35$) and on average larval and juvenile calcification, growth, and survival were severely affected by OA, whereas adults showed positive responses in terms of calcification and growth (survival was not tested). A recent study alludes to the notion that changing digestion in the larvae may be central to OA effects in echinoderms (Stumpp et al. 2013). Sea urchin larvae have alkaline (pH 9.5) conditions in the stomach and larvae exposed to decreased seawater pH suffered decreased gastric pH, which generated decreased digestive efficiencies and triggered compensatory feeding.

19.3.1.2 Acclimatisation, Adaptation, and Parental Effects

Acclimatisation is the process by which an organism changes its phenotype to accommodate the new environment (i.e. phenotypic plasticity) (see also Sect. 18.3). This results in a recovery of functions within a timespan of much less than the generation time of that species. If this recovery does not occur at a rate sufficiently fast to avoid decreased lifetime fitness (i.e. reduced life time production of offspring) then the change in environment will carry potential negative effects for that species. Should such negative effects occur, they may also inflict natural selection in the populations. This is the process by which species adapt to changing environments through generations. Positive selection of individuals less sensitive to the changes will allow a general shift to less affected phenotypes within the affected populations.

While short term studies may contribute knowledge on the general sensitivity of a species to OA, we still need long term studies to enable any predictions of acclimatisation or adaptation potential of affected populations (Sunday et al. 2014). Long term studies on mussels and echinoderms have shown considerable acclimation to high pCO_2. For instance, while short term exposure have shown acute effects on calcification in the bivalve *Mytilus edulis* (Gazeau et al. 2007), longer term studies on this species (Berge et al. 2006) and a closely-related species (*Mytilus galloprovincialis*) (Michaelidis et al. 2005) showed acclimation to hypercapnia. Another calcifier, the sea urchin *Strongylocentrotus droebachiensis* experienced reduced female fecundity after 4 months of exposure. But after 16 months exposure fecundity was fully recovered (Dupont et al. 2013). Reciprocal transplantation of organisms between two different environments (in this case high and low pH) is an easy and powerful way to weigh the importance of adaptation and acclimatisation. Transplantation of benthic polychaetes inhabiting underwater volcanic CO_2 vents have shown metabolic adaptation to high pCO_2 in *Platyneries dumerilii* but acclimatisation in *Amphiglena mediterranea* (Calosi et al. 2013). This study shows that adaptation and acclimatisation are equally viable strategies for countering effects of OA. Another study on the sea urchin *Strongylocentrotus purpuratus* has shown that such adaptation to OA may arise from natural selection for larvae with specific alleles in genes related to membrane composition and ion transport that improve performance under OA (Pespeni et al. 2013). OA has been shown to impair copepod larval development beyond the second generation in the copepod *Tisbe battagliai*. A multi-generation study showed significantly reduced copepodite size and changes in cuticle carbon and oxygen composition (Fitzer et al. 2012). However, adaptation can alleviate OA effects also in copepods. A reciprocal transplant study on the copepod *Pseudocalanus acuspes* from the North Sea showed that while fecundity would decreased by as much as 67% at 1550 µatm CO_2 compared to present day 400 µatm CO_2 without adaptation, selection in genes involved in ribosome formation and mitochondrial metabolic function partly reduced OA effects so that the loss of fecundity was reduced to 29% (De Wit et al. 2016; Thor and Dupont 2015). In a study on oysters, *Saccostrea glomerata*, Parker and colleagues found increased capacity of adults to regulate extracellular pH at elevated pCO_2 if previous generations were exposed to elevated pCO_2. Moreover, offspring from these adults experienced less shell abnormality, faster development rate, and faster shell growth at high pCO_2 compared to offspring from unexposed adults (Parker et al. 2015). Alleviation through exposure of ancestors is not limited to invertebrates. OA combined with an increase in temperature predicted for year 2100 cause an increase in metabolic rate and decreases in length, weight, condition and survival of juvenile anemonefish, *Amphiprion melanopus*. However, these effects are absent or reversed when parents also experience high pCO_2 (Miller et al. 2012).

19.3.1.3 Variations in OA Effects Within Species or Among Closely Related Species

Different environments among locations may create differently pre-adapted populations within the same species, and several studies have found differences in OA responses among different populations of the same species. Populations from Svalbard and Skagerrak of the copepod *Pseudocalanus acuspes* respond differently for both their metabolism and rate of prey ingestion (Thor and Oliva 2015), and studies of the isopod *Idotea balthica* have shown that metabolic rate and osmoregulatory activity responded differently to increased pCO_2 (1000 μatm) in populations from low and high salinity environments (Wood et al. 2016). Larvae of spider crab *Hyas araneus* also show differences in growth responses between two populations at Svalbard and the North Sea (Walther et al. 2010). Different responses may come about due to dissimilar adaptation through different selection pressure among environments. Complicating matters further, differential OA responses may co-evolve along selection posed by other environmental factors than pH, as in the Wood et al. study where salinity adaption induced differential responses to pH.

19.3.1.4 Community Effects

While effects may appear as directly influencing the physiology of organisms, they will also affect trophic interactions in affected communities. Predator-prey interactions depend on the performance of both prey and predator, and when motor function or perception of prey or predator becomes impaired, so does the trophic transport of matter. Scallops have showed impaired clapping performance following low pH exposure. Force production was significantly reduced between present day pCO_2-exposed and high pCO_2-exposed scallops (Schalkhausser et al. 2012). These scallops may thus be more exposed to predation. Small juveniles of four damselfish species sustained greater predation mortality at high CO_2 levels (Ferrari et al. 2011). For large prey, the pattern of prey selectivity by predators was reversed under elevated CO_2. These results demonstrate both quantitative and qualitative consumptive effects of CO_2 on small and larger damselfish recruits respectively, resulting from CO_2-induced behavioural changes likely mediated by impaired neurological function (Munday et al. 2009). Another study showed that settlement-stage larvae of the Clown fish (*Amphiprion percula*) changed from complete avoidance of the olfactory cues from predators to complete attraction to these cues at 1000 μatm CO_2 (Dixson et al. 2010).

Growing theoretical evidence suggests that the stability and functioning of ecosystems may depend, not only on aggregate biomass and production of producers and consumers, but also on the diversity at the species level within those compartments (Duffy and Stachowich 2006) (for a comprehensive description of effects of biodiversity changes see Chap. 18). In general, diversity of ecosystem key species may increase resilience against ecological and environmental perturbations. Even subtle differences in average resilience among key populations may favour some species over others. This may result in a loss of key functions in the community, and significantly change the ecosystem. The results from the Dutkiewicz et al. meta-analysis on phytoplankton described above was entered into a marine ecosystem model with diverse and flexible phytoplankton communities, coupled to an Earth system model to explore possible global changes to phytoplankton during the twenty-first century (Dutkiewicz et al. 2015). In the model, the changes included warming waters, decreased macronutrient supply, altered light environments, increased pCO_2, and lower pH. The outcome was a ~50% alteration of the global functional diversity with broad-scale changes in dominant functional groups relative to pre-industrial conditions. OA contributed considerably to these changes and keeping all other parameters constant did not change the outcome considerably.

Evidence exists from empirical studies as well. The effects of OA on plankton communities have been studied using the Kiel Offshore Mesocosms for Oceanographic Studies (KOSMOS) at several different locations including Svalbard, the Norway coast, the Skagerrak, and the Canary Islands. At the time of writing, much of the results are still being processed, but the results from the Svalbard study have been published (summary in Riebesell et al. 2013). In this study the composition of the plankton in terms of phytoplankton groups and mesozooplankton species, as well as the transfer of carbon from dissolved inorganic carbon (DIC) to phytoplankton, bacterial and zooplankton consumers, and export to the ocean floor were followed in nine 50 m^3 floating mesocosms at increasing pCO_2 (185–1420 μatm). The study showed that increasing pCO_2 can shift the community by increasing concentrations of pico- and nano-phytoplankton on the expense of larger diatoms (Brussaard et al. 2013; Leu et al. 2013) while mesozooplankton composition do not change (Niehoff et al. 2013). These changes were accompanied by a general increase in primary production, but with a decrease in mesozooplankton grazing probably due to lower grazing efficiency on smaller size phytoplankton cells. Moreover, these changes increased the export to the ocean floor (de Kluijver et al. 2013; Engel et al. 2013). Halfway through the experiment nutrients were added to simulate mixing of water masses during a storm or an upwelling event. This shifted the general dynamics of the plankton community. Now primary production was lower at high pCO_2 and this caused the export of matter to the ocean floor to decrease. This study is a very good example of possible community effects of OA. Should such changes occur, then the transfer of organic matter will be shifted away from the classic grazing food chain, phytoplankton-zooplankton-fish, to enter the microbial loop. Such changes will obviously impact fish production and ultimately fisheries.

19.3.2 Ecosystems of Particular Concern

Coral reefs, both shallow water tropical reefs and the lesser known deep water reefs constitute the foundation for marine communities flourishing high biodiversity. Most species associated with coral reefs are endemic and the whole ecosystem rely on the production and physical structure of the reef. The reef itself is produced from aragonite, a mineral form of calcium carbonate, deposited at the base of the coral polyps. Decreased sea water pH reduces the saturation of all mineral forms of calcium carbonate, including aragonite, and this pose two severe consequences for coral reef integrity. Decreasing aragonite saturation (Ω_a) boost coral skeleton dissolution and decreases calcification rates. The IPCC's Fourth Assessment Report (AR4) stated that doubling of atmospheric CO_2 would reduce calcification of corals by 20–60% (Reynaud et al. 2003) and by 2070 many reefs could reach critical aragonite saturation states (Feely et al. 2004).

Much knowledge originates from models applying empirical relationships between aragonite saturation state and net coral calcification. While such studies should be interpreted with caution (Jokiel 2016), most predict a grim future for the world's coral reefs. Drawing on results from several different lab studies on effects of high pCO_2 on calcification as well as one community study from the Red Sea, Silverman and colleagues concluded that acidification-induced reductions in calcification will shift coral reefs from a state of net accretion to one of net dissolution already at 560 ppm CO_2 (Silverman et al. 2009). Ricke and colleagues extended these concerns to encompass coral reefs world-wide (Ricke et al. 2013). Using Earth system models from the Coupled Model Inter-comparison Project, Phase 5 (CMIP5), they concluded that if OA develops according to the RCP8.5 scenario, aragonite saturation will be too low for any local differences in water chemistry to counteract severe long-term effects of coral reefs. Rather, all coral reefs will experience an environment well beyond sustainability. Predictions varied little among the different models in the CMIP5 ensemble, which should indicate a high level of confidence in these results. The authors conclude that very aggressive reductions in emissions are required to avoid these effects.

Probably the most visible hands on evidence for present day effects of OA on whole coral communities can be found in a recent study from the Southern part of the Great Barrier Reef. By returning water chemistry at part of the reef to its pre-industrial era condition, coral calcification increased (Albright et al. 2016). The authors concluded that calcification and coral growth at this reef is presently suppressed by 7%.

But determining the contribution of OA to coral reef fate is difficult owing to the confounding effects of other environmental factors, first of all temperature, which is probably the main determinator of the future of coral reefs. At the time of writing, severe bleaching (loss of photosynthesising zooxanthellae symbionts supplying energy to the polyps) is far progressed in many reefs worldwide, including the Great Barrier Reef where bleaching extends to 93% of the reef (http://www.globalcoralbleaching.org). This is foremost an effect of increased sea surface temperatures as a result the 2015–2016 El Niño Southern Oscillation event (ENSO). The chance of recovery from this relies on the development of temperatures in the coming decade but may also depend on aragonite saturation state.

Arctic waters are already acidifying at a higher rate than the average global ocean. Arctic organisms are therefore the first to feel the effects of OA and will continue to do so in the future. Contrary to cold adapted eurythermal fauna (animals that can tolerate a wide range of temperatures), true Polar species show low energetic costs for maintenance at low temperatures. But such low costs are also mirrored in low turnover rates of transmembrane ion exchange and a lower capacity for acid-base regulation (Whiteley 2011). Consequently, true Arctic species will be lesser capable of countering OA. Moreover, Arctic communities are characterized by simple food webs both in terms of number of trophic levels and diversity on each trophic level. This introduces increased sensitivity to environmental changes. Effects of environmental change on predator-prey interactions are often buffered by niche sharing both at the predator level and the prey level. If any particular species is severely impacted, another will be able to take its place. In simple food webs with a low number of predator-prey interactions, this buffering is lessened.

The Arctic is logistically challenging to study and our knowledge on OA effects there is still limited (AMAP 2013). However, in addition to the Arctic food web effects found by the Riebesell group (described in Sect. 19.3.1.4), studies do show effects in particular keystone species. Copepods are such keystone species globally and in the Arctic. Globally, they contribute 80% of the zooplankton biomass and are important prey for larvae and juveniles of a wide range of fish species (Last 1980). The importance of copepods for fish populations is visible in several different studies world-wide. Stock recruitments of Mackerel, *Scomber scombrus*, have been shown to co-vary with copepod biomass through at least two decades in the Gulf of St. Lawrence (Runge et al. 1999; Castonguay et al., 2008) and survival of larval Cod (*Gadus morhua*) has been shown to depend on size and abundance of their copepod prey in the North Sea (Beaugrand et al. 2003). In the Baltic Sea, increase in rainfall since the 1980s and lack of intrusion of high saline water from the North Sea have affected reproduction and maturation in *Pseudocalanus elongatus* (Möllmann et al. 2003). Investigations of stomach contents showed that Herring (*Clupea harengus*) have been forced to revert to less favourable prey than *P. elongatus* during this period, and this has had serious implications for herring growth and development. In the Arctic, *Calanus glacialis* is the dominant species on the shelves. Nauplius larvae of this species have shown increased mortality under OA (Lewis et al. 2013) but there seem to be no effects on the development of the larvae that do survive (Bailey et al. 2016). While one study show no effects on ingestion rates (Hildebrandt et al. 2016) another suggest severe effects on both metabolism and ingestion rates at OA levels predicted for year 2100 (Thor et al. 2017). There is no doubt that the future of Arctic fish stocks depend on effects on copepods but we are still in need of more knowledge of effects on these important Arctic crustaceans.

19.4 Mitigation of Ocean Acidification

Proof of present day negative effects of OA abounds, and there is no doubt that effects will continue to increase in strength. Many species of corals, echinoderms, crustaceans, and fish are affected. Especially, the future for tropical coral reefs is bleak in the face of OA. Evolutionary adaptation may well lessen effects in some particular species but it is by no means something we should rely on for mitigation. The mesocosm study described in Sect. 19.3.1.4 show how entire planktonic communities may shift under future OA. Plankton lies at the bottom of the food web and such shifts will affect the ocean ecosystem including fish and mammals in a very fundamental way. As for climate change, the obvious mean to abate OA is reduced emission of greenhouse gases. Present increases in emissions has mostly been driven by an increased energy intensity of the gross domestic product (GDP) along with increased carbon intensity of energy production and not so much, as one perhaps would expect, by the increase in the human population or an increasing per-capita GDP (Raupach et al. 2007). This indicates that management of energy consumption by shifting to sustainable energy production would be a viable mean to control emissions from a growing human population. Initiatives to reduce emissions (like the installation of large solar power plants) have receive increased attention in recent years. However, several studies stress the need for aggressive reductions in emissions. Employing a coupled atmosphere-ocean-carbon cycle model to examine the long term consequences of various emission reduction targets, Weaver and colleagues have shown that the 2.0 °C warming threshold agreed upon at the United Nations Climate Change Conference in 2015 will not be met without a 60% reduction in emission rates by the year 2050 (Weaver et al. 2007). The authors conclude that the 2.0 °C target will not be reached without large scale active CO_2 removal from the atmosphere.

Several different geoengineering CO_2 removal schemes have been considered (see Chap. 13). These include geological storage, ocean storage, mineral carbonation, and storage in plant biomass and soils. While the first involve injection of CO_2 into porous rock, ocean storage would be accomplished by injecting CO_2 into the deep ocean. Needless to say, this method would only exacerbate OA. Mineral carbonation would involve enhancement of chemical breakdown of rock (weathering) that ultimately leads to CO_2 being captured and locked into carbonates, which ultimately will end up on the ocean floor. Natural weathering of silicate and carbonate rock absorbs 0.25 PgC/year of atmospheric CO_2 presently, which amount to 3% of fossil fuel emissions (9–10 PgC/year) (Taylor et al. 2016). Several studies have investigated the possibility of artificial acceleration of this process by distribution of pulverised silicate rock across terrestrial landscapes. It has been estimated that employing such strategies on a third of tropical terrestrial areas could ameliorate OA (as predicted by IPCC scenario RCP4.5) by the year 2100 (Taylor et al. 2016). Such actions are of course extreme and would induce significant economic costs, which on the other hand would be countered by reduced costs of OA itself. Distributing pulverised rock across tropical lands would of course also have potential issues of social acceptance. As another option, storage of CO_2 in plant biomass and soil would require decreased slash-and-burn practices, the preservation of wetlands, peatlands, and old-growth forest, and reforestation of e.g. marginal agricultural lands and lands subject to severe erosion. While such practice would carry in itself additional advantages of environmental restoration, it has been estimated that about 20% of anthropogenic CO_2 emission would be countered by reforestation of all globally available land (Oelkers and Cole 2008).

OA works in concert with many other environmental stressors. While OA itself is hard to harness, human activities resulting in loss of species diversity, habitat destruction, and other direct effects on nature are more easily managed. Establishment of marine protected areas (MPA) is a much used action to counter environmental degradation (see also Sect. 18.7). Knowledge on OA should be incorporated into decisions on suitable areas to protect so as to minimise effects of other stressors in habitats most vulnerable to OA. Of many prominent areas to protect two stand out as very important. Tropical coral reefs are endangered not only by OA but also by climate change, overgrowth due to eutrophication, and by attacks from the increasing population of the predatory Crown-of-Thorns starfish (*Acanthaster planci*) in the Pacific and Indian Ocean. OA combines with climate change to increase the severity of effects on coral reefs (Hoegh-Guldberg et al. 2007) and taking OA and climate change into consideration when establishing MPAs is pivotal to coral reef management. The Arctic Ocean will experience the most severe OA and the temperature increase will be highest in these regions. Due to vanishing multi-year ice, the Arctic Ocean will be assessable for fishing and shipping in the future. There is no doubt that such activities will cause increased stress to the Arctic ecosystem and establishing Arctic MPAs will be an efficient tool to manage these activities.

References

Albright R, Caldeira L, Hosfelt J, Kwiatkowski L, Maclaren JK, Mason BM, Nebuchina Y, Ninokawa A, Pongratz J, Ricke KL, Rivlin T, Schneider K, Sesboüé M, Shamberger K, Silverman J, Wolfe K, Zhu K, Caldeira K (2016) Reversal of ocean acidification enhances net coral reef calcification. Nature 531:362–365

AMAP (2013) AMAP assessment 2013: Arctic Ocean acidification. Arctic Monitoring and Assessment Programme (AMAP), Oslo

Bailey A, Thor P, Browman HI, Fields DM, Runge J, Vermont A, Bjelland R, Thompson C, Shema S, Durif CMF, Hop H (2016) Early life stages of the Arctic copepod *Calanus glacialis* are unaffected by increased seawater pCO_2. ICES J Mar Sci 74:996–1004

Beaugrand G, Brander KM, Lindley JA, Souissi S, Reid PC (2003) Plankton effect on cod recruitment in the North Sea. Nature 426:661–664

Berge JA, Bjerkeng B, Pettersen O, Schaanning MT, Øxnevad S (2006) Effects of increased sea water concentrations of CO_2 on growth of the bivalve *Mytilus edulis* L. Chemosphere 62:681–687

Browman HI (2016) Applying organized scepticism to ocean acidification research. ICES J Mar Sci 73:529–536

Brussaard CPD, Noordeloos AAM, Witte H, Collenteur MCJ, Schulz K, Ludwig A, Riebesell U (2013) Arctic microbial community dynamics influenced by elevated CO_2 levels. Biogeosciences 10:719–731

Calosi P, Rastrick SPS, Lombardi C, de Guzman HJ, Davidson L, Jahnke M, Giangrande A, Hardege JÂD, Schulze A, Spicer JI, Gambi MC (2013) Adaptation and acclimatization to ocean acidification in marine ectotherms: an in situ transplant experiment with polychaetes at a shallow CO_2 vent system. Philos Trans R Soc B Biol Sci 368:20120444

Castonguay M, Plourde S, Robert D, Runge JA, Fortier L (2008) Copepod production drives recruitment in a marine fish. Can J Fish Aquat Sci 65:1528–1531

Chierici M, Fransson A (2009) Calcium carbonate saturation in the surface water of the Arctic Ocean: undersaturation in freshwater influenced shelves. Biogeosciences 6:2421–2432

Collins M, Knutti R, Arblaster J, Dufresne J-L, Fichefet T, Friedlingstein P, Gao X, Gutowski WJ, Johns T, Krinner G, Shongwe M, Tebaldi C, Weaver AJ, Wehner M (2014) Long-term climate change: projections, commitments and irreversibility. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) The physical Science basis contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

De Wit P, Dupont S, Thor P (2016) Selection on oxidative phosphorylation and ribosomal structure as a multigenerational response to ocean acidification in the common copepod *Pseudocalanus acuspes*. Evol Appl 9:1112–1123

Dixson DL, Munday PL, Jones GP (2010) Ocean acidification disrupts the innate ability of fish to detect predator olfactory cues. Ecol Lett 13:68–75

Doney SC, Fabry VJ, Feely RA, Kleypas JA (2009) Ocean acidification: the other CO_2 problem. Annu Rev Mar Sci 1:169–192

Duffy JE, Stachowich JJ (2006) Why biodiversity is important to oceanography: potential roles of genetic, species, and trophic diversity in pelagic ecosystem processes. Mar Ecol Prog Ser 311:179–189

Dupont S, Dorey N, Thorndyke M (2010) What meta-analysis can tell us about vulnerability of marine biodiversity to ocean acidification? Estuar Coast Shelf Sci 89:182–185

Dupont S, Dorey N, Stumpp M, Melzner F, Thorndyke M (2013) Long-term and trans-life-cycle effects of exposure to ocean acidification in the green sea urchin *Strongylocentrotus droebachiensis*. Mar Biol 160:1835–1843

Dutkiewicz S, Morris JJ, Follows MJ, Scott J, Levitan O, Dyhrman ST, Berman-Frank I (2015) Impact of ocean acidification on the structure of future phytoplankton communities. Nat Clim Change 5:1002–1006

Engel A, Borchard C, Piontek J, Schulz KG, Riebesell U, Bellerby R (2013) CO_2 increases 14C primary production in an Arctic plankton community. Biogeosciences 10:1291–1308

Fabry VJ, McClintock JB, Mathis JT, Grebmeier JM (2009) Ocean acidification at high latitudes: the bellweather. Oceanography 22:160–171

Feely RA, Sabine CL, Lee K, Berelson W, Kleypas J, Fabry VJ, Millero FJ (2004) Impact of anthropogenic CO_2 on the $CaCO_3$ system in the oceans. Science 305:362–366

Ferrari MCO, McCormick MI, Munday PL, Meekan MG, Dixson DL, Lonnstedt Ö, Chivers DP (2011) Putting prey and predator into the CO_2 equation – qualitative and quantitative effects of ocean acidification on predator–prey interactions. Ecol Lett 14:1143–1148

Fitzer SC, Caldwell GS, Close AJ, Clare AS, Upstill-Goddard RC, Bentley MG (2012) Ocean acidification induces multi-generational decline in copepod naupliar production with possible conflict for reproductive resource allocation. J Exp Mar Biol Ecol 418–419:30–36

Fransson A, Chierici M, Anderson LG, Bussmann I, Kattner G, Peter Jones E, Swift JH (2001) The importance of shelf processes for the modification of chemical constituents in the waters of the Eurasian Arctic Ocean: implication for carbon fluxes. Cont Shelf Res 21:225–242

Gazeau F, Quiblier C, Jansen JM, Gattuso JP, Middelburg JJ, Heip CHR (2007) Impact of elevated CO_2 on shellfish calcification. Geophys Res Lett 34:L07603

Hendriks IE, Duarte CM, Álvarez M (2010) Vulnerability of marine biodiversity to ocean acidification: a meta-analysis. Estuar Coast Shelf Sci 86:157–164

Hildebrandt N, Sartoris FJ, Schulz KG, Riebesell U, Niehoff B (2016) Ocean acidification does not alter grazing in the calanoid copepods *Calanus finmarchicus* and *Calanus glacialis*. ICES J Mar Sci 73:927–936

Hoegh-Guldberg O, Mumby PJ, Hooten AJ, Steneck RS, Greenfield P, Gomez E, Harvell CD, Sale PF, Edwards AJ, Caldeira K, Knowlton N, Eakin CM, Iglesias-Prieto R, Muthiga N, Bradbury RH, Dubi A, Hatziolos ME (2007) Coral reefs under rapid climate change and ocean acidification. Science 318:1737–1742

Hofmann GE, Smith JE, Johnson KS, Send U, Levin LA, Micheli F, Paytan A, Price NN, Peterson B, Takeshita Y, Matson PG, Crook ED, Kroeker KJ, Gambi MC, Rivest EB, Frieder CA, Yu PC, Martz TR (2011) High-frequency dynamics of ocean pH: a multi-ecosystem comparison. PLoS One 6:11

Jokiel PL (2016) Predicting the impact of ocean acidification on coral reefs: evaluating the assumptions involved. ICES J Mar Sci 73:550–557

Khatiwala S, Tanhua T, Fletcher SM, Gerber M, Doney SC, Graven HD, Gruber N, McKinley GA, Murata A, Rios AF, Sabine CL (2013) Global ocean storage of anthropogenic carbon. Biogeosciences 10:2169–2191

de Kluijver A, Soetaert K, Czerny J, Schulz KG, Boxhammer T, Riebesell U, Middelburg JJ (2013) A 13C labelling study on carbon fluxes in Arctic plankton communities under elevated CO_2 levels. Biogeosciences 10:1425–1440

Last JM (1980) The food of twenty species of fish larvae in the west-central North Sea. Ministry of Agriculture, Fisheries and Food, Lowestoft (UK)

Leu E, Daase M, Schulz KG, Stuhr A, Riebesell U (2013) Effect of ocean acidification on the fatty acid composition of a natural plankton community. Biogeosciences 10:1143–1153

Lewis CN, Brown KA, Edwards LA, Cooper G, Findlay HS (2013) Sensitivity to ocean acidification parallels natural pCO_2 gradients experienced by Arctic copepods under winter sea ice. Proc Natl Acad Sci U S A 110:E4960–E4967

Maneja RH, Frommel AY, Browman HI, Geffen AJ, Folkvord A, Piatkowski U, Durif CMF, Bjelland R, Skiftesvik AB, Clemmesen C (2015) The swimming kinematics and foraging behavior of larval Atlantic herring (Clupea harengus L.) are unaffected by elevated pCO_2. J Exp Mar Biol Ecol 466:42–48

Melzner F, Gutowska MA, Langenbuch M, Dupont S, Lucassen M, Thorndyke MC, Bleich M, Pörtner HO (2009) Physiological basis for high CO_2 tolerance in marine ectothermic animals: pre-adaptation through lifestyle and ontogeny? Biogeosciences 6:2313–2331

Michaelidis B, Ouzounis C, Paleras A, Pörtner HO (2005) Effects of long-term moderate hypercapnia on acid–base balance and growth rate in marine mussels Mytilus galloprovincialis. Mar Ecol Prog Ser 293:109–118

Miller GM, Watson SA, Donelson JM, McCormick MI, Munday PL (2012) Parental environment mediates impacts of increased carbon dioxide on a coral reef fish. Nat Clim Change 2:858–861

Möllmann C, Kornilovs G, Fetter M, Koster FW, Hinrichsen HH (2003) The marine copepod, Pseudocalanus elongatus, as a mediator between climate variability and fisheries in the Central Baltic Sea. Fish Oceanogr 12:360–368

Munday PL, Dixson DL, Donelson JM, Jones GP, Pratchett MS, Devitsina GV, Doving KB (2009) Ocean acidification impairs olfactory discrimination and homing ability of a marine fish. Proc Natl Acad Sci U S A 106:1848–1852

Niehoff B, Schmithüsen T, Knüppel N, Daase M, Czerny J, Boxhammer T (2013) Mesozooplankton community development at elevated CO_2 concentrations: results from a mesocosm experiment in an Arctic fjord. Biogeosciences 10:1391–1406

Oelkers EH, Cole DR (2008) Carbon dioxide sequestration: a solution to a global problem. Elements 4:305–310

Orr JC, Fabry VJ, Aumont O, Bopp L, Doney SC, Feely RA, Gnanadesikan A, Gruber N, Ishida A, Joos F, Key RM, Lindsay K, Maier-Reimer E, Matear R, Monfray P, Mouchet A, Najjar RG, Plattner GK, Rodgers KB, Sabine CL, Sarmiento JL, Schlitzer R, Slater RD, Totterdell IJ, Weirig MF, Yamanaka Y, Yool A (2005a) Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature 437:681–686

Orr JC, Pantoja S, Pörtner H-O (2005b) Introduction to special section: the ocean in a high-CO_2 world. J Geophys Res Oceans 110

Parker LM, O'Connor WA, Raftos DA, Pörtner H-O, Ross PM (2015) Persistence of positive carryover effects in the oyster, *Saccostrea glomerata*, following transgenerational exposure to ocean acidification. PLoS One 10:e0132276

Pespeni MH, Sanford E, Gaylord B, Hill TM, Hosfelt JD, Jaris HK, LaVigne M, Lenz EA, Russell AD, Young MK, Palumbi SR (2013) Evolutionary change during experimental ocean acidification. Proc Natl Acad Sci U S A 110:6937–6942

Pörtner HO (2008) Ecosystem effects of ocean acidification in times of ocean warming: a physiologist's view. Mar Ecol Prog Ser 373:203–217

Pörtner H-O (2010) Oxygen- and capacity-limitation of thermal tolerance: a matrix for integrating climate-related stressor effects in marine ecosystems. J Exp Biol 213:881–893

Pörtner HO, Langenbuch M, Reipschläger A (2004) Biological impact of elevated ocean CO_2 concentrations: lessons from animal physiology and earth history. J Oceanogr 60:705–718

Raupach MR, Marland G, Ciais P, Le Quere C, Canadell JG, Klepper G, Field CB (2007) Global and regional drivers of accelerating CO_2 emissions. Proc Natl Acad Sci U S A 104:10288–10293

Reynaud S, Leclercq N, Romaine-Lioud S, Ferrier-Pagés C, Jaubert J, Gattuso J-P (2003) Interacting effects of CO_2 partial pressure and temperature on photosynthesis and calcification in a scleractinian coral. Glob Change Biol 9:1660–1668

Rhein M, Rintoul SR, Aoki S, Campos E, Chambers D, Feely RA, Gulev GC, Johnson GC, Josey SA, Kostianoy A, Mauritzen C, Roemmich D, Talley LD, Wang F (2013) Observations: ocean. In: Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) Climate change 2013: the physical science basis contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge and New York

Ricke KL, Orr JC, Schneider K, Caldeira K (2013) Risks to coral reefs from ocean carbonate chemistry changes in recent earth system model projections. Environ Res Lett 8:034003

Riebesell U, Gattuso JP, Thingstad TF, Middelburg JJ (2013) Arctic ocean acidification: pelagic ecosystem and biogeochemical responses during a mesocosm study—preface. Biogeosciences 10:5619–5626

Runge JA, Castonguay M, De LaFontaine Y, Ringuette M, Beaulieu JL (1999) Covariation in climate, zooplankton biomass and mackerel recruitment in the southern Gulf of St Lawrence. Fish Oceanogr 8:139–149

Sabine CL, Feely RA, Gruber N, Key RM, Lee K, Bullister JL et al (2004) The oceanic sink for CO_2. Science 305:367–371

Schalkhausser B, Bock C, Stemmer K, Brey T, Pörtner H-O, Lannig G (2012) Impact of ocean acidification on escape performance of the king scallop, Pecten maximus, from Norway. Mar Biol 160:1995–2006

Silverman J, Lazar B, Cao L, Caldeira K, Erez J (2009) Coral reefs may start dissolving when atmospheric CO_2 doubles. Geophys Res Lett 36

Stumpp M, Hu M, Casties I, Saborowski R, Bleich M, Melzner F, Dupont S (2013) Digestion in sea urchin larvae impaired under ocean acidification. Nat Clim Change 3:1044–1049

Sunday JM, Calosi P, Dupont S, Munday PL, Stillman JH, Reusch TBH (2014) Evolution in an acidifying ocean. Trends Ecol Evol 29:117–125

Taylor JRA, Gilleard JM, Allen MC, Deheyn DD (2015) Effects of CO_2-induced pH reduction on the exoskeleton structure and biophotonic properties of the shrimp Lysmata californica. Sci Rep 5:10608

Taylor LL, Quirk J, Thorley RMS, Kharecha PA, Hansen J, Ridgwell A, Lomas MR, Banwart SA, Beerling DJ (2016) Enhanced weathering strategies for stabilizing climate and averting ocean acidification. Nat Clim Change 6:402

Thor P, Dupont S (2015) Transgenerational effects alleviate severe fecundity loss during ocean acidification in a ubiquitous planktonic copepod. Glob Change Biol. doi:10.1111/gcb.12815

Thor P, Oliva EO (2015) Ocean acidification elicits different energetic responses in an Arctic and a boreal population of the copepod *Pseudocalanus acuspes*. Mar Biol 162:799–807

Thor P, Bailey A, Dupont S, Calosi P, Søreide JE, De Wit P, Gushelli E, Loubet-Sartrou L, Deichmann I, Candee M, Svensen C, King AL, Bellerby R (2017) Contrasting physiological response to future ocean acidification among Arctic copepod population. Global Change Biology DOI: 10.1111/gcb.13870

Walther K, Anger K, Pörtner HO (2010) Effects of ocean acidification and warming on the larval development of the spider crab Hyas araneus from different latitudes (54° vs. 79°N). Mar Ecol Prog Ser 417:159–170

Weaver AJ, Zickfeld K, Montenegro A, Eby M (2007) Long term climate implications of 2050 emission reduction targets. Geophys Res Lett 34:L19703

Whiteley NM (2011) Physiological and ecological responses of crustaceans to ocean acidification. Mar Ecol Prog Ser 430:257–271

Wittmann AC, Pörtner HO (2013) Sensitivities of extant animal taxa to ocean acidification. Nat Clim Change 3:995–1001

Wood HL, Sundell K, Almroth BC, Sköld HN, Eriksson SP (2016) Population-dependent effects of ocean acidification. Proc R Soc Lond B Biol Sci 283. doi:10.1098/rspb.2016.0163

Zeebe RE, Wolf-Gladrow DA (2001) CO_2 in seawater: equilibrium, kinetics, isotopes. Elsevier, Amsterdam

Chapter 20
Pollution with Hazardous Substances

Katja Broeg and Norbert Theobald

Abstract This chapter provides a short overview on the historical background of marine environmental pollution by hazardous substances and the measures implemented to minimize its amount and impact. In order to better understand the problems involved with contaminants in the marine environment, the basic common principles, e.g. their physico-chemical properties, persistency, behavior, and environmental impacts are described. Sources and fate of chemicals as well as their way into the environment also belong to the factors which are needed to know in order to assess the environmental risks of contaminants and protect the environment from its exposure and effects.

Examples are given for selected contaminants synthetized and used during different periods, starting in the mid of 1900 until the first decade of 2000, representing different classes of compounds: organochlorines (PCBs), organometals (TBT), and pharmaceuticals. For those examples, also information about the current status in areas of the Northeast Atlantic or the Baltic Sea is provided together with references and sources for further reading. The chapter ends with a summary on challenges and future perspectives.

Keywords Environmental pollution • Contaminants • Marine environment • Properties of chemicals • Sources • Fate • Biological effects • Monitoring and assessment • TBT • PCB • Pharmaceuticals

20.1 Introduction

Our seas and oceans constitute a final sink for many chemical compounds used and intentionally or unintentionally released into the environment. During the early phase of chemical industrialization with a limited knowledge on the effects and toxicity of

K. Broeg (✉) • N. Theobald
German Federal Maritime and Hydrographic Agency (BSH), Hamburg, Germany
e-mail: Katja.Broeg@bsh.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_20

the produced chemicals, the common opinion had been that the high amount of water would dilute any of these substances to a level where no toxic effects can be expected: “the solution to pollution is dilution” was a common concept.

These expectations turned out to be wrong. In the early 1960s, causal links between the production and use of organochlorine pesticides, dead birds and failed reproduction were established by Rachel Carson (“The silent spring” 1962).The response was political and legislative regulation of the responsible substances, starting with DDT and PCBs, and a rising awareness concerning the potential environmental risks of chemical substances in general. HELCOM and OSPAR, regional marine conventions for the protection of the seas from chemical pollution and other man-made threats were founded.

Even though regulation of these substances led to their significant reduction over time (e.g. Bignert and Helander 2015) these responses didn’t provide enough sustainable protection and precaution. Historic and present cases show that the story continues: substances like Tributyltin (TBT), per- and polyflourinated compounds (PFAS, e.g. PFOS), and brominated flame retardants (BFR), just to name a few, entered the environment decade after decade and displayed their toxic potential to marine animals and people as the end-user of fish and shellfish (HELCOM 2010). Response time between the use and release of hazardous substances, and their final regulation and ban is still long since response doesn’t start until considerable harm has occurred and scientifically proved. Still, it has not to be demonstrated in all cases that a newly synthetized compound doesn’t pose an environmental risk before it is put on the market. In fact, banned chemical compounds are often replaced by others with unknown behavior and toxicity as seen in case of PFOS and BFRs (Blum et al. 2015; EFSA 2012).

Hazardous substances have seldom been developed, produced and released into the environment in order to harm the environment on purpose. In fact, these compounds have been developed to obtain a positive effect to people, e.g. to gain energy, enhance crop production, ease technical processes, make life easier or more agreeable or to heal human or animal diseases. However, often it turned out that because of the huge amounts produced and/or because of their great persistency or toxicity, some compounds show negative effects in the environment which had not been considered before. Chemical industry constitutes a main “problem solver” in modern society. Wherever a problem arises, new industrial chemicals and pesticides are developed in order to overcome problems: repellents, smoothers, plasticizers, flame retardants, biocides, and many others. Remarkably, human and veterinary pharmaceuticals which are prescribed for health benefit are meanwhile measured in so called “effect concentrations” in the aquatic environment which means that negative health effects for fish and other marine organisms cannot be excluded (Brodin et al. 2013). Experience from the last years clearly demonstrate, that environmental behavior, persistency, and toxic effects of these substances are still not sufficiently understood before chemicals are used in products and production processes (Blum et al. 2015). Many substances from consumer products enter the aquatic environment as so-called “micropollutants” from sewage treatment plants where they are not sufficiently retained (Luo et al. 2014). It is suspected that even the implementation of the European Union Water Framework Directive (WFD) and the European regulation on Registration, Evaluation; Authorization, and Restriction of Chemicals (REACH) might fail in thoroughly safeguarding the marine environment from the impact of contaminants (for PFAS see Blum et al. 2015) (see also Gilek and Karlsson, Chap. 37). Most recently, the European Marine Strategy Framework Directive (MSFD), aimed at reaching the good environmental status (GES) of the marine environment by 2020, has been implemented. It also includes hazardous substances under its descriptor 8 with the target to reach “concentrations of contaminants that are at levels not giving rise to pollution effects”.

Beside the industrial chemicals and pesticides, heavy metals still give rise to concern in the marine environment (HELCOM 2010). Like already described above for the synthetic compounds, metals and their use have partly been regulated, e.g. mercury, cadmium, and lead. But after a phase of decrease of concentrations, some of them remain at their levels or are even increasing in recent times.

A third, likely underestimated while understudied pollutant category is anthropogenic particles. These small particles can interact with biota not only by chemical but often by physical effects. In contrast to chemicals, where quantitative environmental risk assessments follow standardized procedures, there are at present no such procedures in place to analyze environmental risks of particles like micro/nanoplastics and engineered nanoparticles (Klaine et al. 2012).

Since the above mentioned compounds are all not appearing as single pollutants in the environment but constitute various complex mixtures, there is growing scientific concern that their impact in general is underestimated as their interaction might potentiate their toxicity (see Sect. 20.3) (Altenburger et al. 2015).

Impact of hazardous substances on the marine and coastal environment shows strong regional differences. The highest impact is measured or estimated in coastal areas, close to cities, harbors, marinas, estuaries, followed by shipping lanes and hot-spot areas like offshore oil and gas platforms, and dumping grounds of warfare agents and industrial chemicals (HELCOM 2010). This chapter will provide you with information on sources, behavior, fate, and effects of examples of different types of chemical compounds. We end it with a prospective outlook to challenges and problems which still have to be addressed and solved if we aim to reach a sustainable, environmentally friendly, and healthy use of chemical substances in the future, and thereby protect the marine environment.

20.2 Sources and Common Principles of Marine Pollution

20.2.1 Sources

Because of the wide uses of the man-made (or man-used) substances and applications, their potential sources are widespread and variable. The knowledge about the sources of pollutants is essential for possible regulation and reduction measures.

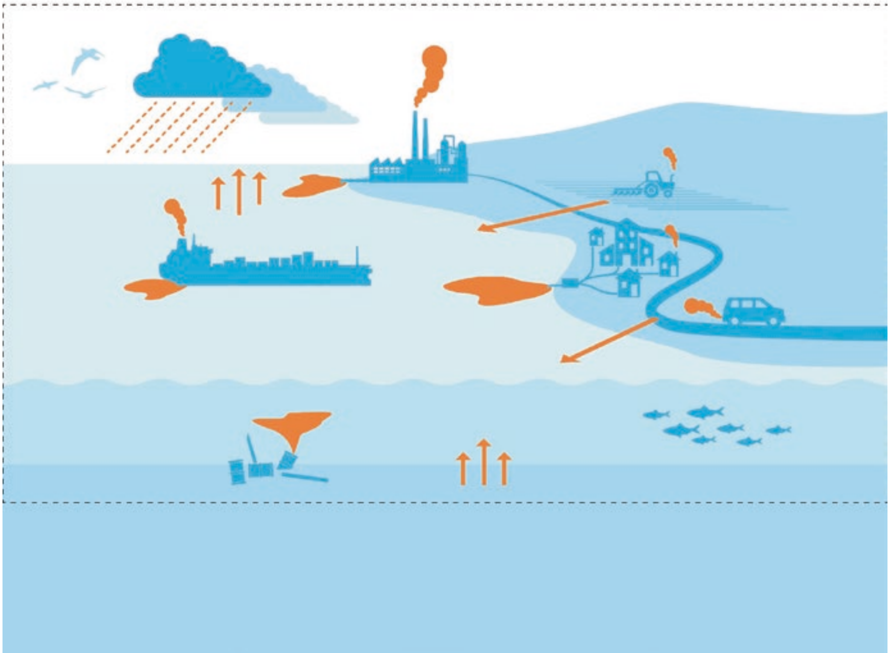


Fig. 20.1 Overview of sources of marine pollution by chemicals (source: Baltic Eye, Stockholm University)

Roughly, sources can be divided by geographic aspects into sea- and land-based sources as shown in Fig. 20.1.

The main chemical inputs from sea-based sources are coming from shipping (e.g. emissions by operation: exhaust fumes, tank washing, leaching from antifouling paints), offshore industry (oil-, gas-, ore-, sand exploration and exploitation), legacies like dumped munitions and industry waste, as well as dredging of contaminated sediments. Remarkably, even environmentally friendly techniques like offshore wind energy have to be considered for possible inputs of hazardous substances such as biocides, lubricating oils, anticorrosion paints, or sacrificial anodes.

Hazardous substances inputs from land-based sources are even more diverse and multifaceted:

Riverine inputs, inputs from point sources like industries (Schmid, Chap. 15), households, sewage treatment plants, and runoff from agriculture and traffic infrastructure, constitute the main land-based sources. Examples for substance groups released from the different sources are given in Table 20.1.

Another significant source is air-borne, via local traffic and combustion, or via atmospheric transport (see physical-chemical properties).

Table 20.1 Examples for pollutant groups from different sources

Shipping	Offshore industry	Aquaculture	Dumping	Household	Agriculture	Industry	Traffic
Antifouling	Process chemicals	Fertilizers	Industrial chemicals	Pharmaceuticals and personal care products	Fertilizers	Industrial chemicals	Waste (plastics)
Combustion gases and washwater	Combustion gases	Nutrients	Munition	Plasticizers	Pesticides	Wastewater	Combustion gases
Waste	Sacrificial anodes	Pharmaceuticals		Flame retardants	Pharmaceuticals	Combustion gases	Oil
Oil	Oil	Antifouling		Combustion gases			

20.2.2 Common Principles of Marine Pollution

Modern life in our highly industrialized and globalized world puts significant effects on the environment by removing natural resources, by changing the distribution of natural compounds, and by introducing new, man-made substances. The effects of these activities are complex and depend on a great number of both, quantitative and qualitative parameters. Qualitative, substance specific aspects which influence the behavior and impact of chemicals in the environment are e.g. their chemical stability, physical-chemical properties and their effects towards organisms (Sect. 20.3.2). Quantitative aspects are roughly dependent on the use or production amounts of the substances, their emission rates, and the proportion which enters the environment. For the evaluation of the ecological effects, the combination of both aspects have to be considered, as both influence the behavior and fate in the environment.

Chemical stability is dependent on the molecular structure of a specific compound. If the stability under environmental conditions (e.g. temperature less than 50 °C, UV-radiation by sunlight, presence of oxygen and water, pH range of 2–10) is high, there is a great potential that these compounds have a long life time and are persistent in the environment. Often the stability of compounds is characterized by their environmental half-life. Chemical reactivity can be fairly well estimated and predicted from the molecular structure of a chemical compound. A special form of degradation is the transformation of substances by biological organisms. This **biodegradation** is structure dependent as well. Often but not always the affinity to chemical and biological degradability are similar. Figure 20.2 presents a very general overview on the influence of the structure of organic substances on their chemical behavior: At the right side, the most simple substances containing only carbon and hydrogen atoms (hydrocarbons) are chemically fairly stable compounds and thus quite persistent in the environment. However, they can be biodegraded by specialized bacteria. Examples for these hydrocarbons are the major constituents of

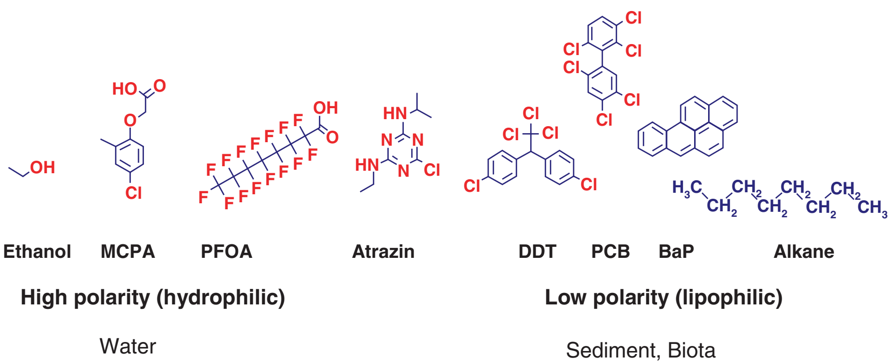


Fig. 20.2 Examples of chemicals of environmental concern demonstrating the wide range of chemical structures and their chemical and physical-chemical properties. The compounds are ordered by their polarity (*right side*: non polar, left side polar compounds). The chemical reactivity (degradation potential) increases from right to left

mineral oil. Even more stable are hydrocarbons with a ring structure like polycyclic aromatic hydrocarbons (PAHs) which are an important pollutant-class found ubiquitously in the environment. Replacing all hydrocarbons by halogen atoms (fluorine, chlorine, or bromine), leads to molecules with increased stability as well, because the C-halogen bonds are very strong and need high energy for degradation. Chlorinated hydrocarbons (CHC) like polychlorinated biphenyls (PCBs), polybrominated biphenyl ethers (PBDEs, used as flame retardants) and polyfluorinated chemicals (PFAS, used as surface protection agents) are examples for pollutants being presently of environmental concern. Replacing hydrogen atoms by other functional groups like $-OH$, $-COOH$, $-SO_3H$, $-NH_2$, $-NO_2$ generally leads to substances which are more reactive and often more easily transformed and degraded. Many of the new chemicals of emerging concern (CECs) belong to these compounds (left part of Fig. 20.2). Metals cannot be degraded and are thus in principle persistent, however they can be transformed by speciation into different oxidation states, can be changed by complexation, or eliminated by sedimentation of insoluble forms. By this, their bioavailability and toxicity can be changed and thus, their environmental impact.

Physical-chemical properties determine the behavior of a substance in the environment. The most important parameters are the volatility and polarity of a substance.

The volatility determines how easy a compound can be eliminated from the liquid phase (rivers, oceans) or from the solid phase (soil). Being in the atmosphere, pollutants can be transported much faster and thus be distributed away from their primary sources and spread regionally and even globally (atmospheric transport). By this, even semi-volatile compounds like PCBs and PAHs (with boiling points above 300 °C) have been globally distributed and already found in the Arctic food chain in 1975 (Bowes and Jonkel 1975). In part, these pollutants are not transported in the gaseous state but attached to aerosols.

Polarity strongly influences the distribution of a substance in the water phase: Polar compounds (high polarity) show good water solubility (hydrophilic) and do not show a tendency to adsorb on solid particles. Thus, they can be easily transported over large distances by river or ocean currents. On the other side, non-polar compounds are only sparely soluble in water (hydrophobic or lipophilic) and show a high affinity to solid surfaces like suspended matter in the water, or sediments. By this affinity to solid particles, they are easily sedimented and thus, less mobile in the water phase. Concentration gradients often are much steeper than for water soluble compounds and riverine loads are reduced by more than 90% within the estuary by sedimentation. Lipophilic substances are also adsorbed to biological surfaces, taken-up by organisms, and can be accumulating in biologicals tissues. Thus, non-polar substances and their lipophilic property can lead to bioaccumulation (accumulation of a substance in various tissues of an organism) and, if they are stable, even biomagnification (process by which the concentration of a substance increases in each successive link in the food chain).

A frequently used parameter for quantifying the polarity of a substance is its partition coefficient between octanol (a lipophilic liquid) and water, expressed as a logarithmic value: log K_{OW}. Values of <4 mean relatively polar properties. These substances are found preferably in the water phase, whereas in sediments and biota, accumulation and concentrations are low. Substances with log K_{OW} values of >5 are lipophilic. They show higher concentrations in sediments and have a high potential for bioaccumulation. With very high log K_{OW} values (>7) bioaccumulation often decreases again, because these compounds are less easily transported through biomembranes (e.g. deca-PBDE) and therefore have a lower bioavailability.

Like chemical reactivity, the physical-chemical properties are dependent on the molecular structure of a specific compound. At present, volatility and polarity can be fairly well estimated and predicted from the molecular structure. In Fig. 20.2, the substances are arranged according to their polarity: at the right side, the most lipophilic (non-polar) compounds are found and at the left side the most polar (hydrophilic) ones.

Models and programmes checking the structural similarity of substances regarding their biological activity and mode of action are applied in order to predict the potential impact of new substances, e.g. QSAR (Quantitative structure–activity relationship).

20.3 Environmental Impact

20.3.1 Environmental Risk Assessment

One important parameter for estimating the potential impact of hazardous substances and conduct an environmental risk assessment is the amount that enters the environment, the so-called "predicted exposure concentration" (PEC). Because a direct measurement of concentration is not feasible in most cases, this value is often predicted on the basis of models. One example is the MAMPEC model for the prediction of the release of TBT from antifouling paints. The exposure determines the relevant concentrations in the different matrices which are then set into relation to ecotoxicological criteria and results from ecotoxicological laboratory studies and bioassays which determine the "predicted no effect concentration" (PNEC).

Anthropogenic substances can differ very much in their life cycles and these determine to which extend, how fast and under which conditions they enter the environment. The following examples demonstrate the wide range of possible scenarios:

Mineral oil, consisting of higher alkanes from mineral sources, is a product which is used in the largest amounts of man used goods. Its toxicity is moderate. In principle, no oil should enter the environment, as it is completely used. However, due accidental losses (during production, transport, or use) or non-optimal processing, a certain amount of the oil used in fact enters the environment. Because of the huge amount of oil used, even a small fraction of it is a large amount and can become an environmental problem. Therefore, because of the huge amounts of handlings, not because of its high intrinsic toxicity, oil has become a material of environmental concern.

Polychlorinated dibenzodioxines (PCDDs) can be considered as an example for the other extreme: These compounds exhibit an extremely high toxicity but have never been produced on purpose and have no commercial use. They are generated as by-products in certain technical processes in minute amounts. But because of their extremely high toxicity (together with their persistency and bioaccumulation potential), they are of high environmental concern. Dioxins got worldwide attention due to an industrial accident, the Seveso disaster in 1976, when it had been released into the environment. Within days more than 3300 animals, mostly poultry and rabbits, were found dead. People living in the vicinity of the plant suffered from skin inflammation and chloracne as immediate acute effects. A follow-up study in 2009 found an increase in lymphatic and hematopoietic tissue neoplasms and increased breast cancer rates (Pesatori et al. 2009).

Pesticides may act as an example for medium production amounts and definite toxic effects. These substances are deliberately emitted into the environment on local scales to prevent pests by plants and vermin in agriculture and gardening. At least when they leave their application range (e.g. by run-off or overdosage) and dedicated time period, they become substances at the wrong place or concentration and thus, to contaminants or pollutants.

Various factors influence the environmental impact of a substance. The more of them are critical, the larger the environmental concern becomes. For example: Compounds with a high chemical stability (persistency), showing in their physical-chemical properties a high lipophilicity with a high bioaccumulative potential and exhibit a high toxicity are called PBT (persistent, bioaccumulative and toxic) compounds and are regarded as highly hazardous pollutants and have become subject of international regulation, e.g. Stockholm Convention (Gilek and Karlsson, Chap. 37).

Other groups of special concern are substances of very high production volume (HPV) though with less high toxicity, and compounds with high impact on sensitive physiological processes e.g. hormone regulation (endocrine disrupters) or cell division/ DNA damage (carcinogenic compounds).

20.3.2 Biological Effects

The term “biological effects of contaminants” means the impact of substances, and their mixtures on physiology, fitness, reproduction, and health of marine organisms. Under environmental conditions, chemical substances always occur in combination, as mixtures, whereas risk assessments, chemical regulation, and chemical analysis are mainly performed at single substance level.

Thus, in order to obtain more comprehensive information about the actual status concerning the realistic impact of the respective pollution situation on marine organisms, the so-called biomarkers were developed. These tests are conducted on sentinels/indicator organisms like specific mussel and fish species, caught at study field sites in coastal and open sea areas. This is often done in parallel to the analysis of chemical burden in the same organisms, sediment and/or water within the framework of marine monitoring programmes for example of the regional conventions for the protection of the seas (e.g. Helsinki Commission: HELCOM (Baltic Sea), Oslo-Paris convention: OSPAR (North-East Atlantic); Barcelona Convention (Mediterranean Sea)). In fact, the combination of chemical and biological monitoring is a major step towards an early detection of potential risks posed by various pollution types, e.g. point-sources, chronic pollution situation, and pollution events (Viarengo et al. 2007; Wernersson et al. 2015; HELCOM 2010).

Various biomarkers are currently standardized and partly taken up into common regional monitoring programmes:

Biomarkers for general acute or chronic toxic effects (general toxicity): These biomarkers integrate effects of different contaminants by responding to various contaminant classes. They can be applied at different levels of biological organization. Examples are e.g. (1) at the cellular level such as lysosomal membrane stability; (2) at the individual level: fitness, growth, health; (3) at the population level: reproductive disorders.

In addition, there are biomarkers available for testing the level of e.g. mutagenicity, carcinogenicity, immunotoxicity, and endocrine disruption.

Some compounds cause very specific biological effects in sentinel organisms. These can be used to identify the presence and even concentration of a specific compound (e.g. imposex caused by TBT, see Fig. 20.4b). More detailed information concerning biomarkers, biotests, and bioassays and their potential use in environmental monitoring is summarized by Wernersson et al. (2015).

20.4 Examples for the Current Status of Contaminants

The status of marine environmental pollution by chemical substances is subject to numerous environmental monitoring programmes world-wide. Examples are the HELCOM Cooperative Monitoring in the Baltic Marine Environment (COMBINE), the OSPAR Coordinated Environmental Monitoring Programme (CEMP), and the US National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program (NS&T). In most cases, assessments of the environmental status are conducted within 6-years periods (e.g. HELCOM Holistic Assessment (HOLAS 2010, 2017), OSPAR Quality Status Report). Major objectives concerning hazardous substances are to describe and evaluate the spatial distribution of contaminants and to investigate temporal changes of the burdens. Here we provide some examples from the North-East Atlantic and Baltic Sea for substances which are of environmental concern due to their demonstrated potential to have substantial impact on marine organisms.

The temporal courses of environmental concentrations differ between the various chemicals and are dependent on their start of production, amount, use, and spread in the environment. Figure 20.3 shows an example of a sediment core which had been analyzed for the concentration of selected environmental pollutants. It can

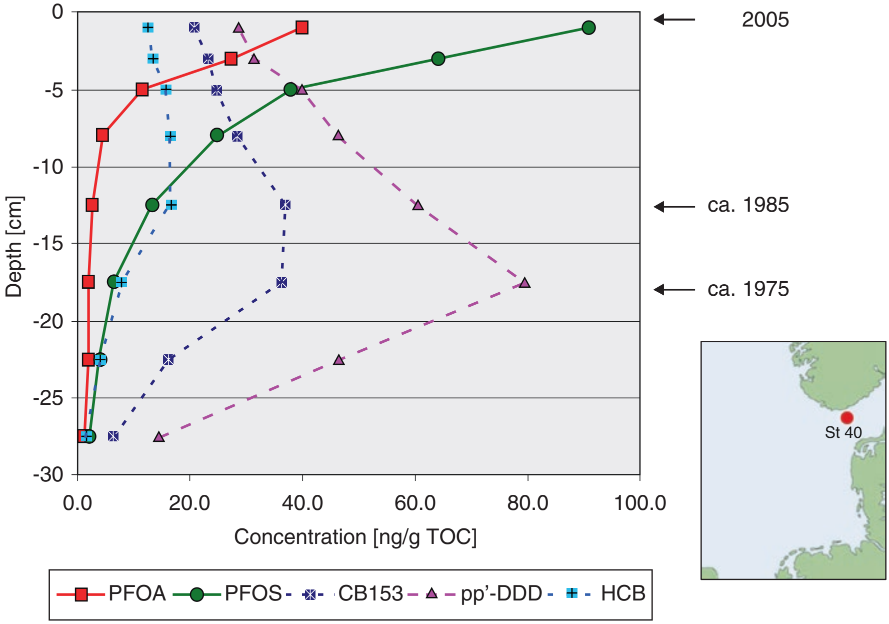


Fig. 20.3 Sediment concentrations (ng/g TOC) of selected contaminants in a sediment core from the Skagerrak (57°48N, 8°00E, Aug. 2005, water depth 700 m)

be seen from the graph, in which time periods the concentrations started to increase for new, emerging compounds like PFOA and PFOS. In case of the regulated contaminants DDD, PCB153, and HCB, concentrations decreased after regulation.

In the following section, developments for three important contaminant classes and groups: TBT, PCBs, and pharmaceuticals, are presented in more detail.

20.4.1 Tributyltin (TBT)

Organotin compounds have been used as efficient and cost-effective antifouling component from the 1960s on, starting in the USA. Antifouling means protecting ship hulls and underwater constructions from biofouling, the unwanted attachment and coverage with marine organisms. The most effective organotin compound proved to be based on tributyltin (TBT).

Relatively soon after the start of using TBT in antifouling paints and thus, deliberately releasing it to the marine environment by contact leaching, first indications of its negative environmental impacts emerged. In response, Canada recommended that TBT should not be used near shellfish farms already in the late 1960s.

From the 1970s on, indications for links between TBT and adverse effects on non-target organisms increased. Larval disorders and imposex (superimposition of male features in females), a condition where female snails developed penises and became sterile, were reported.

By the time that TBT antifouling paints were readily available in the US, Canada, and EU, it was apparent that there were associated problems. Despite this, the efficiency of TBT antifoulings and their wide applicability resulted in prevalent use worldwide.

Even though more and more studies continued to show that even at extremely low organotin concentrations, impact on non-target species occur, restrictions and regulation were not put in place until it was confirmed that commercial shellfish stocks were being affected. The commercial oyster (*Crassostrea gigas*) industry in Arcachon Bay, France, declined at the same time as growers of *C. gigas* along the east coast of England reported abnormal shell forms in the late 1980s. After several national and regional regulations, the IMO adopted the AFS Convention in 2001, which entered into force in 2008. No application of TBT should be performed on ships.

TBT is one example for a substance with extreme endocrine-disrupting potential and has been one starting point for the broad discussion on the use and regulation of endocrine disruptors.

Even though concentrations of TBT declined considerably following to regulation, there are still effect-concentrations measured in harbors in marinas due to release from old paint layers, sediments are still contaminated (HELCOM 2010). Figure 20.4a gives an example for the development of TBT concentrations and

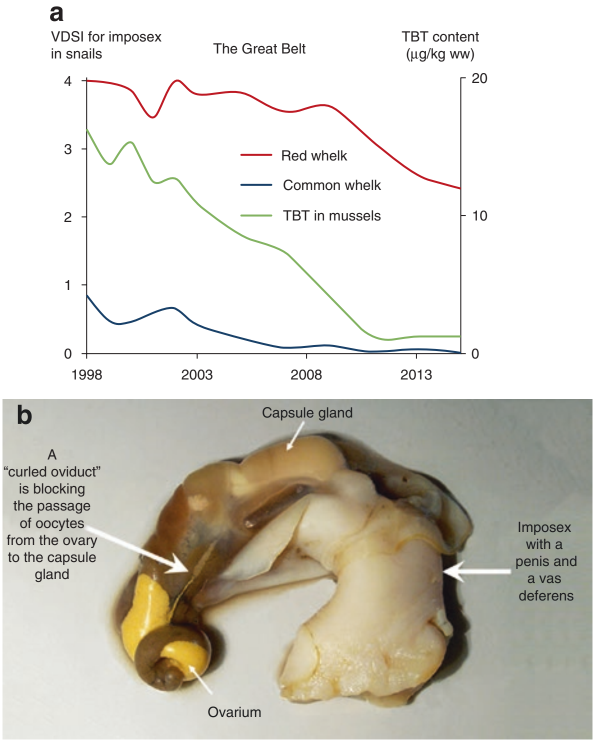


Fig. 20.4 (**a**) Development of imposex levels (expressed as Vas Deference Sequence Index, VDSI with maximum level of 4) in the marine snails red whelk (*Neptunea antiqua*) and common whelk (*Buccinum undatum*) compared to TBT levels measured in blue mussels in the Danish Great belt. Data comes from National monitoring data in the NOVA program in Denmark (provided by Jakob Strand, Aarhus University, Denmark). (**b**) Severe TBT effects lead to imposex and can cause sterile females in snails due to blockage of the oviduct. About 10% of red whelk females in the Great Belt had developed a "curled oviduct" in 2005 (Jakob Strand, Aarhus University, Denmark)

imposex conditions for stations in the Danish Belt Sea. Instead of measuring the TBT concentration, imposex can also be measured as indicator for exposure to TBT (see Sect. 20.3.2). Figure 20.4b shows an example for the highest level of imposex (Vas Deference Sequence Index VDSI 4) in a Red Welk.

20.4.2 Polychlorinated Biphenyls (PCBs)

PCBs are a substance group constituted by 209 possible congeners which are differing by the quantity and the position of chlorine atoms in the biphenyl structure.

PCBs were first synthetized in 1881. They entered the US market in 1929. Due to their very stable, chemically inert characteristics, they show low inflammability, resist heat and degradation, and are electrical insulting. These properties formed the basis for their widespread application as e.g. insulating fluids in transformers, hydraulic fluids, heat transfer fluids, but also as additives in pesticides, paints, inks, copy paper, plastics, and many more.

In the environment, PCBs were first discovered in the late 1960s. After increasing awareness of their hazardous effects on environment and people, a ban of the commercial production of PCBs was implemented in North America in 1977.

As two-third of the total amount of produced PCB (1.8 million tons estimated) is used in completely enclosed systems. It is estimated that only 30% of it has been released so far. The remaining part is most probably still in use until the serviceable lives of the machines and facilities end.

Environmental effects caused by PCBs are numerous. In marine mammals, population effects, immunosuppression, developmental disorders and abnormalities, carcinogenicity, endocrine disruption, skin disorders, tumors and lipid degeneration are reported in the scientific literature (Dedrick et al. 2012).

PCBs fall under the term “POPs”, persistent organic pollutants, a group of synthetic organic chemicals that share similar properties, are highly toxic, and are able to directly and indirectly affect the health of animals and humans. Once they are released to the environment, they will stay there for an unpredictable time period and display their toxic potential. Even though, the “dirty dozen” POPs are regulated by the Stockholm Convention (see Gilek and Karlsson, Chap. 37), PCBs are still measured in the marine environment. Due to their persistency, marine sediments are still acting as a “reservoir”, releasing PCBs, and making them available for organisms. Re-suspending occurs e.g. due to dredging activities and riverbed deepening (Sturve et al. 2005; Broeg et al. 2002), but also due to high prevalence of burrowing invertebrates. Increased re-suspending of PCBs caused by bioturbation of the non-indigenous species *Marenzelleria* and the prevalent amphipod *Monoporeia* has been shown in experiments (Hedman et al. 2009; Granberg et al. 2008).

The lipophilic PCBs biomagnify in the food web and are therefore still found in fatty fish and top predators (Fig. 20.5) but the concentrations decreased significantly during the last decades, accompanied by a significant improvement of the reproduc-

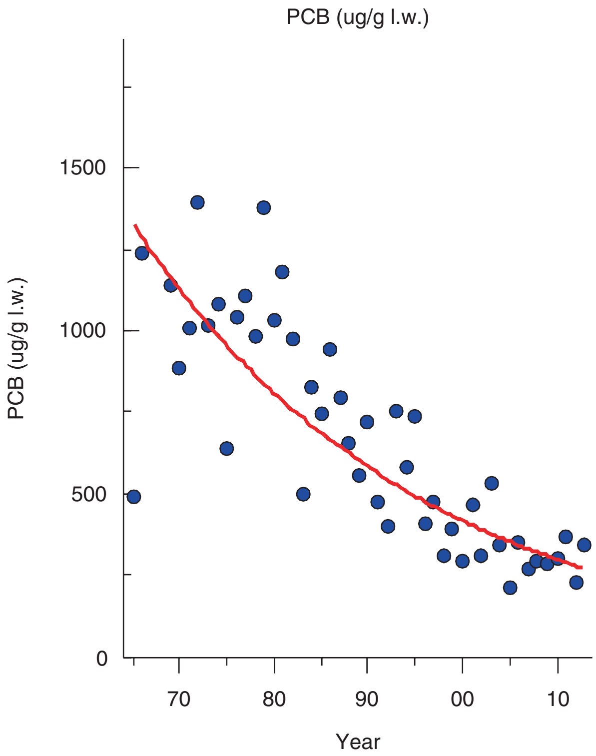


Fig. 20.5 Temporal changes in concentrations of PCB in eggs of the white-tailed sea eagles of the Swedish Baltic Sea coast, 1965–2013 (Bignert and Helander 2015)

tive success of the white-tailed sea eagle for example (Bignert and Helander 2015). Accordingly, water concentration is not a primary indicator for the levels of PCBs in the marine environments—highest concentrations are found in sediments and organisms. Due to the fact that PCBs are semi-volatile compounds, they have reached all areas in the world, even the most remote ones. Especially the Polar Regions are at risk as atmospheric transport of PCBs often ends there by condensation of the compound (global distillation).

20.4.3 Pharmaceuticals and Personal Care Products (PPCP)

Pharmaceuticals and personal care products are compounds with a great variety of molecular structures which makes their analysis quite complex. The fact that pharmaceuticals which are essential for human and farm animal welfare might pose a risk for the marine environment has been addressed only recently. Pharmaceuticals reach the environment by effluents from households and hospitals, run-off from fields as well as from wastewater treatment plans which in most cases are not able to successfully retain them (Köster, Chap. 16).

One of the most persistent pharmaceuticals known in the aquatic environment is carbamazepine, an antiepileptic drug. Its extreme persistency results in ever increasing concentrations in the coastal and marine environment. Figure 20.6 shows the concentration of selected pharmaceuticals in the German Bight in 2007. Remarkably, the observed concentrations are often well above those of “classical” contaminants such as HCH, DDT, PCB or PAK. Moreover they are in a concentration range observed for e.g. herbicides.

There are numerous scientific publications on biological effects of pharmaceuticals which e.g. report about behavioral changes in invertebrates and fish (e.g. Brodin et al. 2013; Guler and Ford 2010). Small crustaceans which hide under stones to avoid being eaten by predators start swimming into the light after exposure to antidepressants (Guler and Ford 2010). Other substances found in considerable concentrations already in the environment are pain killers (diclofenac) and hormones (estradiol), just to name a few.

The discussion started whether to include some of them into the routine monitoring programmes and into the list of priority substances under the EU Water Framework Directive (WFD). A special analytical challenge arises by the great number of different classes of compounds which have to be monitored. For taking measures, there is a certain dilemma as for pharmaceuticals, regulation of use and production is—because of ethical reasons—not a primary measure to stop environmental exposure.

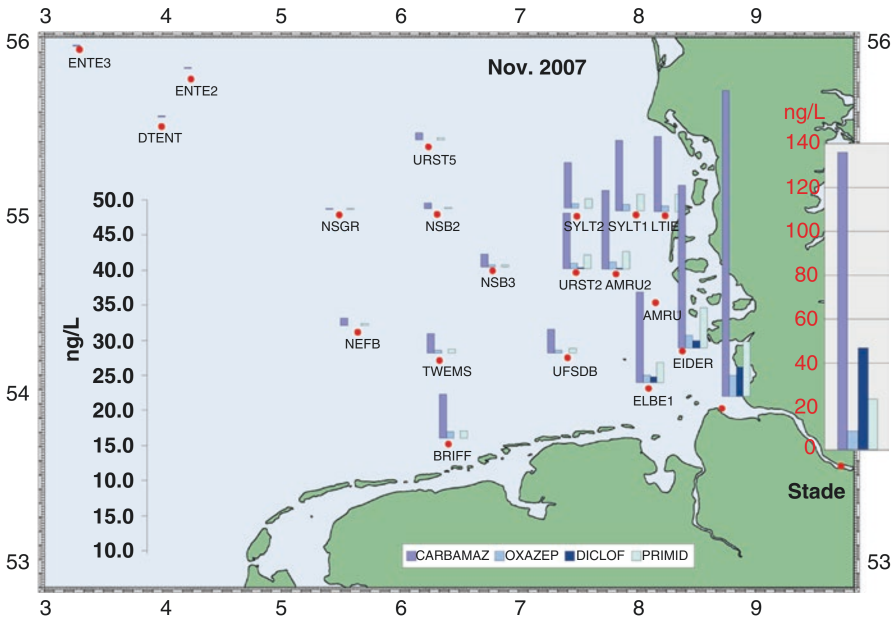


Fig. 20.6 Spatial distribution of the selected pharmaceuticals, carbamazepine, oxazepam, diclofenac, primidone (ng/L) in the surface water (5 m) of the German Bight in November 2007

20.5 Challenges and Future Perspectives

Substances with high persistency, toxicity, and the potential to bioaccumulate and biomagnify (PBT, vPvB) constitute a high environmental risk. Many substances with known PBT characteristics are subject to regulation and environmental monitoring (WFD, MSFD, REACH, Stockholm convention, national regulation, etc.; Gilek and Karlsson, Chap. 37). The problem is that properties and environmental behavior of a high number of chemicals of emerging concern (CECs) are unknown even though these substances are already in use. Another problem is posed by substances which do not necessarily have PBT properties but act hormone disruptive in low concentrations (EDCs), especially on sensitive live stages. Here it is nearly impossible to recapitulate the causative substance since concentrations are low and effects are often seen with a long time delay.

Hazardous substances and pollutants appear as cocktails in the environment. In addition, they may interact with each other and provoke mixture toxicity. Contaminants bind to particles, and particles release contaminants. Within all seas, strong regional differences are observed which have to be considered when solutions and measures for hazardous substances-related problems are elaborated. The combination of chemical and biological monitoring could be one step forward to get early information about potential pollution. As soon as toxic responses at lower organizational level (e.g. cellular responses, health, etc.) are detected in the environment, detailed chemical analyses can help to identify the causal agents, and mitigation measures can be initiated.

Nevertheless, there are also general aspects which have to be addressed:

These are e.g. the implementation of the precautionary principle and a considerable shortening of the political response time to contaminants of high environmental risk. In its report on "*Late lessons from early warnings: the precautionary principle*" the European Environment Agency (EEA 2001) presented e.g. the history of environmental hazards together with the question whether taking action early enough would have prevented harm. Lessons for better decision-making were drawn from cases where clear evidence of hazards to the environment had been ignored.

Due to the fact that the lessons from the 2001 report still remained highly pertinent, a second report has been published in 2013 (EEA 2013). The aim was to consider both kinds of examples, long-known issues with broad societal implications such as lead in petrol, mercury, environmental tobacco smoke and DDT, and issues which have emerged more recently such as the effects of the contraceptive pill on feminisation of fish and the impacts of insecticides on honeybees. The main lesson, people can learn from the reports is that the process of learning must continue to improve the protection of the marine environment from the impact of hazardous substances.

References

Altenburger R, Ait-Aissa S, Antczak P, Backhaus T, Barceló D, Seiler T-B, Brion F, Busch W, Chipman K, López de Alda M, De Aragão Umbuzeiro G, Escher BI, Falciani F, Faust M, Focks A, Hilscherova K, Hollender J, Hollert H, Jäger F, Jahnke A, Kortenkamp A, Krauss M, Lemkine GF, Munthe J, Neumann S, Schymanski EL, Scrimshaw M, Segner H, Slobodnik J, Smedes F, Kughathas S, Teodorovic I, Tindall AJ, Tollefsen KE, Walz K-H, Williams TD, van den Brink PJ, van Gils J, Vrana B, Zhang X, Brack W (2015) Future water quality monitoring—adapting tools to deal with mixtures of pollutants in water resource management. Sci Total Environ 512–513:540–551

Bignert A, Helander BO (2015) Monitoring of contaminants and their effects on the common Guillemot and the White-tailed sea eagle. J Ornithol 156(1):173–185

Blum A, Balan SA, Scheringer M, Trier X, Goldenman G, Cousins IT, Diamond M, Fletcher T, Higgins C, Lindeman AE, Peaslee G, de Voogt P, Wang Z, Weber R (2015) The Madrid statement on poly- and perfluoroalkyl substances (PFASs). Environ Health Perspect 123:A107–A111

Bowes GW, Jonkel CJ (1975) Presence and distribution of polychlorinated biphenyls (PCB) in arctic and subarctic marine food chains. J Fish Board Can 32(11):2111–2123

Brodin T, Fick J, Jonsson M, Klaminder J (2013) Dilute concentrations of a psychiatric drug alter behavior of fish from natural populations. Science 339(6121):814–815

Broeg K, Köhler A, Westernhagen HV (2002) Disorder and recovery of environmental health monitored by means of lysosomal stability in liver of European flounder (*Platichthys flesus* L.) Mar Environ Res 54(3):569–573

Carson R (1962) Silent Spring. Houghton Mifflin Company

Dedrick RL, Hansen LG, Hayes MA, Lutz RJ, Mullin M, Parkinson A, Sipes IG (2012) In: Safe S (ed) Polychlorinated biphenyls (PCBs): mammalian and environmental toxicology, vol 1. Springer Science & Business Media, Berlin, Heidelberg

EFSA Panel on Contaminants in the Food Chain (CONTAM) (2012) Scientific opinion on emerging and novel Brominated Flame Retardants (BFRs) in food. EFSA J 10(10):2908. 133p

European Environment Agency (2001) In: Harremoës P (ed) Late lessons from early warnings: the precautionary principle 1896–2000. Office for Official Publications of the European Communities, Luxembourg

European Environment Agency (2013) Late lessons from early warnings: science, precaution, innovation, EEA report, 1/2013

Granberg ME, Gunnarsson JS, Hedman JE, Rosenberg R, Jonsson P (2008) Bioturbation-driven release of organic contaminants from Baltic Sea sediments mediated by the invading polychaete *Marenzelleria neglecta*. Environ Sci Technol 42(4):1058–1065

Guler Y, Ford AT (2010) Anti-depressants make amphipods see the light. Aquat Toxicol 99(3):397–404

Hedman JE, Tocca JS, Gunnarsson JS (2009) Remobilization of polychlorinated biphenyl from Baltic Sea sediment: comparing the roles of bioturbation and physical resuspension. Environ Toxicol Chem 28(11):2241–2249

HELCOM (2010) Hazardous substances in the Baltic Sea – an integrated thematic assessment of hazardous substances in the Baltic Sea Balt Sea Environ Proc. No. 120B

HELCOM (2017) HOLAS II, HELCOM Second Holistic Assessment of THE Ecosystem Health of the Baltic Sea (2014–2018). http://www.helcom.fi/helcom-at-work/projects/holas-ii

Klaine SJ, Koelmans AA, Horne N, Carley S, Handy RD, Kapustka L, Nowack B, von der Kammer F (2012) Paradigms to assess the environmental impact of manufactured nanomaterials. Environ Toxicol Chem 31:3–14

Luo Y, Guo W, Ngo HH, Nghiem LD, Hai FI, Zhang J, Wang XC (2014) A review on the occurrence of micropollutants in the aquatic environment and their fate and removal during wastewater treatment. Sci Total Environ 473:619–641

Pesatori A, Consonni D, Rubagotti M, Grillo P, Bertazzi P (2009) Cancer incidence in the population exposed to dioxin after the "Seveso accident": twenty years of follow-up. Environ Health 8(1):39. http://ehjournal.biomedcentral.com/articles/10.1186/1476-069X-8-39

Sturve J, Berglund Å, Balk L, Broeg K, Böhmert B, Massey S, Förlin L (2005) Effects of dredging in Göteborg Harbor, Sweden, assessed by biomarkers in eelpout (*Zoarces viviparus*). Environ Toxicol Chem 24(8):1951–1961

Viarengo A, Lowe D, Bolognesi C, Fabbri E, Koehler A (2007) The use of biomarkers in biomonitoring: a 2-tier approach assessing the level of pollutant-induced stress syndrome in sentinel organisms. Comp Biochem Physiol C Toxicol Pharmacol 146(3):281–300

Wernersson AS, Carere M, Maggi C, Tusil P, Soldan P, James A et al (2015) The European technical report on aquatic effect-based monitoring tools under the water framework directive. Environ Sci Eur 27(1):1–11

Chapter 21
Pollution with Radioactive Substances

Hartmut Nies

Abstract Our world is radioactive since the beginning of the universe. Life has learned to resist against highly energetic radiation from natural sources originating from so-called primordial and cosmogenic radionuclides, but in addition the presence of natural radioactivity, man has introduced artificial radionuclides into the environment by various nuclear technical activities, e.g. nuclear weapon tests, by radioactive wastes, controlled releases from nuclear facilities, and accidental releases of huge amounts of radioactive substances. The marine environment is one of the major recipients of these radionuclides, but oceans have the property of dispersion and dilution by ocean currents into the giant water masses. However, we learned in the meantime that the ocean capacity and resilience against pollutants is not unlimited. The following chapter will enlighten some basic knowledge about radioactivity in the environment and processes of the adverse effect of radioactivity in the oceans.

Keywords Radioactive substances • Isotopes • Radionuclides • Radiation exposure • Contamination limits • Radioecology • Marine environment • Nuclear accidents • Nuclear releases

21.1 Introduction to Marine Radioactivity

Radioactivity is very often used as the term to describe the presence of radioactive isotopes or radionuclides. However, the term *radioactivity* describes a property of instable isotopes of an element, which disintegrates at a certain rate into another isotope of a different element or emits energy (gamma-emission) from the nucleus of an element into a lower energy level (excitation) of the same element. This decay

H. Nies
Former at Bundesamt für Seeschifffahrt und Hydrographie (BSH), Hamburg, Germany

International Atomic Energy Agency (IAEA), Monaco, Monaco
e-mail: hartmut.nies@gmx.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_21

is at the same time accompanied by the emission of high energetic radiation from the nucleus of an atom. This radiation is also called *ionizing radiation* and has the potential to break molecular bonds e.g. in a biological cell, which can be a serious deleterious effect to living organisms. However, it must be mentioned that life on earth has learned to live with these deleterious impacts on cells and developed repair mechanisms as soon as the impact dose does not exceed a limit. Radioactive substances and thus radiation have been present on earth since the creation of the universe. In addition to the radiation from radioactive substances we receive high energetic rays from cosmic radiation, whereby the dose depends on the altitude of a person. E.g. flying airline staff or astronauts are a group of occupationally radiation exposed workers and their radiation dose needs to be monitored. Cosmic radiation is significantly higher in high mountains than at sea level due to the protecting shielding effect of the atmosphere. The following chapter will very briefly introduce some of the frequently used terms.

21.2 Elements, Atoms, Isotopes and Nuclides

An atom consists of a central nucleus of positively charged protons (p) and neutrons (n), surrounded by negatively charged electrons. The mass of an atom is almost totally concentrated in the nucleus. The atom is electrically neutral, if the number of negatively charged electrons is equal to the number of positively charged protons in the nucleus. A surplus or a deficit of electrons relatively to the number of protons will produce a charged ionized atom, called anion or cation, respectively.

The number of proton plus neutrons in the nucleus is referred to as the mass number (A) of an isotope. The number of protons (Z) determines the element and the charge of the nucleus, which is referred to as the atomic number. The neutron number (N) in a nucleus is defined as A minus Z. Isotopes of a particular element are defined as containing the same number of protons (= element), but may have different numbers of neutrons. Thus, isotopes of a certain element have different numbers of neutrons, but the same number of protons. Isotopes have almost identical chemical properties.

There exist 81 stable elements in our universe which consists at least of one isotope, which does not disintegrate. All elements above $Z = 83$ (bismuth), and also the elements $Z = 43$ (technetium) and $Z = 61$ (promethium) are instable or radioactive. They decay to elements or isotopes with fewer protons over time. Decay is accompanied with the emission of energy from the nucleus. We know stable elements, which have only one type of isotope, but there exist many elements, which have different numbers of neutrons. If we consider only the nucleus of an element, we call this also nuclide or in the case of an unstable isotope *radionuclide*. The neutrons "glue" the protons together and stabilise the nucleus. However, when the ratios of neutrons to protons are outside a particular ratio, which varies with each element, the nucleus becomes unstable and spontaneously emits particles and/or electromagnetic radiation. This phenomenon, which characterizes radionuclides, is called *radioactive decay*. This is a statistical process in which the decay rate is proportional to the number of radioactive nuclei of a particular type present at any time *t* and is usually accompanied by the emission of charged particles and/or gamma rays. The decay rate over time or *half-live* is characteristic for each radionuclide and cannot be influenced by physical measures.

21.3 Types of Radioactive Decay

There exist three main types of radiation or emitted particles: alpha (α), beta (β), and gamma (γ) decay. Alpha particles consist of two protons and two neutrons (Z = 2 and A = 4) or a helium ion. This decay will produce an element Z minus 2 or A minus 4. Beta decay processes (β^-) emit a high energetic electron from the atom nucleus and change the number of protons by plus one unit (Z + 1), but will not change the mass of the isotopes. Another beta-decay (β^+ or electron capture) will produce the element Z – 1. Very often the emission of an alpha- or beta-particle may leave the new isotope either in its ground state or more frequently in an excited state, which will lead to the emission of a high energetic electromagnetic wave called gamma-quant and the return to the energetic ground state or a state with lower excitation. This process is called gamma radiation with energies typically from several keV[1] to several MeV. Most gamma rays are significantly higher in energy than X-rays and are, therefore, very penetrating. Gamma radiation can only be shielded by dense materials like concrete or lead depending on their energies.

21.4 Law of Radioactivity

The following part will only provide a brief introduction into the mathematic usage of calculation of activities over time. More detailed introduction should be gained from text books about radioactivity and radiation protection.

The probability of the decay of a large number (N) of particular instable atoms is controlled by the decay constant (λ). The activity of these radioactive atoms, which is the total number of disintegrations per unit time, will be λN. The rate of depletion (dN/dt) is equal to the activity (A) as long as there is no new supply of radioactive atoms. N decreases with increasing time. The decay process is given by the following Equation:

$$dN/dt = -\lambda N = -A \tag{1}$$

[1] eV: Electron-Volt is the amount of energy gained (or lost) by the charge of a single electron moving across an electric potential difference of 1 V. This unit is mostly used in nuclear physical processes. It can be converted into the SI-system by 1 eV = 1.6×10^{-19} J. It is common to use 1 keV = 1000 eV or 1 MeV = 10^6 eV.

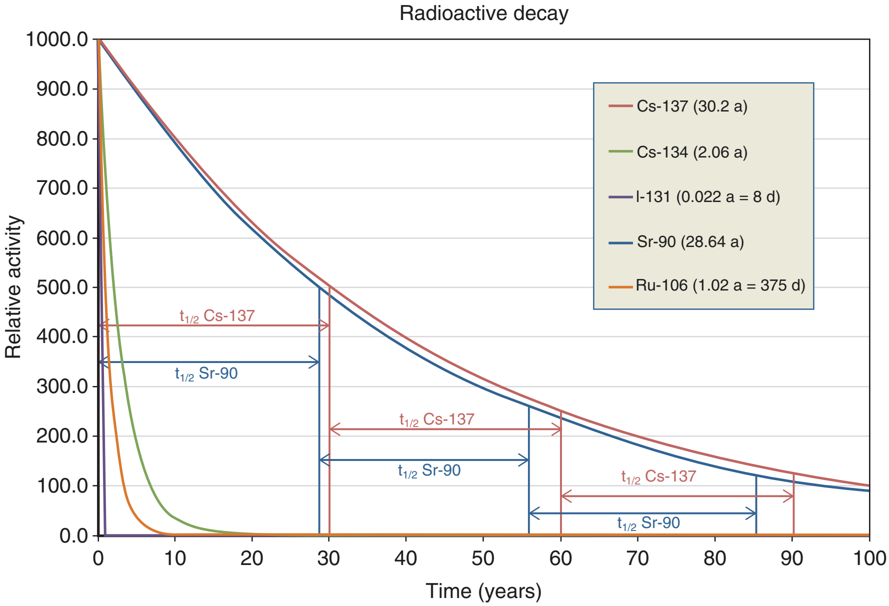


Fig. 21.1 Schematic temporal evolution of a relative activity of the radionuclides Cs-137, Cs-134, I-131, Sr-90 and Ru-106 over a period of 100 years with an initial activity of 1000. The short lived radionuclide I-131 disintegrates to an undetectable amount within 1 year, Ru-106 activity decreases within 10 years to about 1‰ of the initial activity. After 100 years, about 10% of Cs-137 is still present and about 8.9% of Sr-90. The time period of a half live is characteristic for a radionuclide. The half-lives for Cs-137 and Sr-90 are indicated with 30.4 and 28.6 years

This Equation can be solved as follows:

$$N = N_0 \, e^{-\lambda t} \tag{2}$$

where: N_0 is the initial number of the radioactive atoms at $t = 0$; N is the number of remaining radioactive atoms at time t. $N_0\lambda$ is the activity at $t = 0$, A_0, the latter Equation can be expressed in terms of activity ratios as:

$$A/A_0 = N\lambda / N_0\lambda = e^{-\lambda t} \tag{3}$$

The half-life ($t_{1/2}$) is the time interval over which the initial number of radioactive atoms (N_0) is exactly halved: $N = N_0/2$. $t_{1/2}$ is related to decay by $t_{1/2} = ln2/\lambda$, which is characteristic for each radionuclide. Figure 21.1 illustrates the temporal evolution of the activity of some selected man-made radionuclides.

21.5 Units of Activity

In the following sentences, it is the intention to give only a very short introduction for some basic scientific definitions. More detailed information should be taken by topical text books.

The SI unit of activity is the Becquerel (Bq), which is defined as a single nuclear disintegration per second. Before the introduction of SI units, the most commonly used radioactivity unit was the Curie (Ci) corresponding to 3.7 x 10^{10} nuclear disintegrations per second. This activity is approximately equivalent to the activity of 1 g of Ra-226, which was discovered by Marie Curie in 1898.

The activity of a defined radionuclide is mostly given in the unit "*Becquerel*" or Bq[2] which is equivalent to "one disintegration per second" and the concentration (better: activity concentration) referred to a volume would be given in Bq/L or Bq/m^3. The atomic transmutation is connected to the high energetic emission of an alpha- or beta-particle, a gamma-ray or a conversion electron. Radioactive decay is a stochastic process and the decay or a transmutation cannot be predicted for a particular atom. Therefore, the decay rate is calculated from a larger number of atoms and the half-live and the type of decay (alpha, beta, gamma or electron capture) is characteristic for a defined radionuclide. However, it must be emphasised that the activity does not provide any indication of a potential harm to biota.

The impact of radiation is given by the unit Gray (Gy), which is the international derived SI unit of ionizing radiation and defined as 1 J of radiation energy per 1 kg of matter. The older unit is *rad* and connected to the *Gray* by 1 rad = 0.01 Gy = 0.01 J/kg. It can be regarded as the absorbed dose, specific energy, and *kerma*[3]; however the absorbed energy does not take into account the potential biological impact. Normally, the *kerma* is referred to the target material usually dry air at standard temperature and pressure. In order to indicate the health effect of radiation, the unit *Sievert* (*Sv*) was introduced, which is the unit for radiation dose as "equivalent dose", "effective dose" and "committed dose". It takes into account both the internal and external radiation effect to a body or an organ and cannot be measured directly. The radiation exposure is mostly calculated based on the type of radiation and biological system. The old unit, sometimes still used in Russian and American literature, is *rem*[4] with the relation 100 rem = 1 Sv. There is also a difference, if a certain radiation dose was received by a person within a short period of time, e.g. minutes or hours, or within a longer period of a year. We all receive continuously radiation from the natural background or cosmic rays.

It is worth mentioning that X-ray radiation has the same impact as gamma-rays emitted from a nuclide, whereas the medical treatment radiation is mostly responsible for radiation dose received by humans.

The doses to humans should be limited *as low as reasonably achievable*, the so called ALARA principle. We can consider different doses applied within a short period of time. A dose of 10 Sv (= 1000 rem) can be considered as a lethal dose to men within a period of days. A dose between 4 to 6 Sv has a surveillance chance of 50% with good medical treatment over the period of 4 weeks, however, with later serious health deleterious effects. From above 500 mSv so-called non-stochastic radiation effects can be observed like cataracts, hemogram changes and negative

---

[2] The unit *Becquerel* is used in the International System of Units (SI), however in Russian and American literature the old unit curie (Ci) still can be found. 1 Ci is about the activity of 1 g pure Radium-226 and is equivalent to 3.7 × 10^{10} Bq.

[3] Kerma: Acronym for "**k**inetic **e**nergy **r**eleased per unit **ma**ss".

[4] Rem: **R**oentgen **e**quivalent **m**an.

impact on the DNA. Up to the limit of 100 mSv no direct radiation effects can be observed, but stochastic effects might occur like higher probability of development of cancer or leukaemia. The limit for occupationally exposed persons like pilots or nuclear workers has been lowered from before 2001 to 50 mSv/year to 20 mSv per year from 2001 in the European Union. The total occupational life dose should not exceed 400 mSv. The average environmental dose for the population in Europe is estimated with 2.4 mSv per year. Most of this radiation dose is due to medical applications in European countries. It is worth mentioning that there exist areas with naturally occurring high radioactivity in the soil, where the population receives significant annual doses since centuries, like Ramsar (Iran), Kerala (India) or in Guarapari (Brasil), where no negative health effects have been observed.

21.6 Radionuclides in the Marine Environment

Radionuclides are present in our environment since the beginning of the universe. We call those radionuclides *natural* radionuclides. Life has learned to live with radiation from the very beginning. Thorium and Uranium are both radioactive elements with such long half-lives that they are still present on earth. The elements Technetium and Promethium have too short half-lives in comparison to the existence of the earth that all isotopes have decayed. Potassium-40 (K-40) is one very long-lived isotope ($t_{½} = 1.28 \times 10^9$ a) of the element potassium with an abundance of 0.017% of the isotopic composition. The isotopes K-39 (93.3%) and K-41 (6.73%) are stable. K-40 is responsible for most of the internal gamma-radiation of humans and present in the earth's crust and in seawater.

In this respect, radioactive substances or *radionuclides* are present also in seawater or in sediments from natural origin, which by definition cannot be considered as pollution, but there are numerous examples that radioactive substances have been introduced into the ocean by technical processes. Natural radionuclides present since the origin of the universe are called *primordial nuclides*; radionuclides produced by cosmic rays are called *cosmogenic radionuclides*. Table 21.1 indicates the natural background concentration of selected radionuclides in seawater and some examples for their presence in coastal sediments.

This handbook focuses on the impact from anthropogenic origin, therefore, the fowling chapters on radioactivity in the marine environment will primarily also focus on the input and impact from man-made sources. The artificial or man-made radionuclides are introduced into the marine environment by various sources. The main sources are:

1. **Global worldwide fallout** from the atmospheric nuclear tests mainly in the 1950s and 1960s until the *Limited Test Ban Treaty* (LTBT) signed between the governments of the Soviet Union, the United Kingdom and the United States in autumn 1963. This treaty was initiated after massive global contamination by fallout radionuclides of the earth's surface including the oceans. It is officially

Table 21.1 Concentration of some natural occurring radionuclides in the marine environment (compiled various data by Nies et al. (1992))

Natural nuclide (cosmogenic)	Half-life (a)	Concentration in surface water (Bq/m^3)	Concentration in coastal sediment (Bq/kg)
H-3	12.3	20–100	–
Be-7	0.146	1.1–3.4	–
C-14	5730	5.5–6.7	–
Si-32	172 ± 4	0.2–3.3 × 10^{-3}	–
Natural nuclide (primordial)	**Half-life (a)**	**Concentration in surface water (Bq/m^3)**	**Concentration in coastal sediment (Bq/kg)**
K-40	1.28 × 10^9	11,800–12,300	2–1000
Rb-87	4.8 × 10^{10}	~100	–
Th-232	1.41 × 10^{10}	0.4–29 × 10^3	12–50
Ra-228	5.76	0.8–8	–
Th-228	1.91	0.004–0.3	–
U-235	7.04 × 10^8	1.9	–
U-238	4.47 × 10^9	40–44 or 3.3 mg/m^3	2.5–190
Th-234	0.066	0.6–6.8	–
U-234	2.45 × 10^5	47	–
Th-230	9.0 × 10^4	2–52 × 10^{-3}	–
Ra-226	1617	0.8–8	10–100
Pb-210	22.3	1–4.5 ocean 0.4–2 shelf seas	– 100–280 surface
Po-210	0.378	0.5–1.9	100–280 surface

called *treaty banning nuclear weapon tests in the atmosphere*, *in outer space and under water* and it entered into force on October 10, 1963.

2. **Authorised discharges** from nuclear reprocessing plants such as BNFL in Sellafield (UK), COGEMA at Cap de la Hague (F), the Mayak Chemical Combine in Russia, and at sites such as the Tokai plant in Japan, the Tarapur plant in India, and at the West Valley Reprocessing Plant in the United States. The major contributors to marine radioactivity from these sources have been in the past the Russian reprocessing complex near Mayak via the Siberian river system Ob and Yenisei and the two European installations at La Hague and Sellafield. There might be some doubts, if the discharges in the 50s from the Mayak nuclear complex were authorised, because there were extremely high contamination levels of lakes and river system with massive health impacts to the local population.
3. **Authorised discharges from** nuclear power reactors or research establishments, industrial nuclear facilities. In comparison to the discharges from the nuclear reprocessing plants these effluents are almost negligible.

4. **Accidental releases** to the atmosphere and subsequent contamination of the marine surface. The most prominent cases are the nuclear accidents at Windscale (Sellafield) in October 1957 (Crick and Linsley 1984; Editorial from J Radiol Prot 2007), Chernobyl in April 1986 and the accident at the four reactors of the Fukushima Daiichi on March 11, 2011 as the consequence of a massive destructive tsunami.
5. **Accidental releases** from other radioactive sources like re-entering of satellites with radioactive power sources (SNAP) on board or lost sealed radioactive sources like Radioisotope Thermoelectric Generators (RTG), which were often used on remote islands as power source for light houses in the former USSR.
6. **Accidental losses** of nuclear driven ships and submarines like
   Thresher in 1963 (Polmar 1964; Bentley 1975; Naval History Blog 2013),
   Scorpion in 1968 (Rule 2011) and
   Komsomolets in 1989 (Polmar and Moore 2004).
7. **Dumping** of nuclear wastes in the marine environment, such as in the area of the North Atlantic or Arctic regions of the Barents and Kara Seas.

A comprehensive review of the inventory of radioactive materials from historical dumping, accidents and losses at sea has been recently updated by the International Atomic Energy Agency (IAEA 2015). This report covers all presently known sources of radioactive materials which have been deliberately introduced into the Oceans by dumping into coastal areas, Deep Ocean as well as accidental losses of radioactive sources and nuclear weapons. It should be emphasised that the loss of radioactive sources does not necessarily mean that a subsequent release into the ocean water has taken place and the radioactivity is detectable. The two serious accidents with the loss of several nuclear weapons at Palomares (Spain) in 1966 and Thule (Greenland) in 1968 resulted in significant local contamination with Pu-239 in sediments due to the self-destruction mechanism of the weapons. However, there occurred no nuclear explosion.

21.7 Relevant Radionuclides in the Marine Environment

Although, a large number of different short and long-lived radionuclides might be released during a nuclear accident, only a limited number of radionuclides are relevant with regard to the marine environment. Short lived radionuclides will disintegrate within a few days and may not even reach the marine environment. Long lived radionuclides released to the marine environment might be present for many years and may be transported over long distances by the water mass circulation of the world ocean. A special case is the relatively short lived nuclide I-131, which was the major dose contributor at the accidents at Chernobyl and Fukushima Daiichi. In addition this radionuclide is enriched to a very high degree by many algae and may cause external radiation exposure to animals and humans consuming e.g. seaweed like Laverbread, which is traditionally consumed in parts of the

Table 21.2 Relevant radionuclides for the marine environment with their physical properties[a]

Artificial radionuclides			
Nuclide	Half-live (years)	Decay type	Specific activity (Bq/g)
Tritium (H-3)	12.3	β-	3.59×10^{14}
Carbon 14	5730	β-	1.65×10^{11}
Cobalt 60	5.27	β- and gamma	2.51×10^{15}
Strontium 90	28.64	β-	5.13×10^{12}
Technetium 99	213,000	β-	6.28×10^{8}
Ruthenium 106	1.02	β- and gamma	1.22×10^{14}
Antimony 125	2.77	β- and gamma	3.82×10^{13}
Iodine 129	1.57×10^{7}	β-	6.53×10^{7}
Iodine 131	0.0219	β- and gamma	4.61×10^{15}
Caesium 134	2.06	β- and gamma	4.79×10^{13}
Caesium 137	30.17	β- and gamma	3.20×10^{12}
Plutonium 238	87.74	α	6.34×10^{11}
Plutonium 239	24,110	α	2.30×10^{9}
Plutonium 241	14.35	β-	3.83×10^{12}
Americium 241	432.2	α	1.27×10^{11}

[a]Decay data compiled from Magill et al. (2006)

UK and Porphyra known as zicai (紫菜) in China, nori (海苔) in Japan, and gim (김) in Korea. However, these cases are very special and could be avoided during the effective period of a nuclear accident as long as radioactive Iodine is released. Table 21.2 lists the most important radionuclides relevant and monitored in the marine environment. Some of them might be more relevant in relation to potential radiation doses received via the marine pathway and some are discharged from certain nuclear activities and were used to trace them in the marine environment over years and long distances due to ocean transport routes with prevailing ocean currents. The specific activity is given here just for information and can be always calculated from the half-live of a given radionuclide. It can be calculated by the following formula:

$$a = \frac{\lambda \times N}{m \times N / N_A} = \frac{\lambda \times N_A}{m}$$

where a is the specific activity in Bq/g, N_A is Avogadro's constant with 6.022×10^{23} mol^{-1}, N is the number of radioactive atoms, λ is the decay constant with $\frac{\ln 2}{T_{1/2}}$, and m is the mass of the atom. This formula can be simplified to:

$$a = \frac{N_A \times \ln 2}{T_{1/2} \times m}$$

or reformulated to:

$$a\left[\frac{Bq}{g}\right]=\frac{4.17\times10^{23}\left[mol^{-1}\right]}{T_{\frac{1}{2}}\left[s\right]}\times m\left[\frac{g}{mol}\right]$$

The half-live has to be calculated in seconds, where 1 year is $365\times24\times60\times60\ s$ = 31,536,000 s. It is obvious that the longer the half-live the lower is the specific activity of a nuclide.

21.8 Marine Radioecology

The previous chapter was dealing with more physical properties of different radionuclides. This chapter should briefly introduce to the potential impact of radionuclides present in the marine environment. It is not the intension to give a general introduction to the internationally agreed principles of radiation protection, developed over many years by the International Commission on Radiological Protection. These principles and recommendations of radiation protection are the basis for national regulations governing the exposure of radiation workers and members of the public. They also have been incorporated by the International Atomic Energy Agency (IAEA) into its Basic Safety Standards for Radiation Protection published jointly with the World Health Organization (WHO), International Labour Organization (ILO), and the OECD Nuclear Energy Agency (NEA). These standards are used worldwide to ensure safety and radiation protection of radiation workers and the general public. This chapter will only cover some specific aspects of the potential harm from radioactive substances in the oceans. Radiation protection principles from environmental radiation were recently published by the IAEA (2011).

With reference to potential radiation exposure from radionuclides in the environment the competent *International Commission on Radiological Protection* (ICRP 1991) declared that.

"*…the standard of environmental control needed to protect man to the degree currently thought desirable will ensure that other species are not put at risk.*"

This statement was the basic principle for considering the protection of harm to animals and plants for many years. It is the principle that in radiation protection the individual human must be protected, but for animals and other biota the protection will not cover individuals, but the population of a certain species must be protected. If we would introduce also the protection of an individual animal, we must discontinue any killing of living food or fishing. However, in recent years a discussion was initiated, if the ICRP statement from 1990 is still valid. In 2007 the ICRP stated.

"*…is necessary to consider a wider range of environmental situations, irrespective of any human connection with them. The Commission is also aware of the needs of some national authorities to demonstrate, directly and explicitly, that the environment is being protected, even under planned situations…*" (International Commission on Radiological Protection, Draft New Recommendations 2007).

Some of these cases may refer to remote marine environment such as the deep sea. However, in most cases the statement is still valid, that as long as man is protected also other living animals are not put at risk, but the protection of the environment other than man has in the meantime been introduced into EU radiation regulations.

The best protection against the external exposure from ionising radiation from radionuclides in seawater or sediments is the shielding property of seawater. The oceans dilute radionuclides to extremely low concentrations within a relatively short time due to the extremely high volume which will finally lead to low concentrations in seawater. This could be seen at the cases from discharges from the initially high concentrations at Sellafield or the Fukushima Daiichi nuclear power stations disaster.

Radiation exposure from marine sources can in principle occur from two types of pathways:

1. External radiation at beaches or at sea.
2. Biological enrichment and accumulation of radionuclides into biota (fish and marine seafood) and subsequent consumption.

The first case is only limited to extremely rare cases, where high releases from nuclear installations did occur during accidents. This was the case at beaches near the Fukushima Daiichi accident in March 2011, where extremely high levels of radionuclides were released and deposited on coastal areas. These are accidental cases with particular restrictions and interventions to be announced by competent legal authorities. One of these measures was to close a zone of prevention of beaches and restrict fishery activities and the subsequent consumption of marine food. Temporal and spatial regular monitoring has to be initiated in order to control the impact of the adverse releases for many months or even years as it is the case at Fukushima Daiichi on marine biota and the marine food web. Marine radiation should consider the radio-ecological processes with the radionuclides mentioned in Table 21.2. Table 21.3 gives some specific properties of certain radionuclides.

The water–sediment concentration factor explains the degree of affinity for different elements to be bound to sediments. In many cases this depends also on the chemical form of the element. So called *conservative* elements have a relatively low K_d value and are more soluble and would be transported over long distances with ocean currents. Examples are Tritium, Strontium- and Cs-isotopes. A high K_d-value describes high potential to be fixed to sediments and would remain in the sediments near the input area. Examples of more sediment bound elements are Cobalt and Plutonium. The K_d is defined as the equilibrium between the concentration in seawater and mass activity in sediments and has the dimension L/kg. Further explanation should be taken from IAEA (2004).

$$Kd\left(\frac{L}{kg}\right) = \frac{Concentration\ per\ unit\ mass\ of\ particulate\left(\frac{kg}{kg}\ or\ \frac{Bq}{kg\left(dry\ weight\right)}\right)}{Concentration\ per\ unit\ volume\ of\ water\left(\frac{kg}{L}\ or\ \frac{Bq}{L}\right)}$$

Table 21.3 Radio-ecological properties of certain radionuclides in the marine environment

Artificial radionuclides				
Nuclide	Half-live (years)	Water–sediment concentration factor K_d (L/kg)	Enrichment factor water—fish C_F (L/kg)	Effective dose coefficients for ingestion fir adults (Sv/Bq)
Tritium (H-3)[a,b]	12.3	1.0	1.0	1.8×10^{-11}
Carbon 14[a]	5730	1×10^3	2×10^4	5.8×10^{-10}
Cobalt 60	5.27	1×10^5	7×10^2	3.4×10^{-9}
Strontium 90[c]	28.64	8×10^0 or 8	3×10^0 or 3	2.8×10^{-8}
Technetium 99[d]	213,000	1×10^2	8×10^1 or 80	6.4×10^{-10}
Ruthenium 106	1.02	4×10^4	2×10^0 or 20	7.0×10^{-9}
Antimony 125	2.77	2×10^3	6×10^2	1.1×10^{-9}
Iodine 129	1.57×10^7	7×10^1	9×10^0 or 9	1.1×10^{-7}
Iodine 131[e]	0.0219 or 8.04 days			2.2×10^{-8}
Caesium 134	2.06	4×10^3	1×10^2	1.9×10^{-8}
Caesium 137	30.17			1.3×10^{-8}
Plutonium 238	87.74	1×10^5	1×10^2	2.3×10^{-7}
Plutonium 239	24,110			2.5×10^{-7}
Plutonium 241	14.35			4.8×10^{-9}
Americium 241	432.2	2×10^6	1×10^2	2.0×10^{-7}

Recommended sediment water concentrations factors K_d for coastal sediments and recommended concentration factor for marine fish C_F (IAEA 2004). Only the enrichment in marine fish is considered. The effective dose conversion factor is given for intake by food, e.g. marine seafood (ICRP 2012)

[a]Tritium and carbon-14 are both, artificial and natural radionuclides

[b]The value for tritium refers to HTO. Organically bound tritium can (OBT) can have a higher enrichment factor

[c]The low concentration or enrichment factor of Strontium is due to the high non-radioactive Ca and Sr element concentration in seawater

[d]Technetium has a relatively high concentration factor for some crustaceans

[e]Iodine has a high concentration factor to marine algae

The quantity of an element or radionuclide in biological tissue is almost always discussed in terms of concentration, either on a dry or wet weight basis (IAEA 2004). For modelling purposes, this value is then usually represented in terms of a concentration relative to that of the ambient sea water, traditionally expressed as a C_F. If both biological material and seawater concentrations are derived per unit mass, this term is dimensionless. However, in some instances the seawater concentration is derived in terms of unit volume; the C_F is then expressed in L/kg, but this makes, numerically, little difference and we use this expression for simplicity. The C_F thus is defined:

$$CF\left(\frac{L}{kg}\right) = \frac{Concentration\ per\ mass\ of\ organism\left(\frac{kg}{kg}\ or\ \frac{Bq}{kg}\ wet\ weight\right)}{Concentration\ per\ unit\ volume\ of\ seawater\left(\frac{kg}{L}\ or\ \frac{Bq}{L}\right)}$$

It must be emphasised that the listed values for C_F in Table 21.3 can be totally different for crustaceans of other shellfish. This table is only intended to show the simplified model procedure to estimate radiation doses from consumption of marine seafood. The major marine exposure pathway would be:

Radionuclide(s) present in seawater (Bq/L)→.-->
enrichment to seafood (Bq/kg) →.-->
consumption of certain amount by humans (kg/year) →.-->
radiation dose received by man from the consumption of certain amounts of marine food (Sv/year).

The described model for calculation of a dose received by the consumption of marine food is only given in a very simplified manner. Further reading of text books is recommended, if more detailed information would be needed.

Generally, radiation exposure via the marine pathway primarily by consumption of seafood is relatively low, in most cases significantly less than 1% compared to the natural background radiation exposure of about 2.4 mSv per year for the general public. This is even valid for marine areas with higher background from historical discharges and remaining contamination in sediments e.g. in the Irish Sea, or in accidentally contaminated regions like the Baltic Sea by the Chernobyl accident (HELCOM 2013) or Japanese coastal waters in the Pacific (Buesseler et al. 2012; Fisher et al. 2013; Povinec et al. 2013; Fisheries Agency Japan 2015). It depends also on the annual consumption rate, which can be significantly different in different countries. East Asian population (e.g. China, Japan, and Korea) has an average consumption of marine food of partly above 60 kg per capita per year, in Europe the rate is between 8 in eastern countries and 60 kg per capita per year (Portugal).

There exist legal limits for food contamination for the public following a nuclear accident or any other case of radiological emergency. The Maximum Permitted Levels in the EU for radionuclides like Cs-134 and Cs-137 are 1000 Bq/kg or Bq/L for dairy products and 1250 Bq/kg or Bq/L for foodstuffs and feedingsstuffs. Strontium-isotopes, notably Sr-90 have lower limits (125 in dairy products and 750 Bq/kg or Bq/L). Alpha-emitting radionuclides like Plutonium and Americium have limits of 20 or 80 Bq/kg or Bq/L, respectively (EU Council Regulation (EURATOM) No 3954/87). These limits are based on the radiological calculations of the exposure for a "reference person" with certain consumption behaviour and receiving a maximum annual dose from nuclear activities of 1 mSv. It must be mentioned that the average person consumes less than the "reference person" and, consequently, would receive lower dose from contaminated food. In most countries the limit for food contamination was set to 370 Bq/kg (or Bq/L) for dairy and baby food and 600 Bq/kg (Bq/L) for all other food products e.g. for the most critical nuclides Cs-134/Cs-137. Japan however, lowered the limit by 1 July 2011 to 100 Bq/kg (Bq/L) for all type of food with Cs-134 + Cs-137 contamination, in order to exclude any potential higher exposure and to regain trust from the population.

It must however be stated that the highest radiation dose by the consumption of marine food is due to the natural radionuclide Polonium-210 (Po-210), which is partly enriched in fish and crustaceans (Aarkrog et al. 1997). It is the alpha-emitting end product from the decay chain from Uranium-238 before the decay chain terminates at Pb-206, which is stable. Polonium-210 is the final decay product of Lead-210 (Pb-210) ($T_{1/2}$ = 22.3 a), Bismutate-210 (Bi-210) ($T_{1/2}$ = 5.01 d) and has a half-live of 138.4 days. To give one example, Fisher et al. 2013, compared the contribution to the radiation dose from Cs-137 and Cs-134 in Pacific waters contaminated by massive releases from the Fukushima Daiichi accident and from Po-210 in marine food (Fisher et al. 2013).

21.9 Conclusion

Radioactive substances have been introduced into the marine environment by various human nuclear activities. This can lead to contamination of marine foodstuff and radiation exposure of the population. Nuclear accidents like the Windscale fire in 1957, the Chernobyl accident in 1986, and the Fukushima accident in 2011 have significantly resulted in radioactive contamination of ocean waters. However, due to the enormous dilution capacity by the dispersion of marine waters, initial high contamination decreased rapidly. This contamination is transported over long distances due to ocean currents and may result in wide spread contamination of marine waters. In most cases the contamination of marine foodstuff does not pose any harm to humans and biota. Limits for foodstuff contamination e.g. in fish or shellfish will finally limit also the marine exposure pathway by the consumption of marine food below legal limits for the general population. It was shown that in most cases the exposure received from natural radionuclides present in marine biota is significantly higher than from the contamination by man-made radionuclides due to authorised discharges from nuclear installations or accidental releases in highly contaminated marine regions.

References

Aarkrog A, Baxter MS, Bettencourt AO, Bojanowski R, Bologa A, Charmasson S, Cunha I, Delfanti R, Duran E, Holm E, Jeffree R, Livingston HD, Mahapanyawong S, Nies H, Osvath I, Pingyu L, Povinec PP, Sanchez A, Smith JN, Swift D (1997) A comparison of doses from 137Cs and 210Po in marine food: a major international study. J Environ Radioact 34(1):69–90. doi:10.1016/0265-931X(96)00005-7

Bentley J (1975) The thresher disaster; the most trgic dive in submarine history. Doubleday, Garen City, NY. ISBN: 0-385-03057-6

Buesseler KO, Jayne SR, Fisher NS, Rypina II, Baumann H, Baumann Z, Breier CF, Douglass EM, George J, MacDonald AM, Miyamoto H, Nishikawa J, Pike SM, Yoshida S (2012)

Fukushima-derived radionuclides in the ocean and biota off Japan. Proc Natl Acad Sci U S A 109(2012):5984–5988

Crick MJ, Linsley GS (1984) An assessment of the radiological impact of the Windscale reactor fire, October 1957. Int J Radiat Biol Relat Stud Phys Chem Med 46(5):479–506

Editorial from J Radiol Prot (2007) Richard Wakeford: the Windscale reactor accident—50 years on. J Radiol Prot 27:211–215

Fisher NS, Beaugelin-Seiller K, Hinton TG, Baumann Z, Madigan DJ, Garnier-Laplace J (2013) Evaluation of radiation doses and associated risk from the Fukushima nuclear accident to marine biota and human consumers of seafood. Proc Natl Acad Sci U S A 110(26):10670–10675

Fisheries Agency of Japan (2015) Report on the monitoring of radionuclides in fishery products (March 2011–January 2015). Available at: http://www.jfa.maff.go.jp/e/inspection/pdf/report_on_the_monitoring_of_radionuclides_in_fishery_products.pdf

GESAMP (IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution) (1991) Reducing environmental impacts of coastal aquaculture. Rep Stud GESAMP (47):35p

HELCOM (2013) Thematic assessment of long-term changes in radioactivity in the Baltic Sea, 2007–2010. Balt. Sea Environ. Proc. No. 135. Authors: Herrmann J, Hutri K-L, Ikäheimonen TK, Kanisch G, Lüning M, Nielsen SP, Pham MK, Vartti V-P

IAEA (2004) Sediment distribution coefficients and concentration factors for biota in the marine environment. International Atomic Energy Agency, Vienna. 24 cm—(Technical reports series, ISSN: 0074-1914; no. 422) STI/DOC/010/422, ISBN: 92-0-114403-2

IAEA (2011) Radiation protection and safety of radiation sources : international basic safety standards: general safety requirements, interim edn. International Atomic Energy Agency, Vienna; 29 cm—(IAEA safety standards series, ISSN: 1020-525X; no. GRS Part 3 (interim)) STI/PUB/1531, ISBN: 978-92-0-120910-8

IAEA (2015) Inventory of radioactive material resulting from historical dumping, accidents and losses at sea—for the purposes of the London Convention 1972 and London Protocol 1996. IAEA-TECDOC-1776, Vienna

ICRP (1991) 1990 recommendations of the international commission on radiological protection. ICRP Publication 60. Ann ICRP 21(1–3)

ICRP (2007) The 2007 recommendations of the international commission on radiological protection. In: Valentin J (ed), Publication No. 103. Elsevier, Amsterdam

ICRP (2012) Compendium of dose coefficients based on ICRP Publication 60. ICRP Publication 119. Ann ICRP 41 (Suppl). Clement CH (ed). Authors on behalf of ICRP Eckerman K, Harrison J, Menzel H-G, Clement CH, published for The International Commission on Radiological Protection. Elsevier, Amsterdam

Magill J, Pfennig G, Galy J (2006) Karlsruhe Nuclide Chart, 7th edn

Naval History Blog (2013) USS Thresher (SSN-593), 3 August 1961–10 April 1963. http://www.navalhistory.org/2013/04/01/uss-thresher-ssn-593-3-august-1961-10-april-1963

Nies H, van Eck GTM, de Jong EJ (1992) Radionuclides. In: Laane RWPM (ed) Background concentrations of natural compounds. Report DGW-92.033. Ministry of Transport, Public Works and Water Management, Directorate-General of Public Works and Water Management. The Hague, The Netherlands

Polmar N (1964) Death of the *thresher*. Chilton Books, Philadelphia. ISBN: 1-58574-348-8. First published 1964; reissued in 2001 by Lyons Press (Guildford, CT) as: the death of the USS thresher

Polmar N, Moore KJ (2004) Cold war submarines: the design and construction of U.S. and Soviet submarines. Brassey's, Inc., Dulles, VA, pp 286–287. ISBN: 1-57488-594-4

Povinec PP, Hirose K, Aoyama M (2013) Fukushima accident: radioactivity impact on the environment. Elsevier, Amsterdam, pp 1–382

Rule B (2011) Why the USS *Scorpion* (SSN 589) was lost: the death of a submarine in the North Atlantic (31 October 2011 ed.). Nimble Books LLC. P.74. ISBN: 1608881202

Chapter 22
Eutrophication

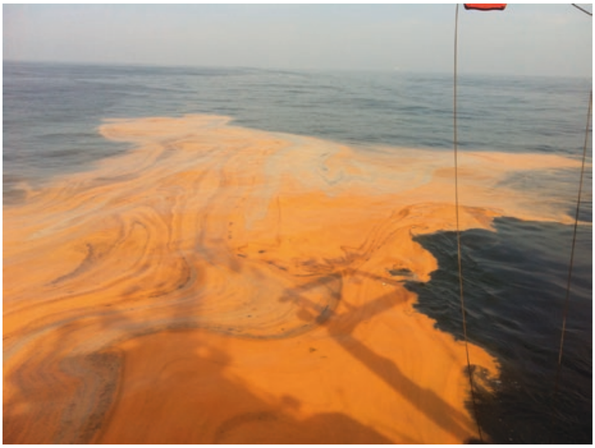
Justus E.E. van Beusekom

Abstract Coastal zones have experienced an increased nutrient load during the past decades. In most cases, strongest increases took place since the 1950s. First signs of consequences of the increased nutrient loads were increased phytoplankton blooms, an increase in Harmful Algae Blooms, a decrease in seagrass and an increase in green macroalgae blooms. As a consequence of the increased production and accumulation of organic matter hypoxic conditions may develop with detrimental consequences for the benthic and pelagic ecosystems. The global extent of hypoxic areas has doubled since the 1960s. Relatively few time series exist, that document the early stages of eutrophication. With new data becoming available, it is now clear that the effects of eutrophication are very complex and in many cases site specific. Moreover, other aspects of human induced global change like temperature increase, or the introduction of non-indigenous species interact with phytoplankton dynamics, posing a challenge to future coastal research. A case study for the Wadden Sea, a coastal sea that is under severe pressure by continental Westeuropean rivers, is presented that shows the eutrophication history, and recent improvements after management decisions lead to decreasing nutrient loads.

Keywords Nitrogen • Phosphorus • Macroalgae • Phytoplankton • Blooms • Hypoxia • Eutrophication

J.E.E. van Beusekom
Institute of Coastal Research, Helmholtz Zentrum Geesthacht, Geesthacht, Germany
e-mail: Justus.van.beusekom@hzg.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_22



Algae may locally discolor the water. The picture shows a local conglomeration of a thin surface layer of the heterotrophic alga *Noctiluca scintillans* in the Germany Bight (North Sea) in June 2015 during very quiet weather conditions (credits: J.E.E. van Beusekom).

22.1 Introduction

The two major factors that determine phytoplankton growth are nutrients and light. Satellite imaging of the world ocean illustrate this with very low phytoplankton biomass in the nutrient-poor subtropical gyres, seasonal spring and summer blooms in the temperate ocean and increased levels in coastal areas. Riverine nutrient loads and upwelling of nutrient-rich ocean water contribute to nutrient availability and shallow depths enable an efficient recycling of nutrients (e.g. Cloern and Jassby 2010; Miller and Wheeler 2012).

Especially since the second half of the twentieth century, nutrient loads into the coastal zone have increased (van Bennekom and Wetsteijn 1990; Boesch 2002). One of the oldest published cases of coastal eutrophication is from small bays along Long Island, USA (Ryther 1954; see De Jong 2006), where effluents from duck farms caused increased summer blooms of small green algae. Further early cases were described in Europe: Untreated effluents from the city of Oslo lead to phytoplankton blooms in the Oslo-fjord in the 1960s (Føyn 1968; De Jong 2006). Van Bennekom et al. (1975) and Gieskes and Kraay (1975) discussed the impact of increased Rhine nutrient loads on the phytoplankton dynamics along the continental coastal North Sea coast. The effects of increased phytoplankton biomass and primary production on the coastal ecosystems were far-reaching and linked to e.g. oxygen deficiency, red tides, seagrass loss, toxic algae blooms or decreased transparency (Cloern 2001; Boesch 2002).

The symptoms of organic matter over-enrichment due to increased nutrient availability and increased primary production are usually addressed to as eutrophication. Several suggestions have been put forward to define eutrophication (Andersen et al. 2006). I will adopt the definition given by Nixon (1995): 'an increase in the rate of supply of organic matter to an ecosystem'. Rather than focusing on the nutrient concentrations, this definition highlights the production of organic matter and its effects.

In this paper, I will first discuss the anthropogenic nutrient enrichment of coastal seas. Much work has been done and is still being done by the LOICZ Programme (Land- Ocean Interaction in the Coastal Zone), an international Project that was carried out in the framework of the IGBP (International Geosphere-Biosphere Programme). Crossland et al. (2005) give a good over view of anthropogenic nutrient fluxes to the coastal ocean. I will then highlight several symptoms of the effects of the nutrient enrichment on the coastal ecosystem including increase in phytoplankton biomass, harmful algae bloom and effects on submersed vegetation including the enhancement of green macroalgae blooms and the global decrease in seagrass. Finally, I will present a case study from the Wadden Sea that highlights regional specific aspects of the eutrophication including interacting effects with other aspects of global change.

22.2 Cultural Nutrient Enrichment

Coastal eutrophication is a globally increasing problem. 75% of the megacities and about 45% of the human population live in the coastal zone (Crossland et al. 2005). Human impact on global nutrient dynamics is particularly demonstrated by nitrogen: Industrial production of nitrogen fertilizers by the Haber Bosch process nowadays surpasses the natural nitrogen fixation (Galloway et al. 2008). Compared to background concentrations, nutrient concentrations in rivers draining densely populated areas have strongly increased. Howarth et al. (1996) reported a 15-fold increase in nitrogen fluxes for rivers flowing into the North Sea and a five to sixfold increase in the Mississippi. The correlation between nitrate export by rivers and population density (Peierls et al. 1991) underpins the human dimension. Largest changes occurred after the mid-twentieth century as documented for the river Rhine (Fig. 22.1).

Processes governing riverine nutrient fluxes are nowadays reasonably well understood and are captured in Global Nutrient Export Models (e.g. Seitzinger et al. 2005). Modeled nutrient fluxes correlated well with observed fluxes (Dumont et al. 2005; Harrison et al. 2005). Dissolved Inorganic Nitrogen (DIN) exports are dominated (almost two-thirds) by anthropogenic sources (see Chaps. 14, 16, 34 and 35) and hotspots of anthropogenic nitrogen loads to the global coastal sea are Europe, south-east Asia and north America (Dumont et al. 2005). Likewise, Dissolved Inorganic Phosphorus (DIP) loads are dominated to about two-thirds by anthropogenic sources. In contrast to DIN, point sources dominated the DIP fluxes (Harrison et al. 2005).

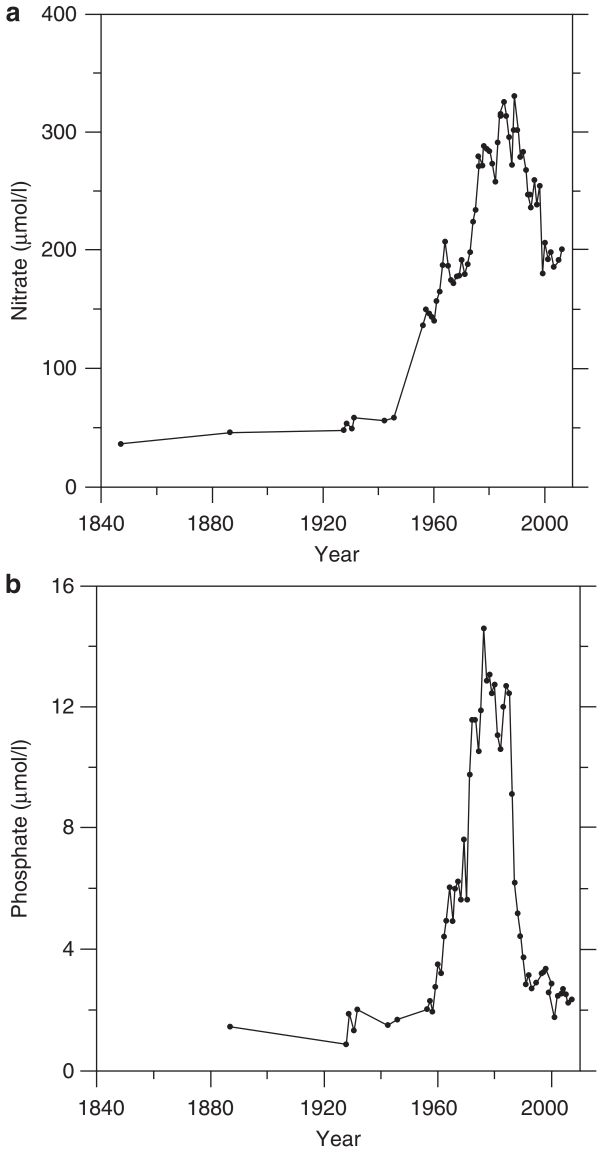


Fig. 22.1 Historic development of nitrate (**a**) and phosphate (**b**) in the Rhine. Original graph is by van Bennekom and Wetsteijn (1990), updated with more recent data from Rijkswaterstaat (live.waterbase.nl) measured at the Dutch-German border near Lobith. Note that nitrate and phosphate do not represent the total N and P concentrations

In addition to riverine sources, atmospheric deposition of especially Nitrogen is an additional nutrient source mainly derived from agriculture and combustion of fossil fuels (Dentener et al. 2006). Especially in off-shore areas, this source is of similar magnitude as biological nitrogen fixation and contributes to about 3.5% of the ocean primary production (Duce et al. 2008).

22.3 Symptoms of Eutrophication

Many symptoms of coastal change are linked to an increased availability of organic matter and nutrients. Cloern (2001) discussed the changed conceptual understanding of coastal eutrophication. Initial concepts were based on our understanding of limnic eutrophication as for instance developed by Vollenweider (1968): a simple input-output model linking P loading to phytoplankton biomass or oxygen consumption (see also Hecky and Kilham 1988). Cloern (2001) discussed that coastal research in recent decades had identified key differences in the responses of lakes and coastal-estuarine ecosystems to nutrient enrichment and suggested that contemporary conceptual models reflect those differences by including complex direct and indirect responses like changes in water transparency, nutrient biogeochemistry and a suite of ecological interactions.

22.3.1 Phytoplankton

The general picture of a eutrophication induced increase in phytoplankton biomass is quite clear (e.g. Boesch 2002). Primary production support the high productivity of coastal zone (mean: 252 gC m^{-2} *y^{-1} being clearly higher than oceanic rates of about 100 gC m^{-2} *y^{-1}; e.g. Behrenfeld and Falkowski 1997) but with a large range spanning from −105 gC m^{-2} *y^{-1} to +1890 gC m^{-2} *y^{-1} (Cloern et al. 2014). The authors pointed out that primary production is the product of phytoplankton biomass on the one hand and photosynthesis rates on the other hand. Thus, a complex suite of factors of which nutrients are only one determine the productivity and organic matter production (Fig. 22.2). Cloern and Jassby (2010) compiled phytoplankton biomass and

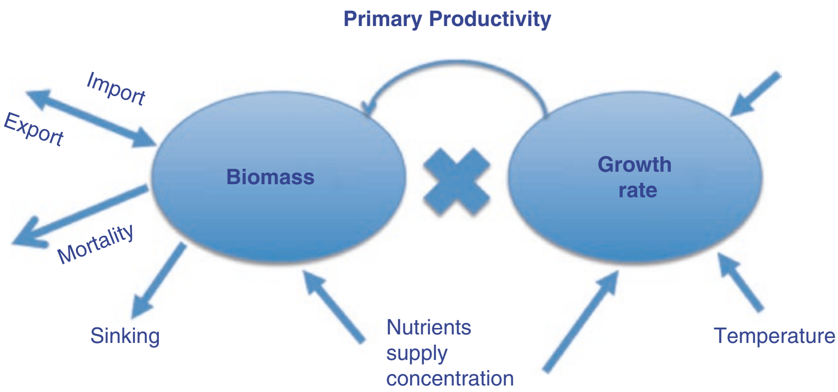


Fig. 22.2 A conceptional graph showing the complex interactions between phytoplankton biomass and productivity and the environment. Primary production is the product of growth rate and biomass, each driven by different factors (from Cloern et al. 2014)

data from 114 coastal sites around the world. Their analysis revealed a broad continuum of seasonal cycles contrasting with the regionally more coherent annual cycles of terrestrial and oceanic primary producers. The authors argued that local processes mask responses to external factors like changing climate. The observations also implicate that it is challenging to extract responses to changes in nutrient load from time series. Borum (1996) already showed that nutrient loading is a bad predictor for primary production in coastal waters and mesocosms.

Both top-down, bottom-up and climatic effects impact the phytoplankton dynamics. For instance, Keller et al. (1999) manipulated temperature in mesocosm experiments and showed that colder temperatures induced larger spring blooms due to a reduced grazing pressure. This seasonal dependent response is also clear in the northern Wadden Sea (see also the Case Study below), where spring phytoplankton blooms are suppressed by warm winter temperatures, summer biomass is determined by riverine nutrient loads and winter biomass reflects resuspension of microphytobenthos (van Beusekom et al. 2009b; van Beusekom and Lindemann, unpublished results; compare De Jonge and van Beusekom 1995). Such variability patterns may indicate how Global Change may impact local phytoplankton dynamics (see Chap. 18).

The interactions between global change and phytoplankton dynamics are also illustrated by the phytoplankton dynamics in San Francisco Bay where an introduced clam (global traffic) changed the seasonal phytoplankton dynamics and suppressed summer and autumn blooms. Autumn blooms developed abruptly in 1999 when a shift in temperatures induced immigration of flatfish and crustaceans reducing clam density and top-down control and autumn blooms reappeared (Cloern et al. 2007). This high variability of coastal phytoplankton dynamics poses a challenge to understanding the response of coastal ecosystems to the diverse drivers including nutrient supply and underlines the need for high resolution time series encompassing a broad scope of biological and abiotic components (Smetacek and Cloern 2008).

22.3.2 Harmful Algae

Harmful Algae Blooms (HAB's) pose a threat to coastal ecosystems either because of the high biomasses and links to oxygen deficiency or because of their toxic effects. Links with eutrophication have been frequently suggested (Anderson et al. 2002). Davidson et al. (2014) however pointed out that toxic blooms can also develop without anthropogenic nutrient enrichment. They stressed the point that eutrophication is mostly related to high biomass HAB's. Davidson et al. (2014) further concluded that the development of HAB's is often site specific (compare the above mentioned analyses by Cloern and co-authors) and pointed to the importance of hydrodynamic conditions for the development of HAB's. Heisler et al. (2008) reviewed the relation between eutrophication and HAB's. They concluded among others that nutrient pollution (both chronic and episodic) promotes the development of HAB's and is one of the reasons for their expansion in US coastal waters, that high biomass blooms must have exogenous nutrients to be sustained and that the composition of the nutrient pool impacts HAB's.

22.3.3 Anoxia and Hypoxia

One of the implications of enhanced phytoplankton blooms is the enhanced supply of organic matter. This may lead to hypoxic (<2 mL O_2/L) or anoxic conditions especially under stratified conditions. Diaz and Rosenberg (2008) compiled data from coastal areas worldwide. First observations of hypoxic events were already observed in the 1930s (Chesapeake Bay), in the 1950s in the Adriatic, between 1940s and 1960s in the Black Sea and in the 1970s in the Gulf of Mexico. When benthic ecosystems are increasingly loaded with organic matter, an initially diverse benthic community changes to a system where a few species survive and eventually becomes azoic under anoxic conditions (Pearson and Rosenberg 1978). Whereas hypoxia can be natural, the sites with hypoxia doubled since the 1960s (Diaz and Rosenberg 2008). Most of the areas where hypoxic conditions occur are found in human impacted regions (Fig. 22.3).

Recovery is possible: After the collapse of the former Soviet Union, nutrient loads into the Black Sea by the Danube decreased by a factor of 2–4, hypoxic conditions disappeared in 1995 and the benthic community slowly recovered (Mee 2006; Diaz and Rosenberg 2008). However, it is an open question, whether reduction measures will lead to restoration of former conditions as other factors have impacted coastal ecosystems as well (shifting baselines; Duarte et al. 2009). In contrast, the nutrient loads by Chinese rivers continue to increase and hypoxic conditions are now observed near the outflow of the Chiangjiang river (Wang et al. 2016).

22.3.4 Macrophytes

Seagrass and green macroalgae respond in an opposite way to eutrophication: loss of seagrass and often an increase in macroalgae blooms (see case study on the Wadden Sea). Seagrasses provide key ecological services, including organic carbon production and export, nutrient cycling, sediment stabilization, enhanced

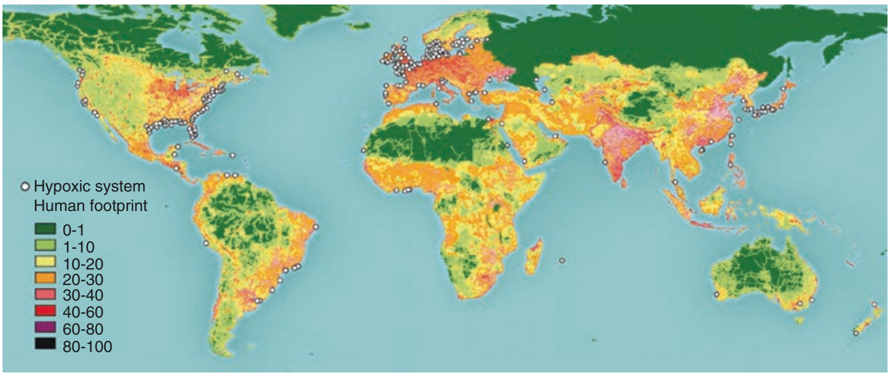


Fig. 22.3 Distribution of hypoxic areas along the global coast. The colors indicate the human footprint. From Diaz and Rosenberg (2008). Reprinted with permission from AAAS

Fig. 22.4 Green macroalgae bloom in the Yellow Sea, about 80 km south of Yantai. Photo provided by Prof. Zhiqiang Gao, Yantai Institute of Coastal Zone Research, China

biodiversity, and trophic transfers to adjacent habitats in tropical and temperate regions (Orth et al. 2006). Green macroalgae blooms are often associated with eutrophication (e.g. Reise 1983). Green algae blooms are a worldwide phenomenon with an increasing trend (Ye et al. 2011; Smetacek and Zingone 2013). Prominent examples by Ye et al. (2011) are the macroalgae blooms in Chinese coastal waters during 2008 (up to 20,000 km^2) and 2009 (cf. Fig. 22.4).

Liu et al. (2009) suggested that rafts used for aquaculture of *Porphyra* were the source of these bloom. Green macroalgae attach to the rafts, are disposed of during harvesting, continue to grow as floats and can beach during certain hydrodynamic and weather conditions (see also Smetacek and Zingone 2013). The effects of macroalgae blooms range from smothering of seagrass and sediments (anoxia) to negative effects on tourism (Ye et al. 2011; Smetacek and Zingone 2013).

22.4 The Wadden Sea: A Case Study

To illustrate the general aspects of eutrophication mentioned above, I will focus on the Wadden Sea because of its long history of observations documenting the increased eutrophication and because management actions have greatly contributed to the recent improvement in the eutrophication status.

The Wadden Sea is a shallow coastal sea along the Dutch, German and Danish North Sea coast. In consists of large intertidal flats, shallow subtidal areas and tidal channels that connect the Wadden Sea to the North Sea. The northern and southern parts are protected from the Wadden Sea by barrier islands. The Wadden Sea is influenced by continental rivers: Several rivers like the Ems, Weser and Elbe directly debouche into the Wadden Sea. The major European River Rhine indirectly impacts the Wadden Sea through the residual currents carrying Atlantic Water through the English Channel towards the north along the Dutch, German and Danish North Sea coast (Fig. 22.5).

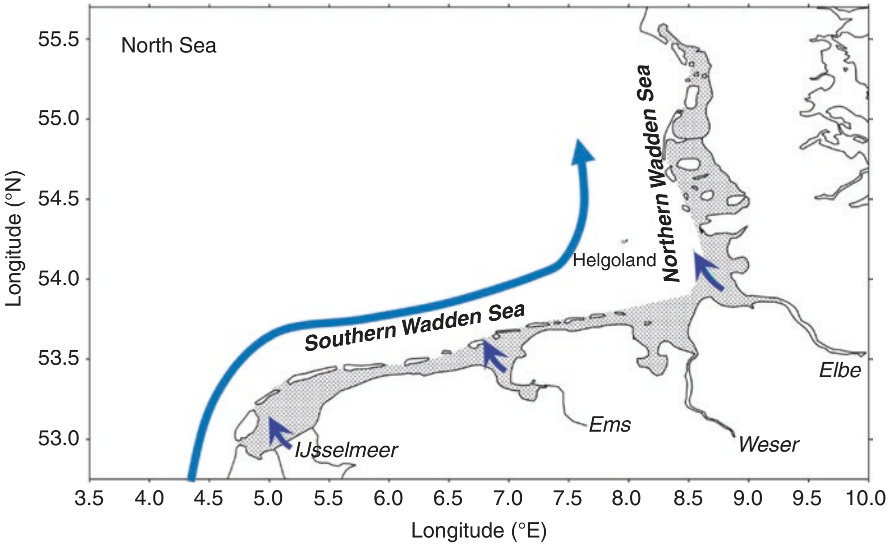


Fig. 22.5 A map of the Wadden Sea (hatched area) showing the direct (IJsselmeer, Ems, Weser, Elbe) and indirect (Rhine, Meuse) riverine influences. The Western Dutch Wadden Sea is situated in the westernmost part of the Southern Wadden Sea and is influenced by Lake IJssel (IJsselmeer) and the rivers Rhine and Maas. The latter rivers debouche south of the Wadden Sea into the North Sea and the river water is carried towards the north with the residual currents (*long curved arrow*)

22.4.1 Eutrophication Increase and Recovery

Historic measurements in the river Rhine document the nutrient enrichment (Fig. 22.1). In the nineteenth century, the nutrient concentrations already amounted to about 50 µM NO_3 and 1–2 µM PO_4 being clearly higher than pristine concentrations of about 14 µM Total Nitrogen and 0.3 µM Total P (Topcu et al. 2011). The largest increases started during the 1950s reaching peak concentrations of about 325 µM Nitrate and 13 µM PO_4 around 1980. Note that the maximum total Nitrogen (TN) and Total Phosphorus concentrations (for which no historic measurements are available) were much higher (about 500 µM TN and 30 µM TP; mean annual concentrations at Lobith; data: Rijkswaterstaat). The eutrophication problem was recognized during the 1970s and 1980s, measures were taken to reduce the nutrient loads (De Jong 2006) and since the 1980s riverine loads to the Wadden Sea decrease at a pace of about 2–3% per year (van Beusekom et al. 2009a).Earliest symptoms of an increased eutrophication are from the Western Dutch Wadden Sea (WDWS). De Jonge and Postma (1974) compared the phosphorus dynamics during the early 1950s and the early 1970s and observed a two- to threefold increase in organic phosphorus compounds. Primary production measurement in the WDWS by Postma and Rommets (1970) and Cadée and Hegeman (2002) document the increase until the mid 1990s followed by a decrease (Philippart et al. 2007). An analysis of long-term data from the Wadden Sea (most starting in the 1980s or

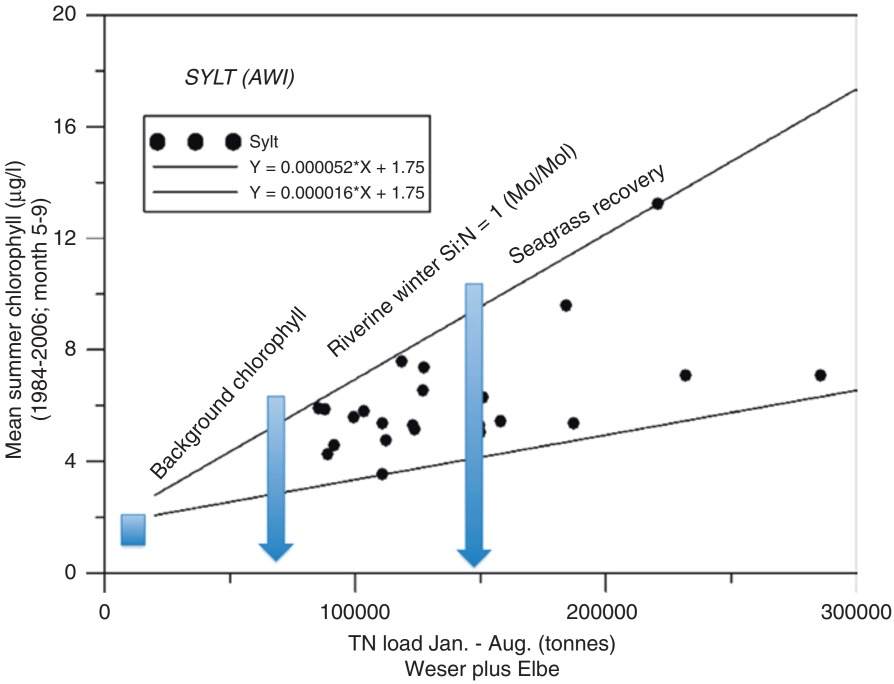
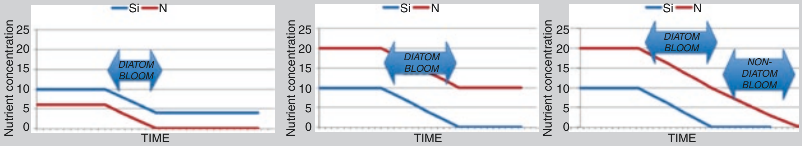


Fig. 22.6 Relation between summer chlorophyll (mean of May–September; AWI time series at Sylt/northern Wadden Sea; van Beusekom et al. 2009b) and riverine nitrogen input by the rivers Weser and Elbe. Also shown are an estimate of background chlorophyll levels (van Beusekom 2006), the river loads that may lead to a Si/N ratio of 1 (possibly leading to a N limited spring bloom compare Brzezinski 1985) and the river load that prevailed when seagrass recovery started during the early 1990s (Dolch et al. 2013)

later) documents a general decrease in chlorophyll levels (van Beusekom et al. 2009a). The relation between riverine nitrogen loads and summer chlorophyll levels in the northern Wadden Sea (Fig. 22.6) exemplifies this and is in accordance with riverine N as a driver of summer phytoplankton dynamics. The variability is large and depends on the nitrogen load (about +/− 40% at both high and low nitrogen loads).

Nutrient ratios may play an important role in phytoplankton dynamics (Box 22.1). Increasing N and P concentrations during the early 1950s lead to increasing N/Si and P/Si ratios eventually leading to a Si limited spring diatom bloom and a surplus of N and P compounds (Gieskes and Kraay 1975). The latter enabled phytoplankton species that did not depend on Si to thrive and in particular the haptophyte *Phaeocystis* became a dominant phytoplankton species in the entire Wadden Sea. Recent observations from the northern Wadden Sea document still a Si limited diatom bloom and a nitrate limited *Phaeocystis* bloom (Loebl et al. 2007). Whereas the role of Si on phytoplankton composition is quite

Box 22.1 Nutrient Ratios and Limiting Nutrients



When growth conditions are good (no grazing, enough light, enough nutrients), algae biomass can accumulate. During such blooms, nutrients can be taken up faster than they are supplied by external sources (e.g. rivers) or by internal cycling (e.g. grazing) ultimately leading to the depletion of that nutrient.

Nutrient poor rivers may supply low amounts of N (nitrogen) to the coastal zone and may contain high concentrations of natural nutrients like Si (dissolved silica, used by diatoms for theirs cell wall). In that case (left graph), N limits a short bloom and Si is left over implying low N/Si ratios before and especially after the bloom (when N will approach zero).

Nutrient rich rivers may supply high amounts of N to the coastal zone but unchanged amounts of Si (high N/Si ratios). In that case (middle graph) a longer bloom develops that is Si limited implying very high N/Si ratios after the bloom when Si will approach zero.

If algae are present that can use the leftover N (right graph) a second bloom may develop.

clear, it is less obvious, whether N or P limitation prevails. Loebl et al. (2009) compared time nutrient, light and phytoplankton time series including three from different parts of the Wadden Sea. Using a method developed by Cloern (1999) they calculated potential nutrients or light limitation. In all cases, light played a major role. During summer, DIN (dissolved inorganic nitrogen) and Si limited phytoplankton growth in the Northern Wadden Sea whereas in the Marsdiep area (Western Dutch Wadden Sea) Si and PO_4 potentially limited phytoplankton. Ly et al. (2014) indeed demonstrated a P limitation during spring. During summer however, P release by sediments potentially counterbalanced P requirements by phytoplankton.

Seagrass is a good indicator of ecosystem health (Orth et al. 2006). Two species occur in the Wadden Sea: *Zostera marina* was decimated in the 1930s from the Wadden Sea due to the wasting disease and did not recover in the Dutch Wadden Sea due to adverse light condition (e.g. de Jonge et al. 1993). In addition, eutrophication was involved in further decline of both *Zostera noltii* and *Z. marina*. Long-term observations by airplane (including historic aerial photography) documented a long-term decrease in seagrass distribution from the 1930s to around 1980 and recovery since the mid-1990s to the 1930s level (Dolch et al. 2013). The recovery coincides with the decreasing riverine nutrient loads since the late 1980s with phosphorus loads decreasing somewhat faster than nitrogen loads (compare van Beusekom et al. 2009a). It is interesting to note that seagrass did not recover in the southern part of the Wadden Sea (Folmer et al. 2016) possibly due to the higher eutrophication level in the southern part (van Beusekom et al. 2009a).

Seagrass and green macroalgae show an opposite response to eutrophication in the Wadden Sea. Green macroalgae– mainly *Enteromorpha* sp. – used to be a marginal phenomenon in the Wadden Sea of the 1930s (the so-called Wattblühen) but large blooms were observed since the 1980s consisting of *Enteromorpha* sp., *Chaetomorpha* sp. and *Ulva* sp. (Reise 1983; Reise and Siebert 1994; Reise et al. 2008) and linked to eutrophication. Regular aerial observations are available since the mid 1990s demonstrating that during the past decades the area covered by green macroalgae has decreased. The area covered with green macroalgae generally showed a good correlation with riverine nitrogen input (van Beusekom et al. 2009a).

Eutrophication led to a higher benthic macrobenthos biomass (Beukema 1989; De Jonge et al. 1996). The response of higher trophic levels is, however complex as other factors like temperature also have a large effect. The decreasing nutrient levels after the mid 1990s in combination with an increasing N/P ratios due to the faster decrease of riverine P compounds than N compounds may have consequences for the carrying capacity of coastal ecosystems: Philippart et al. (2007) demonstrate that long-term variations in limiting nutrients (phosphate and silicon) were weakly correlated with biomass and more strongly with community structures of phytoplankton, macrozoobenthos and estuarine birds in the Dutch Wadden Sea.

Especially long time series from the Wadden Sea dating back to before the 1980s clearly demonstrate the effect of nutrient enrichment on the entire ecosystem. Many time series however started in the 1980s at the height of the riverine nutrient loads. Although several of these time series document a decreasing eutrophication, other long-term signals are picked up as well. One of the dominant factors on the Wadden Sea ecosystem shown by these regular observations is temperature. In the northern Wadden Sea, temperatures rose by almost 2 °C from the 1950s until 2007 (Witte et al. 2010) with warmer winters leading to a reduced, possibly grazing – mediated phytoplankton spring bloom (van Beusekom et al. 2009b, compare Keller et al. 1999), an increase in zooplankton (Martens and van Beusekom 2008), a proliferation of non-indigenous species (e.g. Witte et al. 2010; Diederich et al. 2005; Loebl et al. 2006) and reduced bivalve survival (Strasser 2002; Strasser et al. 2001).

22.4.2 Outlook and Implications for Management

Wherever a long-term view going back to times before the onset of increased nutrient loads is possible, the impact of eutrophication on the Wadden Sea ecosystem is clear. Several time series now also document the de-eutrophication (or oligotrophication) of the Wadden Sea. The decrease in riverine nutrient loads has not been fast (about

2–3%; van Beusekom et al. 2009a) but demonstrates that proper management measures (De Jong 2006) do have a positive effect on the environmental quality.

One of the challenges in managing eutrophication is to put the diverse ecosystem responses to the nutrient loads into one perspective (an ecosystem approach) as an aid to develop management goals. Figure 22.6 shows the relation between summer chlorophyll and the combined nitrogen loads of the rivers Weser and Elbe. As discussed above, chlorophyll levels decreased with decreasing Nitrogen loads but with a high variability. An extrapolation of the two lines enveloping the chlorophyll data suggests chlorophyll levels of about 2 μg/L at low riverine loads and is in line with background estimates (van Beusekom 2006). The relation between riverine Nitrogen loads and chlorophyll however does not show any discontinuities (thresholds) and does not give a clue to what extent river loads have to be reduced to reach a good environmental status. Seagrass loss was a clear discontinuity in the ecological development of the Wadden Sea. The decreasing riverine Nitrogen loads probably contributed to the recovery of seagrass and mark a first success in the ecological recovery of the Wadden Sea. A clear discontinuity in the phytoplankton development was the transition from a N (or P) limited spring bloom to a Si limited spring bloom (compare van Beusekom et al. 2009b). An Si limited spring bloom has not been reached yet and reaching this status could be a next objective reduction goal (rather than pursuing a certain subjective percentage of present day input levels).

Given all other aspects of Global Change (temperature, global traffic, aquaculture, invasive species, sea level rise, etc.) it remains a challenge to foresee the interacting effects on the eutrophication status of the Wadden Sea (Reise and van Beusekom 2008).

The decisions to reduce the eutrophication of the Wadden Sea specifically and the North Sea in general were justified with regard to the observed problems. It remains a great challenge for science to understand the effects of (changing) nutrient loads and the interacting effects of global change with coastal biogeochemistry and ecology. For society and coastal managers it will be a major challenge to find a balance between requirements for a good environmental status and the societal consequences of measures.

22.5 Conclusions and Outlook

1. Enrichment of the coastal zone with anthropogenic nutrients leads to a suit of environmental problems, like phytoplankton blooms, toxic blooms, loss of seagrass, green macroalgae blooms, hypoxia and negative consequences for benthic organisms.
2. The effects of increasing nutrient loads on coastal ecosystems are site-specific.
3. Riverine nutrient loads can be reduced and an improvement of the ecosystem state is likely. However, it is an open question, whether reduction measures will lead to restoration of former conditions as other factors have impacted coastal ecosystems as well (shifting baselines; Duarte et al. 2009).

4. The question whether N or P is limiting is unresolved: both can play a role. Action should be to reduce both N and P loads aiming at balanced ratios (Conley et al. 2009)
5. Climate change is impacting coastal ecosystems and interactive effects with anthropogenic nutrient loads are not yet fully understood.

References

Andersen JH, Schlüter L, Ærtebjerg G (2006) Coastal eutrophication: recent developments in definitions and implications for monitoring strategies. J Plankton Res 28:621–628

Anderson DM, Glibert PM, Burkholder JM (2002) Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. Estuaries 25:704–726

Behrenfeld MJ, Falkowski PG (1997) Photosynthetic rates derived from satellite-based chlorophyll concentration. Limnol Oceanogr 42:1–20

Beukema JJ (1989) Long-term changes in macrozoobenthic abundance on the tidal flats of the western part of the Wadden Sea. Helgoländer Meeresuntersuchungen 43:403–415

Boesch DF (2002) Challenges and opportunities for science in reducing nutrient over-enrichment of coastal ecosystems. Estuaries 25:886–900

Borum J (1996) Shallow waters and land/sea boundaries. In: Jørgensen BB, Richardson K (eds) Eutrophication in coastal marine ecosystems. American Geophysical Union, Washington, DC, pp 179–203

Brzezinski MA (1985) The Si:C:N ratio of marine diatoms: interspecific variability and the effect of some environmental variables. J Phycol 21:347–357

Cloern JE, Foster SQ, Kleckner AE (2014) Phytoplankton primary production in the world's estuarinecoastal ecosystems. Biogeosciences 11:2477–2501

Cadée GC, Hegeman J (2002) Phytoplankton in the Marsdiep at the end of the 20th century; 30 years monitoring biomass, primary production, and *Phaeocystis* blooms. J Sea Res 48:97–110

Cloern JE (1999) The relative importance of light and nutrient limitation of phytoplankton growth: a simple index of coastal ecosystem sensitivity to nutrient enrichment. Aquat Ecol 33:3–16

Cloern JE (2001) Our evolving conceptual model of the coastal eutrophication problem. Mar Ecol Prog Ser 210:223–253

Cloern JE, Jassby AD (2010) Patterns and scales of phytoplankton variability in estuarine–coastal ecosystems. Estuar Coasts 33:230–241

Cloern JE, Jassby AD, Thompson JK, Hieb KA (2007) A cold phase of the East Pacific triggers new phytoplankton blooms in San Francisco Bay. Proc Natl Acad Sci 104:18561–18565

Conley DJ, Paerl HW, Howarth RW, Boesch DF, Seitzinger SP, Havens KE, Lancelot C, Likens GE (2009) Controlling eutrophication: nitrogen and phosphorus. Science 323:1014–1015

Crossland CJ, Kremer HH, Lindeboom HJ, Marshall Crossland JI, LeTissier MDA (2005) Coastal fluxes in the anthropocene: the land-ocean interactions in the coastal zone project of the international geosphere-biosphere programme. Spriger-Verlag, Berlin

Davidson K, Gowen RJ, Harrison PJ, Fleming LE, Hoagland P, Moschonas G (2014) Anthropogenic nutrients and harmful algae in coastal waters. J Environ Manag 146:206–216

De Jong F (2006) Marine eutrophication in perspective. On the relevance of ecology for environmental policy. Springer-Verlag, Berlin

De Jonge VN, Bakker JF, van Stralen M (1996) Recent changes in the contributions of river Rhine and North Sea to the eutrophication of the Western Dutch Wadden Sea. Neth J Aquat Ecol 30:27–39

De Jonge VN, Postma H (1974) Phosphorus compounds in the Dutch Wadden Sea. Netherland J Sea Res 8:139–153

De Jonge VN, van Beusekom JEE (1995) Wind- and tide-induced resuspension of sediment and microphytobenthos from tidal flats in the Ems estuary. Limnol Oceoanogr 40:766–778
Dentener F, Drevet J, Lamarque J, Bey I, Eickhout B, Fiore AM, Hauglustaine D, Horowitz L, Krol M, Kulshrestha U (2006) Nitrogen and sulfur deposition on regional and global scales: a multimodel evaluation. Glob Biogeochem Cycles 20:GB4003
Diaz RJ, Rosenberg R (2008) Spreading dead zones and consequences for marine ecosystems. Science 321:926–929
Diederich S, Nehls G, van Beusekom JEE, Reise K (2005) Introduced Pacific oysters (*Crassostrea gigas*) in the northern Wadden Sea: invasion accelerated by warm summers? Helgol Mar Res 59:97–106
Dolch T, Buschbaum C, Reise K (2013) Persisting intertidal seagrass beds in the northern Wadden Sea since the 1930s. J Sea Res 82:134–141
Duce RA, LaRoche J, Altieri K, Arrigo KR, Baker AR, Capone DG, Cornell S, Dentener F, Galloway J, Ganeshram RS, Geider RJ, Jickells T, Kuypers MM, Langlois R, Liss PS, Liu SM, Middelburg JJ, Moore CM, Nickovic S, Oschlies A, Pedersen T, Prospero J, Schlitzer R, Seitzinger S, Sorensen LL, Uematsu M, Ulloa O, Voss M, Ward B, Zamora L (2008) Impacts of atmospheric anthropogenic nitrogen on the open ocean. Science 320:893–897
Dumont E, Harrison J, Kroeze C, Bakker E, Seitzinger S (2005) Global distribution and sources of dissolved inorganic nitrogen export to the coastal zone: results from a spatially explicit, global model. Glob Biogeochem Cycles 19:GB4S02
Duarte C, Conley D, Carstensen J, Sánchez-Camacho M (2009) Return to Neverland: shifting baselines affect eutrophication restoration targets. Estuar Coasts 32:29–36
Føyn E (1968) Biochemical and dynamic circulation of nutrients in the Oslofjord. Helgoländer Meeresun 17:489–495
Folmer E, van Beusekom JEE, Dolch T, Gräwe U, van Katwijk MM, Kolbe K, Philippart CJM (2016) Consensus forecasting of intertidal seagrass habitat in the Wadden Sea. J Appl Ecol 53:1800–1813
Galloway JN, Townsend AR, Erisman JW, Bekunda M, Cai ZC, Freney JR, Martinelli LA, Seitzinger SP, Sutton MA (2008) Transformation of the nitrogen cycle: recent trends, questions, and potential solutions. Science 320:889–892
Gieskes WWC, Kraay GW (1975) The phytoplankton spring bloom in Dutch coastal waters of the North Sea. Neth J Sea Res 9:166–196
Harrison JA, Seitzinger SP, Bouwman AF, Caraco NF, Beusen AHW, Vorosmarty CJ (2005) Dissolved inorganic phosphorus export to the coastal zone: results from a spatially explicit, global model. Glob Biogeochem Cycles 19:GB4S03
Hecky R, Kilham P (1988) Nutrient limitation of phytoplankton in freshwater and marine environments: a review of recent evidence on the effects of enrichment. Limnol Oceanogr 33: 796–822
Heisler J, Glibert PM, Burkholder JM, Anderson DM, Cochlan W, Dennison WC, Dortch Q, Gobler CJ, Heil CA, Humphries E, Lewitus A, Magnien R, Marshall HG, Sellner K, Stockwell DA, Stoecker DK, Suddleson M (2008) Eutrophication and harmful algal blooms: a scientific consensus. Harmful Algae 8:3–13
Howarth RW, Billén G, Swaney D, Townsend A, Jaworski N, Lajtha K, Downing JA, Elmgren R, Caraco N, Jordan T, Berendse F, Freney J, Kudeyarov V, Murdoch P, Zhao-Liang Z (1996) Regional nitrogen budgets and riverine N & P fluxes for the drainages to the North Atlantic Ocean: natural and human influences. Biogeochemistry 35:141–180
de Jonge VN, Essink K, Boddeke R (1993) The Dutch Wadden Sea - a changed ecosystem. Hydrobiologia 265:45–71
Keller AA, Oviatt CA, Walker HA, Hawk JD (1999) Predicted impacts of elevated temperature on the magnitude of the winter-spring phytoplankton bloom in temperate coastal waters: a mesocosm study. Limnol Oceanogr 44:344–356
Liu D, Keesing JK, Xing Q, Shi P (2009) World's largest macroalgal bloom caused by expansion of seaweed aquaculture in China. Mar Pollut Bull 58:888–895

Loebl M, Colijn F, van Beusekom JEE, Baretta-Bekker JG, Lancelot C, Philippart CJM, Rousseau V, Wiltshire KH (2009) Recent patterns in potential phytoplankton limitation along the Northwest European continental coast. J Sea Res 61:34–43

Loebl M, Dolch T, van Beusekom JEE (2007) Annual dynamics of pelagic primary production and respiration in a shallow coastal basin. J Sea Res 58:269–282

Loebl M, van Beusekom JEE, Reise K (2006) Spread of the neophyte *Spartina anglica* reently enhanced by increasing temperatures? Aquat Ecol 40:315–324

Ly J, Philippart CJ, Kromkamp JC (2014) Phosphorus limitation during a phytoplankton spring bloom in the western Dutch Wadden Sea. J Sea Res 88:109–120

Mee L (2006) Reviving dead zones. Sci Am 295:78–85

Martens P, van Beusekom JEE (2008) Zooplankton response to a warmer northern Wadden Sea. Helgol Mar Res 62:67–75

Miller CB, Wheeler PA (2012) Biological oceanography. Wiley, Hoboken

Nixon SW (1995) Coastal marine eutrophication: a definition, social causes and future concerns. Ophelia 41:199–220

Orth RJ, Carruthers TJB, Dennison WC, Duarte CM, Fourqurean JW, Heck KL, Hughes AR, Kendrick GA, Kenworthy WJ, Olyarnik S, Short FT, Waycott M, Williams SL (2006) A global crisis for seagrass ecosystems. Bioscience 56:987–996

Pearson T, Rosenberg R (1978) Macrobenthic succession in relation to organic enrichment and pollution of marine environment. Oceanogr Mar Biol Ann Rev 16:229–311

Peierls BL, Caraco NF, Pace ML, Cole JJ (1991) Human influence on river nitrogen. Nature 350:386–387

Philippart CJM, Beukema JJ, Cadée GC, Dekker R, Goedhart PW, Iperen JMV, Leopold MF, Herman PMJ (2007) Impact of nutrients on coastal communities. Ecosystems 10:95–118

Postma H, Rommets J (1970) Primary production in the Wadden Sea. Neth J Sea Res 4:470–493

Reise K (1983) Sewage, green algal mats achored by lug-worms, and the effect on Turbullaria and small Polychaeta. Helgoländer Meeresuntersuchungen 36:151–162

Reise K, Herre E, Sturm M (2008) Mudflat biota since the 1930's: change beyond return? Helgol Mar Res 62:13–22

Reise K, Siebert I (1994) Mass occurrence of green algae in the German Wadden Sea. Deutsche Hydrographische Zeitschrift 1:171–188

Reise K, van Beusekom JEE (2008) Interactive effects of global and regional change on a coastal ecosystem. Helgol Mar Res 62:85–91

Ryther JH (1954) The ecology of phytoplankton blooms in moriches bay and Great South Bay, Long Island, New York. Biol Bull 106:198–209

Seitzinger SP, Harrison JA, Dumont E, Beusen AHW, Bouwman AF (2005) Sources and delivery of carbon, nitrogen, and phosphorus to the coastal zone: an overview of Global Nutrient Export from Watersheds (NEWS) models and their application. Glob Biogeochem Cycles 19:GB4S01

Smetacek V, Cloern JE (2008) On Phytoplankton trends. Science 319:1346–1348

Smetacek V, Zingone A (2013) Green and golden seaweed tides on the rise. Nature 504:84–88

Strasser M (2002) Reduced epibenthic predation on intertidal bivalves after a severe winter in the European Wadden Sea. Mar Ecol Prog Ser 241:113–123

Strasser M, Reinwald T, Reise K (2001) Differential effects of the severe winter 1995/1996 on the intertidal bivalves *Mytilus edulis*, Cerastoderma edulis and *Mya arenaria* in the Northern Wadden Sea. Helgoland Marine Res 55:190–197

Topcu D, Behrendt H, Brockmann U, Claussen U (2011) Natural background concentrations of nutrients in the German Bight area (North Sea). Environ Monit Assess 174:361–388

van Bennekom AJ, Gieskes WWC, Tijssen SB (1975) Eutrophication of Dutch coastal waters. Proc R Soc London B 189:359–374

van Bennekom AJ, Wetsteijn FJ (1990) The winter distribution of nutrients in the southern bight of the North Sea (1961–1978) and in the estuaries of the Scheldt and the Rhine/Meuse. Neth J Sea Res 25:75–87

van Beusekom JEE 2006 Eutrophication proxies in the Wadden Sea: regional differences and Background concentrations. In: Laursen K (ed), Monitoring and Assessment in the Wadden

Sea. Proceedings from the 11. Scientific Wadden Sea Symposium. National Environmental Research Institute, Esbjerg, Denmark, p 45–51

van Beusekom JEE, Bot P, Carstensen J, Goebel J, Lenhart H, Pätsch J, Petenati T, Raabe T, Reise K, Wetsteijn B 2009a Eutrophication. Thematic Report No. 6. In: Marencic H, de Vlas J (eds), Quality Status Report 2009, Wadden Sea Ecosystem. No 25. Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, Wilhelmshaven, Germany

van Beusekom JEE, Loebl M, Martens P (2009b) Distant riverine nutrient supply and local temperature drive the long-term phytoplankton development in a temperate coastal basin. J Sea Res 61:26–33

Vollenweider RA (1968) Scientific fundamentals of eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication, Tech. Rep. DAS/CSI/68.27, OECD, Paris

Wang H, Dai M, Liu J, Kao S-J, Zhang C, Cai W-J, Wang G, Qian W, Zhao M, Sun Z (2016) Eutrophication-driven hypoxia in the East China Sea off the Changjiang Estuary. Environ Sci Technol 50:2255–2263

Witte S, Buschbaum C, van Beusekom JEE, Reise K (2010) Does climatic warming explain why an introduced barnacle finally takes over after a lag of more than 50 years? Biol Invasions 12:3579–3589

Ye N-H, Zhang X-W, Mao Y-Z, Liang C-W, Xu D, Zou J, Zhuang Z-M, Wang Q-Y (2011) 'Green tides' are overwhelming the coastline of our blue planet: taking the world's largest example. Ecol Res 26:477–485

Chapter 23
Marine Litter

Stefanie Werner and Aleke Stöfen O'Brien

Abstract The pollution of the marine environment as a result of the introduction of plastic and other waste is one of the major global environmental problems. Life cycle assessments of plastic products so far do not consider the fact that the oceans are a sink for plastics. It is estimated that 6–10% of the global annual plastic production, currently 315 million tons, end up as marine litter. Being bioavailable to many species, micro-plastic particles smaller than 5 mm in size, which originate from the breakdown and use of bigger items as well as from their direct application in products, are of special concern. Plastics are highly persistent and often contain toxic or hormonal effective chemicals or adsorb them from seawater. At present, around 800 species have been shown to have detrimental interactions with marine litter, the majority relating to entanglement in and ingestion of plastic litter items. Additionally, marine litter causes socio-economic costs and may impact the wellbeing of society at large. Analyses of the composition and amounts of marine litter as well as the materials litter items are made of are important because they provide vital information on the land- or sea-based sources marine litter originates from. Even though some uncertainty remains with regard to specific pathways of introduction and the impacts of marine litter, which is due to the complex set of potential sources of marine litter, it is evident that the issue needs to be addressed so as to urgently implement prevention and complementary removal measures. In this regard, harmonized monitoring and sound assessment schemes play an important role in informing decision-makers about suitability and effectiveness of measures taken. Regional Action Plans on Marine Litter for the North-East Atlantic (OSPAR), the Mediterranean (UNEP/MAP) and the Baltic Sea (HELCOM) demonstrate the wide scope of required potential solutions to combat marine litter and are powerful instruments for cross-regional cooperation, which is ongoing between the Regional Seas Conventions.

S. Werner (✉) • A.S. O'Brien
German Environment Agency, Dessau-Roßlau, Germany
e-mail: Stefanie.Werner@uba.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_23

Keywords Marine plastic pollution • Marine litter monitoring • Marine litter sources • Distribution and impacts of marine litter • Solutions to combat marine litter • Regional action plans on marine litter

23.1 Introduction

The pollution of the oceans with anthropogenic litter is nowadays recognised as a major stressor for the marine and coastal environment, with severe impacts on marine biodiversity. It is meanwhile even identified as one of the main global environmental problems and future challenges alongside other key issues such as climate change, ocean acidification and the loss of biodiversity (Sutherland et al. 2010). It has been suggested to name the current epoch the Anthropocene, which started in the middle of the last century when human activities began to have a major impact on the earth's geology and ecosystems, with plastics being a major geological indicator. Already present in large amounts, the occurrence of plastics in the environment is expected to grow several fold in the upcoming decades, not only but also due to the fact that temporary rubbish dumps, in the form of landfills, will erode and release additional amounts of litter. Over time plastics, which end up in terrestrial and marine sediments, become covered with further sediment layers. As with plant and animal remains, these plastics are likely to fossilize and become "technofossils" (Zalasiewicz et al. 2016).

Marine litter covers any persistent, manufactured or processed solid material which has been deliberately discarded, or unintentionally lost on beaches, shores or at sea including materials transported into the marine environment from rivers, draining or sewage systems or winds. Marine litter consists of different materials, amongst others plastics, wood, metal, glass, rubber, textile and paper. The definition does not include semi-solid remains of for example mineral and vegetable oils, paraffin and chemicals found on beaches and in the sea (UNEP 2009; Galgani et al. 2010; OSPAR 2014). On average, three-quarters of all marine litter consists of various forms of plastics that are highly persistent and often contain toxic or hormonal effective chemicals or adsorb them from the seawater. Plastic products facilitate our safety, health, comfort and well-being, but the downside of the use of plastics is that it can enter the environment. Life-cycle analyses so far do not consider the fact that the oceans are a major sink for plastics.

23.2 Occurrence and Quantities

Scientific estimations claim that around 6–10% of the global annual plastic production, currently around 315 million tonnes, sooner or later end up as marine litter. For Europe this is equivalent to 3.4–5.7 million tonnes per year (Essel et al. 2015). This assumption is backed up by a recent modelling exercise for 192 coastal countries, which were estimated to produce a total of 3.5 billion metric tonnes of solid waste in 2010 from which 275 million tons were plastics. Mismanagement of plastic litter in these countries alone led to an estimated introduction of eight million metric tonnes plastic waste into the bordering seas including the Mediterranean and Black Sea (Jambeck et al. 2015). Leakages of plastics into the oceans can occur at all stages of the product's life cycle (production-use-disposal), especially due to inadequate wastewater and solid waste collection and management. However, the total amounts of marine plastics originating from both land- and sea-based sources is still poorly known (UNEP 2016).

Litter and especially light weight plastics can be transported by ocean currents over long distances and it is pervasive throughout our oceans from the poles to the equator, from sea surface to deep sea, and from rivers to lakes and coastal areas. Since the 1960s, when first anecdotal records of litter in the marine environment were made, the reported quantities of marine litter have increased tremendously. It is estimated that the 1982 figure of eight million litter items entering the world's oceans every day probably needs to be multiplied several times (Barnes 2005) and that a minimum of 5.25 trillion plastic particles weighting 269,000 tons are afloat in the sea (Eriksen et al. 2014). These numbers do not include litter on the seafloor, washed up on beaches or ingested by biota. A time-series of litter caught in fishing nets in the north Atlantic identified plastics in 62% of the trawls conducted, with densities of litter on the seabed calculated to be up to 580,000 particles per square kilometer (Law et al. 2010).

Beside large items such as plastic bags or bottles, the occurrence of micro particles, with a size of less than 5 mm, have also been verified in all marine compartments and in biota. Microplastics are defined as either primary (directly manufactured at this size as raw material or for use in products) or secondary (particles originating from the degradation of bigger items by exposure to wind, waves and ultraviolet light or from the use of products, such as tyre abrasion or fibres from clothing). Because the specific densities of plastics vary and because biofouling can alter buoyancy, some float and some sink in sea water. Microplastics can thus be found in all marine habitats and, therefore, a range of organisms from different trophic levels are vulnerable to exposure. The ratio of microplastic particles to zooplankton in the northwestern Mediterranean in litter accumulation areas is 1:2, which illustrates the problem marine biota are exposed to Collignon et al. (2012).

23.3 Sources and Pathways of Marine Litter

One common method is to classify marine litter sources as either land-based or sea-based, depending on where items entered the marine environment. Information on sources and pathways of marine litter is essential to identify operative, efficient and cost-effective measures to prevent and reduce inputs of litter to the marine environment. Sea-based sources include commercial shipping, ferries and liners, both commercial and recreational fishing activities, marine aquaculture, military and research

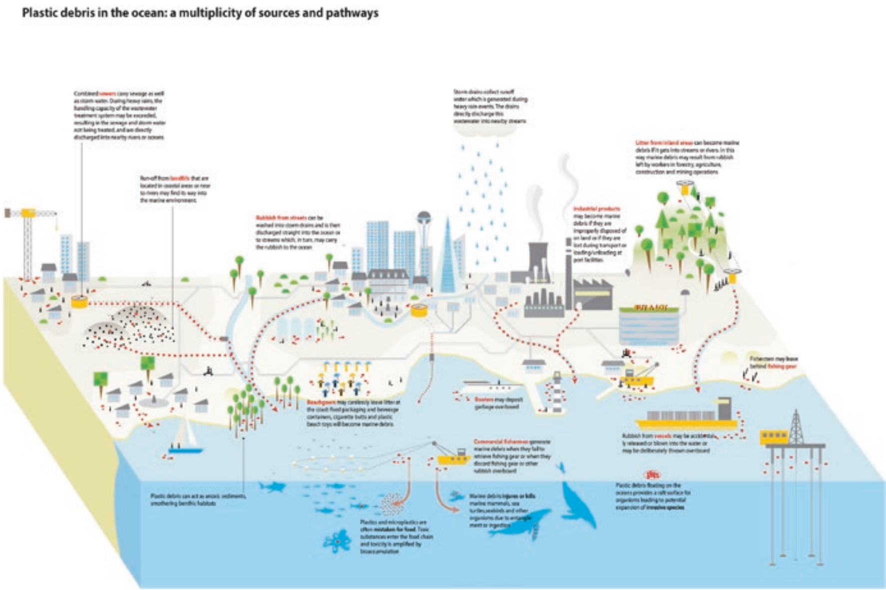


Fig. 23.1 Sources and pathways of marine litter (Source: GRID-Arendal and Maphoto/Riccardo Pravettoni)

fleets, pleasure boats and offshore installations, such as platforms and rigs (Bergmann et al. 2015). Litter is transported into the oceans by wind, rivers and canals. It can travel great distances from inland areas before it reaches the coast. The European Commission indicates that in particular the following land-based sources are responsible for the discharge of plastic waste: rain water run-off, sewage system overflow, especially after heavy rains, tourism, illegal deposition of waste into the landscape, industrial activity and improper transport. Microplastic particles also enter the sea from a variety of sources including inputs from rivers, sewage plants and stormwater overflows and include e.g. plastic pellets, cosmetic agents, plastic blasting agents used for cleaning ship hulls at shipyards, and polyacrylic fibres washed from clothing (European Commission 2013) (Fig. 23.1).

Referring to work done by UNEP, it is often stated that approximately 80% of marine litter arises from land-based sources and the remaining 20% from sea-based sources. However, the basis for this assumption is poorly documented. The 80% are most likely derived from data from the International Coastal Cleanup in Greece 2003 only, since UNEP refers to this study (UNEP 2005). In general it can be concluded, that findings are not consistent and it is more useful to assess available data e.g. for Europe depending on the region, as was identified by the Issue Paper to the International Conference on Prevention and Management of Marine Litter in European Seas. Here available literature on sources, pathways, items and material composition was reviewed, which provided the following generic picture (for more detail see Interwies et al. 2013).

23.3.1 North-East Atlantic

Maritime activities (fishing, commercial shipping, ferries and cruise shipping, leisure boat traffic, offshore installations and aquaculture facilities) and land-based activities (tourism and recreational activities) account for about 80% of waste input. Other sources include discharges from municipal waste through rivers and canals, and solid waste from industrial facilities, dumpsites or sewage systems near the coast.

23.3.2 Baltic Sea

The majority of marine litter items can be traced to consumer waste, with a high share of household goods and equipment associated with tourism (including toiletries). Its input occurs is via rivers and direct deposition on the coastline. The greatest sea-based source of input is the fishing industry.

23.3.3 Mediterranean Sea

Land-based sources account for the majority of marine litter. About 40–50% of litter input emanates from tourist activities, with volumes rising significantly during the holiday season. An estimated additional 40% consists of household items (including toiletries). In addition to inputs from the fishing industry, cigarette butts are also present on a substantial scale along the Mediterranean coast.

23.3.4 Black Sea

Relatively little data is available. Some data points to municipal waste, which is discharged in sewage, e.g. from poorly managed dumpsites, as a dominant source of marine litter followed by inputs from maritime transport, ports, inland coastal tourism and part-time fisheries. Many household items (including toiletries) are also found. Illegal fishing activities are also identified repeatedly as a major source.

Freshwater systems are considered to represent important pathways for the input of litter to the oceans. Yet our understanding about the accumulation, transport and impacts of litter in freshwater systems lags behind that of the marine environment. Only recently researchers began to investigate European rivers and streams for microplastic particles of various size, shape and polymer composition, e.g. in the rivers Danube, Elbe, Moselle, Neckar, Rhine and Rhone. Investigations of beach sediments of the subalpine Lake Garda revealed a microplastic contamination in the same order of magnitude as have been described for marine sediments (Imhof et al. 2013).

23.4 Impacts of Marine Litter

In 2014 the Convention of Biological Diversity updated the total number of species known to be affected by marine litter to almost 800 (CBD 2014). Many of these species are protected and are considered vulnerable to marine litter. To exemplify this, of 120 marine mammals species listed on the IUCN list, 54 (45%) of these were reported to have interacted through entanglement or ingestion with marine litter, 15% of them are red-listed. The analyses of studies on the topic, indicate that globally rope and netting account for 57% of encounters of marine organisms with litter, followed by fragments (11%), packaging (10%), other fishing related litter (8%) and microplastics (6%). Beside the physical consequences of the ingestions of plastic particles such as internal blockages, injuries, starvation and translocation, the consequences of exposure to chemicals associated especially with microplastics are becoming more and more an issue of concern, also with regard to human food safety.

23.4.1 Entanglement

The most visible effect of plastic pollution is entanglement of wildlife in marine litter, often but not exclusively, in discarded or lost fishing gear or rope. Fishing gear accounts for about one-tenth of the waste in the world's oceans and is of particular concern because it can continue to 'fish' ownerless for decades, a process referred to as ghost fishing (CBD 2012).

A comprehensive review in 2015 identified that 161 marine species were reported to be affected by entanglement, thereof all marine turtles, 67% of seals, 31% of whales, 25% of seabirds with rapid increases in the number of fish and invertebrate species being recorded (Kühn et al. 2015). Other findings indicate that worldwide between 57,000 and 135,000 pinnipeds and baleen whales are entangled each year, in addition to the inestimable—but likely millions—of birds, turtles, fish and other species (CMS 2014). Active entanglement may cause immediate and severe welfare problems for the animal. For example, if the entanglement or entrapment prevents marine mammals from resurfacing, they will asphyxiate and drown, a process which can take minutes to hours. Rapid death can also be caused because of reduced ability to escape from predators, to avoid collisions with ships or to obtain food (Butterworth et al. 2012). It is however likely that a much higher number of individuals are affected by sub-lethal effects that have not been fully investigated. However, they include reduced mobility and reduced ability to ingest and digest food, which both lead to reduced fitness, reproduction success and ability to migrate (CMS 2014) (Fig. 23.2).

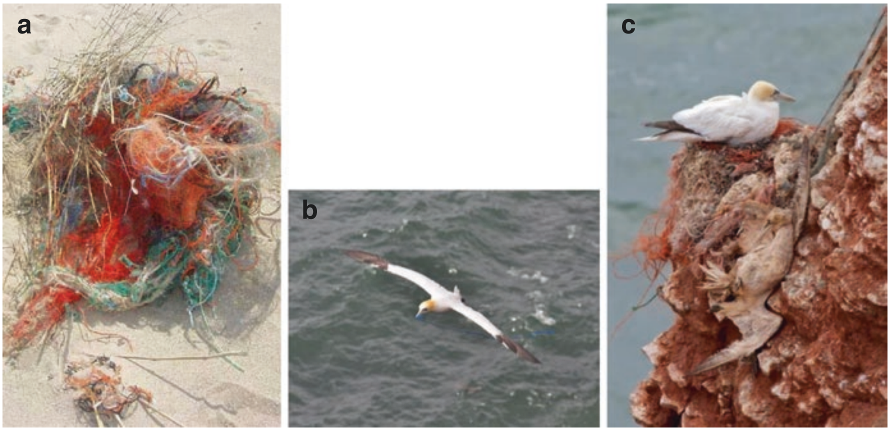


Fig. 23.2 Photo (**a**)–(**c**): Remains of fishing gear, Northern gannets transporting and entangled in fishing gear (Sources: OSPAR, N. Guse and P. Hübner)

23.4.2 Ingestion

Since the first major review by Laist in 1997, the number of animal species known to ingest plastics has increased considerably, from 177 to 331 species (CBD 2014). The recent review by Kühn et al. (2015), documents that at least 40% of the world's seabird species, 100% of marine turtle species and 50% of marine mammals are currently known to have ingested marine plastic litter. Rapid increases in marine litter interaction records for fishes and invertebrates are likely to be more related to an increased numbers of studies than a sudden increase in ingestion rates. Whereas only in few cases interactions pose a threat to entire populations, it is indisputable that the known impacts cause a deterioration of the physical condition of the affected individuals, and a far greater number of organisms are affected by as yet undocumented sublethal effects. In the context of ingestion, plastic materials are of particular concern due to their persistence, and inherent or acquired toxicity (Werner et al. 2016). Lost or littered (discarded) plastics degrade and fragment into millions of small pieces making them available to a wide range of marine biota, from primary producers to higher trophic-level organisms, potentially infiltrating the entire marine food web. Often so-called biodegradable plastics are suggested as a potential solution, but one has to keep in mind, that the large majority of biodegradable plastics can only biodegrade under specific conditions of constant temperature and humidity in industrial composting installations. Therefore they do not degrade in a reasonable time in the marine environment. Moreover, many biodegradable plastics may not degrade in the intestines of marine species. Hence injury and starvation are likely to remain issues even if alternatives are found (OSPAR 2014).

The potential physical impacts of microplastics on marine organisms have been reviewed in various publications (e.g. Wright et al. 2013; GESAMP 2015). Under laboratory conditions inflammatory responses have been demonstrated for different species, thereunder mussels and crustaceans (Von Moos et al. 2012; Browne et al. 2008; Cedervall et al. 2012). The ability of nano material to pass cell membranes is well documented. In contrast, available data occurrence of plastic particles in this size range is insufficient.

Furthermore, plastics often contain substances which are added during production to facilitate certain product characteristics (so-called additives) and tend to adsorb persistent organic pollutants from the surrounding sea water. For short-tailed shearwaters (*Puffinus tenuirostris*) it was shown that a transfer of additives from plastic particles to the tissues of the organism, which ingested the plastic, is possible (Tanaka et al. 2013). Rochman et al. (2013) proved a possible chemical transfer of adsorbed persistent organic pollutants from plastic fed to lantern fish (*Myctophidae*), causing liver inflammation in response. However, with regard to the adsorption process of organic pollutants, one has to keep in mind that those substances are already present in marine organisms due to their presence in the surrounding waters and sediments and due to normal food web interactions (Teuten et al. 2009; Rainbow 2007). It is known that the health as well as reproduction of some populations of killer whales, dolphins and harbor porpoises are negatively affected due to their pollutant load with PCBs (Jepson et al. 2016). Unclear is the significance of the ingested plastic particles in comparison to the background pollution and if a causal relationship can be identified in the natural environment, where the exposition to plastic particles is most likely much lower. Whereas the fatal mechanical impacts from interactions with plastic litter are indisputable, more research is required with regard to the additional potential chemical consequences (Fig. 23.3).

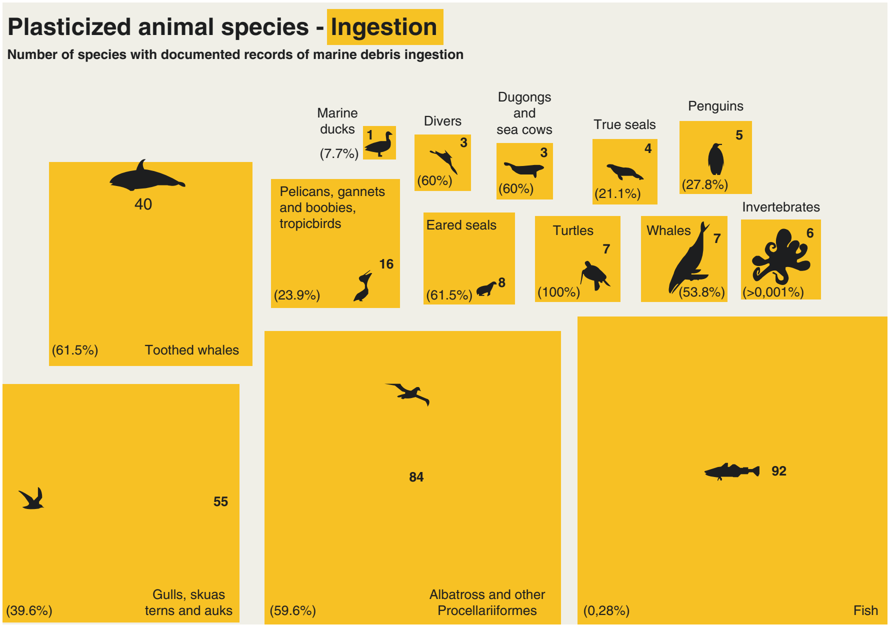


Fig. 23.3 Species with records of marine litter ingestion (Source: GRID-Arendal and Maphoto/ Riccardo Pravettoni)

23.4.3 Other Impacts

A range of problems are associated with marine litter, making it a complex problem. Marine litter can impact organisms on different levels of biological organizations and habitats in a number of ways. Beside the above mentioned impacts of entanglement and ingestion marine litter is known to act as vector for the transport of biota, including invasive species, and to smother and damage habitats, altering species composition and abundance. In addition a commonly debated ethical point concerns the issue of animal welfare. Unlike many societal challenges the suffering of animals due to interaction with marine litter is not related to one single human activity.

Marine litter is a threat not only to marine species and assemblages but also has significant social implications including a reduction in the aesthetic value e.g. of beaches (driving away tourists) and public safety (e.g. when beach litter composes medical and sanitary waste, divers become entangled in ghost fishing gear or ship propeller are blocked by litter items threatening navigations safety). The economic component implies costs to various industry sectors and local communities, e.g. the significant costs arising from coastal clean-up campaigns, damage of vessels and fishing gear and contamination of catches (see also Fig. 23.4).

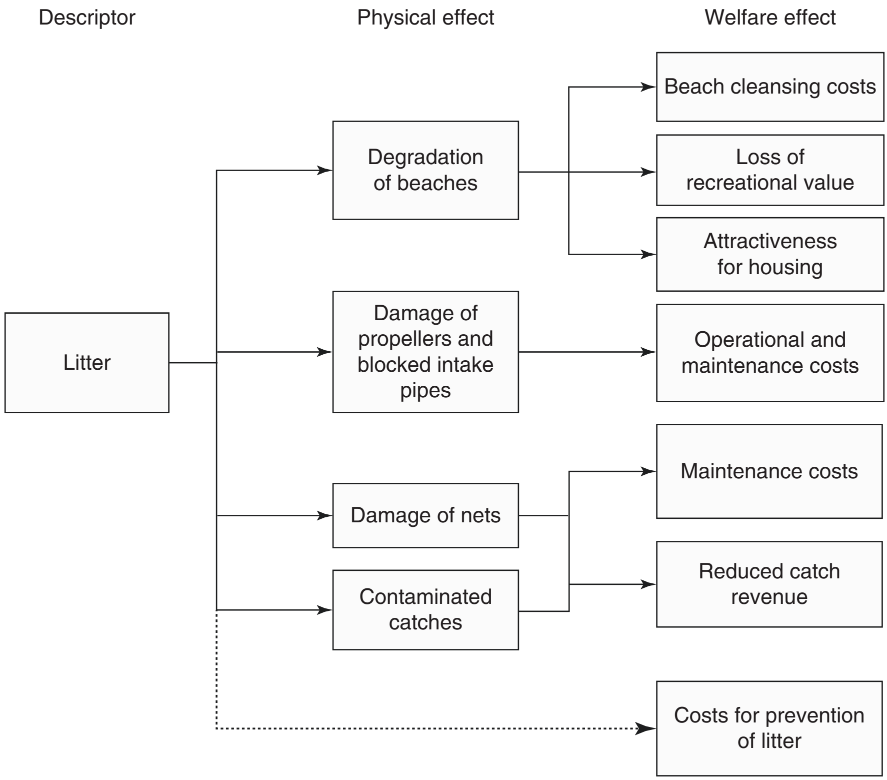


Fig. 23.4 Potential impact of marine litter on socioeconomic activities (Werner et al. (2016) taken from Reinhard et al. (2012))

23.5 From Existing Knowledge to Sound Solutions to Combat Marine Litter

23.5.1 Monitoring

There exist a number of monitoring programs for marine litter. For example the European Member States have established such programs in order to fulfill the requirements of the Marine Strategy Framework Directive (MSDF). Effect since 2008 the MSFD is the environmental pillar of the European Maritime Strategy. While for litter on beaches and ingestion of litter items by seabirds, datasets were already available before the MSFD, corresponding data for other marine compartments, namely the sea surface and the seafloor, for micro particles and the major biological impacts of entanglement and ingestion by further indicator species, are currently being derived and validated. To facilitate the achievement of comparable data, the European Technical Group on Marine Litter was established in 2010 in order to assist EU Member States in the implementation of the MSFD. In a first step, monitoring protocols were developed partly on the basis of existing monitoring programmes: for beach (meso and macro) litter monitoring, for monitoring of litter on the sea-surface (ship-based and aerial surveys, pelagic trawls and litter in sea-birds (Northern fulmar) stomachs), for monitoring of litter on the sea floor (bottom trawl surveys, submersibles and SCUBA-Surveys for shallow waters), for monitoring of micro litter (in sediments, the water column and invertebrates) and for monitoring the biological impacts of litter (ingestion in sea birds, fish and turtles and entanglement in terms of plastics as nesting material in birds breeding colonies and associated mortality rates (JRC 2013)).

Existing data from monitoring programs, which in part have been running for over a decade, already allow us in some regions to identify the most important litter items found in the marine environment. Although the composition of litter differs between regions, general patterns are obvious and the data can already be used as a basis for defining appropriate measures e.g. in the OSPAR region. When developing measures for the litter items recorded during monitoring, not only their abundance but also their potential harm to the marine environment should be taken into consideration. Furthermore, it is essential to specify the reasons why and how the specific item enters the oceans.

23.5.2 Risk Assessment

In simple terms risk is defined as the likelihood (or probability) that a consequence (or hazard) will occur. In the context of marine litter, the hazard is the presence and potential impact of litter items/particles and the likelihood is the extent or rate of encounter. Estimating the degree of risk provides a more robust basis for decisions on whether or how to act to reduce the risk (UNEP 2016). Although a large number of empirical studies provide emerging evidence of impacts of marine litter to wildlife, there has been little systematic assessment of risk (Galloway and Lewis 2016). Wilcox et al. (2016) elicited information from experts on the ecological threat (both severity and specificity) of entanglement, ingestion and chemical contamination for three major marine taxa: seabirds, sea turtles and marine mammals. The threat assessment focused on the most common types of litter that are found along the world's coastlines, based on data gathered during three decades of international coastal cleanup efforts. Fishing related gear, balloons and plastic bags were estimated to pose the greatest entanglement risk to marine fauna. In contrast, experts identified a broader suite of items of concern for ingestion, with plastic bags and plastic utensils ranked as the greatest threats. Entanglement and ingestion affected a similar range of taxa, although entanglement was rated as slightly worse because it is more likely to be lethal. Contamination was scored as the lowest risk for marine biota, affecting a smaller portion of taxa and being rated as having solely non-lethal impacts. This work points towards a number of opportunities both for policy-based actions and consumer-driven changes in plastic use.

23.5.3 Regional Action Plans on Marine Litter

The above given overview on sources and impacts clearly indicates, that the reduction of the input and existing amounts of marine litter necessitates the inclusion of a vast amount of activities, sectors and sources that cannot be addressed by a single measure and organization. Tight collaboration between regional and global organizations and initiatives is therefore needed, including UNEP and Regional Seas Conventions, the International Maritime Organisation (IMO), the Convention on Biological Diversity (CBD), the European Union (EU), the Food and Agriculture Organization (FAO) and River and River Basin Commissions. Partnerships with the private sector and with non-governmental organizations need to be an integral part of the working approach right from the start.

In 2011 the United Nations Environment Programme (UNEP) and the National Oceanic and Atmospheric Administration (NOAA) initiated the fifth "International Marine Debris Conference" which led to the thematic breakthrough. The so-called Honolulu-Strategy can be regarded as the first step towards a global Action Plan to combat marine litter. The Regional Seas Conventions for the protection of the North-East Atlantic (OSPAR), the Mediterranean Sea (UNEP/MAP) and the Baltic Sea (HELCOM) meanwhile developed Regional Action Plans on Marine Litter (RAPs ML). The RAPs ML demonstrate the wide scope of required potential solutions to combat marine litter and are powerful instruments for cross-regional cooperation, which is ongoing between the Regional Seas Conventions. In addition to fulfill the requirements of the MSFD national programmes of measures for all Descriptors including marine litter had to be determined (2015) and are currently implemented which are closely linked to the demands of the RAPs ML. Beyond the implementation of the MSFD there is a growing awareness for the need to harmonise and revise definitions and methodologies in a wide range of EU legislation, i.e. waste law (Waste Framework Directive, Landfill Directive, Packaging and Waste Packaging Directive), production law (e.g. Ecodesign Directive) and water and soil law (Water Framework Directive, Port Reception Facilities, European Strategy on Plastic Waste in the Environment**,** Circular economy package) in order to address and combat litter in the environment (see also Chap. 39).

The existing Action Plans under OSPAR, UNEP/MAP and HELCOM deal with a comprehensive set of actions by targeting the major sea-based and land-based sources. Whereas prevention measures including education and outreach are key to the plans, removal actions for the different marine and river compartments have also been formulated (see Table 23.1).

Implementation of the RAPs ML is ongoing and some improvements are already visible (e.g. green deals with fishing industry, recommendation by Cosmetics Europe to their member companies to step out of the use of microplastics in personal care and cosmetic products, wide application of passive fishing for litter schemes etc.). Delaying of actions which are signed up can be observed as well, often caused by lack of sufficient funding to support the plans. Being strongly

Table 23.1 Key issues, which are addressed by the OPSAR Regional Action Plan for the North-East Atlantic

Field of action	Key issues
Actions to combat sea-based sources	• Enforcement of international legislation/regulation regarding all sectors • Incentives for responsible behavior/disincentives for littering • Development of best practice in relation to waste from fishing industry • Penalties/fines for littering at sea • Harmonized/improved system for port reception facilities including standardized fee system (e.g. no-special-fee-system)
Actions to combat land-based sources	• Improved waste prevention and management • Reduction of sewage and storm water related waste • Incentives for responsible behavior/disincentives for littering • Redesign of harmful products • Reduction of single use items • Reduction of the use of primary microplastics in industrial applications • Development of sustainable packaging • Removal of microplastics/zero pellet loss
Removal actions	• Application of fishing for litter activities • Cleaning environmental compartments and keeping them clean (e.g. beach clean ups) • Reduction of abandoned, lost and otherwise discarded fishing gear • Mapping floating litter hotspots • Emission of microplastics (e.g. through improved filtering in waste water treatment plants and washing machines)
Education and Outreach actions	• Joint database on initiatives/best practise examples based on existing ones (such as MARLISCO or data base of "international conference on prevention and Management of Marine Litter in European seas") • Communication strategies • Development of information sheets and education tools, e.g. for relevant sectors such as the maritime industry

involved in the implementation of the RAPs ML it is the strong belief of the authors that they represent the best instrument for efficient and effective horizontal multi stakeholder involvement. They address the major action fields where improvement is needed. By considering the implications for the marine environment as the ultimate sink for litter they add weight to existing sectoral approaches of other regimes. The fact that they are implemented in parallel and address related topics represents a historic chance which should not be "wasted".

References

Barnes KA (2005) Remote Islands reveal rapid rise of southern hemisphere sea debris. Sci World J 5:915–921. ISSN: 1537-744X. doi:10.1100/tsw.2005.120

Bergmann M, Gutow L, Klages M (eds) (2015) Marine anthropogenic litter. Springer, Berlin. http://link.springer.com/book/10.1007%2F978-3-319-16510-3

Browne MA, Dissanayake A, Galloway T, Lowe DM, Thompson R (2008) Ingested microscopic plastic translocates to the circulatory system of the mussel, *Mytilus edulis* (L.) Environ Sci Technol 42(13):5026–5031

Butterworth A, Clegg I, Bass C (2012) Untangled – marine debris: a global picture of the impact on animal welfare and of animal focused solutions. World Society for the Protection of Animals, London

CBD – Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel— GEF (2012) Impacts of marine debris on biodiversity: current status and potential solutions, Montreal, Technical Series No. 67, 61p

CBD (2014) Background document on the preparation of practical guidance on preventing and mitigating the significant adverse impacts of marine debris on marine and coastal biodiversity, UNEP/CBD/MCB/EM/2014/3/2

Cedervall T, Hansson L-A, Lard M, Frohm B, Linse S (2012) Food chain transport of nanoparticles affects behaviour and fat metabolism in fish. PLoS One 7:e32254., 6p. doi:10.1371/journal.pone.0032254

CMS – Convention on Migratory Species (2014) Report I: migratory species, marine debris and its management UNEP/CMS/COP11/Inf27, 16 Aug 2014

Collignon A, Hecq J, Galgani F, Voisin P, Collard F, Goffart A (2012) Neustonic microplastic and zooplankton in the north western Mediterranean Sea. Mar Pollut Bull 64:861–864

Eriksen M, Lebreton LCM, Carson HS, Thiel M, Moore CJ, Borerro JC, Galgani F, Ryan P, Reisser J (2014) Plastic pollution in the World's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. PLoS One 9(12):e111913. doi:10.1371/journal.pone.0111913

Essel R et al (2015) Sources of microplastic relevant to marine protection, Nova Institute für Oekologie und Innovation GmbH. UBA Texte 64/2015

European Commission (2013) Green paper – on a strategy on plastic waste in the environment. COM(2013) 123 final

Galgani F, Fleet D, Van Franeker J, Katsanevakis S, Maes T, Mouat J, Oosterbaan L, Poitou I, Hanke G, Thompson R, Amato E, Birkun A, Janssen C. Marine Strategy Framework Directive Task Group 10 Report Marine litter (2010) JRC Scientific and Technical Reports: EUR 24340 EN – 2010

Galloway T, Lewis C (2016) Marine microplastics spell big problems for future generations. Proc Natl Acad Sci U S A 113:2331–2333. doi:10.1073/pnas.1600715113

GESAMP (2015) Sources, fate and effects of microplastics in the marine environment: a global assessment. In: Kershaw PJ (ed) IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP joint group of experts on the scientific aspects of marine environmental protection. Rep Stud GESAMP No 90, 96p

Imhof HK, Ivleva NP, Schmid J, Niessner R, Laforsch C (2013) Contamination of beach sediments of a subalpine lake with microplastic particles. Curr Biol 23:867–868. doi:10.1016/j.cub.2013.09.001

Interwies E, Görlitz S, Stöfen A, Cools J, van Breusegem W, Werner S, de Vrees L (2013) Issue paper to the international conference on prevention and management of marine litter in European seas. Online: http://www.marine-litter-conference-berlin.info

Jambeck JR, Geyer R, Wilcox C, Siegler TR, Perryman M, Andrady A, Narayan R, Law KL (2015) Plastic waste inputs from land into the ocean. Science 347:768–771. doi:10.1126/science.1260352

Jepson PD, Deaville R, Barber JL, Aguilar A, Borrell A, Murphy S, Barry J, Brownlow A, Barnett J, Berrow S, Cunningham AA, Davison NJ, ten Doeschate M, Esteban R, Ferreira M, Foote AD, Genov T, Giménez J, Loveridge J, Llavona A, Martin V, Maxwell DL, Papachlimitzou A, Penrose R, Perkins MW, Smith B, de Stephanis R, Tregenza N, Verborgh P, Fernandez A, Law RJ (2016) PCB pollution continues to impact populations of orcas and other dolphins in European waters. Nat Sci Rep 6:18573. doi:10.1038/srep18573

JRC Scientific and Policy Reports (2013) Guidance on monitoring of marine litter in European seas. MSFD technical subgroup on marine litter. ISBN: 978-92-79-32709-4

Kühn S, Bravo Rebolledo EL, Van Franeker JA (2015) Deleterious effects of litter on marine life. In: Bergmann M, Gutow L, Klages M (eds) Marine anthropogenic litter. Springer, Berlin. (open access). doi:10.1007/978-3-319-16510-3_4

Law K, Moret-Ferguson S, Maximenko N, Proskurowski G, Peacock E, Hafner J, Reddy C (2010) Plastic accumulation in the North Atlantic subtropical gyre. Science 329:1185–1188

OSPAR (2014) Regional action plan on marine litter, online: http://www.ospar.org/documents?v=34422

Rainbow PS (2007) Trace metal bioaccumulation: models, metabolic availability and toxicity. Environ Int 33(4):576–582

Reinhard S, de Blaeij A, Bogaardt M-J, Gaaff A, Leopold M, Scholl M, Slijkerman D, Strietman WJ, van der Wielen P (2012) Cost-effectiveness and cost-benefit analysis for the MSFD. Framework for the Netherlands. LEI, The Hague

Rochman CM et al (2013) Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress. Sci Rep 3:3263

Sutherland WJ, Clout M, Cote IM, Daszak P, Depledge MH, Fellman L, Fleishman E, Garthwaite R, Gibbons DW, De Lurio J, Impey AJ, Lickorish F, Lindenmayer D, Madgwick J, Margerison C, Maynard T, Peck LS, Pretty J, Prior S, Redford KH, Scharlemann JPW, Spalding M, Watkinson AR (2010) A horizon scan of global conservation issues for 2010. Trends Ecol Evol 25:1–7. doi:10.1016/j.tree.2009.10.003

Teuten EL, Saquing JM, Knappe DRU, Barlaz MA, Jonsson S, Björn A, Rowland SJ, Thompson RC, Galloway TS, Yamashita R, Ochi D, Watanuki Y, Moore C, Viet PH, Tana TS, Prudente M, Boonyatumanond R, Zakaria MP, Akkhavong K, Ogata Y, Hirai H, Iwasa S, Mizukawa K, Hagino U, Imamura A, Saha M, Takada H (2009) Transport and release of chemicals from plastics to the environment and to wildlife. Philos Trans R Soc B 364:2027–2045

Tanaka K, Takada H, Yamashita R, Mizukawa K, Fukuwaka, M, Watanuki Y (2013) Accumulation of plastic-derived chemicals in tissues of seabirds ingesting marine plastics. Mar Pollut Bull 69:219–222

UNEP (2005) Marine litter. An analytical overview, 58p

UNEP (2009) Marine litter – a global challenge, 234p

UNEP (2016) Marine plastic debris & microplastics. Global lessons and research to inspire actions and guide policy change, 274p

Von Moos N et al (2012) Uptake and effects of microplastics on cells and tissue of the blue mussel Mytilus edulis L. after an experimental exposure. Environ Sci Technol 46(20):11327–11335

Werner S, Budziak A, van Franeker J, Galgani F, Hanke G, Maes T, Matiddi M, Nilsson P, Oosterbaan L, Priestland E, Thompson R, Veiga J, Vlachogianni T (2016) Harm caused by Marine Litter. MSFD GES TG Marine Litter-Thematic Report; JRC Technical report; EUR 28317 EN; doi: 10.2788/690366

Wilcox C, Mallos NJ, Leonard GH, Rodriguez A, Hardesty BD (2016) Using expert elicitation to estimate the impacts of plastic pollution on marine wildlife. Mar Policy 65:107–114

Wright SL et al (2013) Microplastic ingestion decreases energy reserves in marine worms. Curr Biol 23(23):R1031–R1033

Zalasiewicz J, Waters CN, do Sul I, Corcoran P, Barnosky AD, Cearreta A, Edgeworth M, Galuszka A, Jeandel C, Leinfelder R, McNeill JR, Steffen W, Summerhayes C, Wagreich M, Williams M, Wolfe AP, Yonan Y (2016) The geological cycle of plastics and their use as a stratigraphic indicator of the Anthropocene. Anthropocene 13:4–17

Chapter 24
Input of Energy/Underwater Sound

Olaf Boebel, Elke Burkhardt, and Ilse van Opzeeland

Abstract Underwater sound is ubiquitous throughout the world's oceans. Evaluating its impact and relevance for the marine fauna is highly complex and hampered by a paucity of data, lack of understanding and ambiguity of terms. When comparing sound (an energetic pollutant) with substantial pollutants (chemical, biological or marine litter) two notable differences emerge: Firstly, while sound propagates instantaneously away from the source, it also ceases immediately within minutes of shutting off the source. Anthropogenic noise is hence *per-se* ephemeral, lending itself to a set of *in-situ* mitigation strategies unsuitable for mitigation of persistent pollutants. Secondly, while pollution with hazardous substances can readily be described quantitatively with few parameters (concentration as the most important one), the description of sound and its impact on aquatic life is of much higher complexity, as to be evidenced by the issue's multifaceted description following hereinafter.

Keywords Underwater sound • Underwater acoustic environment • Marine life • Soundscape • Anthropogenic noise • Marine management

24.1 Introduction

This chapter's format prohibits a comprehensive discussion of the current state of knowledge and the provision of multifaceted guidelines that would do justice to the complexity of this topic. While hence having to refer the interested reader to comprehensive compilations on its specific aspects (i.a. Ainslie 2015; National Research Council 2003, 2005; Popper et al. 2014; Richardson et al. 1995; Southall et al. 2007b), we here present this topic's overarching concepts by presenting sets of

O. Boebel (✉) • E. Burkhardt • I. van Opzeeland
Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung, Bremerhaven, Germany
e-mail: Olaf.Boebel@awi.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_24

contrasting terms as basis for a structured approach to its appraisal, while also highlighting some of its more common pitfalls. The succeeding chapters first introduce terms of the trade (printed bold) as required for the further discussion, followed by a generalized categorization of the effects of sound on marine fauna. Thereafter we provide a brief listing of the major anthropogenic sound producers, followed by short section on current mitigation approaches to conclude with a discussion of requirements for prudent management of underwater sound.

24.2 A brief Introduction to Underwater Acoustics: Concepts and Terms

Underwater ***sound***[1] is ubiquitous throughout the world's oceans. Nothing could be, or ever was, further from truth than the common notion of a quiet ocean, as stipulated by the title of Jacques-Yves Cousteau's and Louis Malle's influential movie from 1956 "*Le Monde du silence*". Until the late nineteenth century, when steamships became more common sights, the natural underwater ***acoustic environment***[2] was shaped by biotic (marine mammals, fish, invertebrates) and abiotic (waves and rain, undersea earthquakes, lightning strikes) sound sources, some of which match the source levels of today's loudest anthropogenic sources. Commencing with the mechanization of shipping, a multitude of additional anthropogenic sources emerged throughout the last century: ships, underwater explosions, sonars and seismic sources now produce acoustic sound signatures that contribute to the underwater acoustic environment year-round.

The underwater acoustic environment may be decomposed into ***discrete*** and ***diffuse***[3] components. Discrete contributions can be assigned to their respective acoustic sources, such as a ship passing nearby or a clicking sperm whale. Discrete sources are often of high intensity with significant mid- and high frequency components, yet local or regional in range and limited in time. Diffuse contributions (such as caused by distant storms or shipping lanes) cannot be assigned to a specific sound

[1] "***Sound***", as defined by ISO/DIS 18405.2 constitutes the "alteration in pressure, stress or material displacement propagated via the action of elastic stresses in an elastic medium and that involves local compression and expansion of the medium, or the superposition of such propagated alterations." The scientific meaning of sound therefore has no judgmental connotation, i.e. it is not used as the antonym of "noise", regardless of its origin or deliberateness of emission. Hereinafter, use of the term ***sound*** is strictly confined its physical meaning.

[2] The "***acoustic environment***" represents the sound at the receiver from all sound sources as modified by the environment (ISO 2014. ISO 12913-1:2014(E) Acoustics—Soundscape—Part1: Definitions and conceptual framework.) In marine acoustics it is currently used synonymously with the term "soundscape", which, however, in terrestrial acoustics represents a subjective perception, i.e. the acoustic environment as perceived by the listener.

[3] Sometimes called "ambient noise", a term we deprecate, due to the ambivalent meanings of the term noise. See also footnote #7.

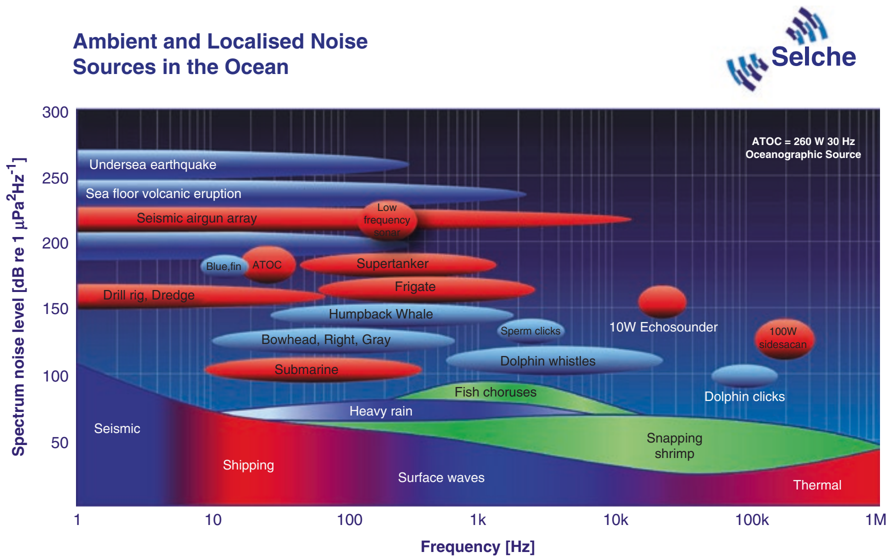


Fig. 24.1 (© Seiche Ltd. 2006) Spectral source levels versus frequency content of diffuse (called ambient in this figure) and discrete (called localized in this figures) sound sources in the ocean. Reproduced with permission by Seiche Ltd., The Advanced SONAR Course, Seiche (2002) ISBN 1-904055-01-X

source. They are usually of lower intensity and frequency, but far-reaching and often chronic.

Characteristics of sound differ widely between sources, with ***frequency*** and (nominal) ***source level***[4] being the most fundamental parameters (Fig. 24.1). Together they govern the range at which a specific sound will influence the acoustic environment. While louder sounds of course generally reach farther, sounds of different frequencies are subject to differences in absorption, diffraction, refraction and reflection. ***Low-frequency*** sounds *(<200 Hz)*[5] propagate much farther (hundreds of km) than ***mid-frequency*** (*200 Hz < f < 25 kHz*) sounds, which reach tens of kilometres, and ***high-frequency*** sounds *(>25 kHz*) which cover a few or even less than a kilometre.

Temporal characteristics of specific sounds vary across orders of magnitude. Impulse-like, ***transient*** signals from odontocetes (toothed whales) and sonars are of few to tens of milliseconds duration, followed by pauses on the order of seconds to tens of seconds until the next pulse is emitted. Grounding and colliding icebergs or

[4] "Nominal source levels" are used as parameter in far-field sound level calculations and must not be confused with true sound levels near the source. Note that Figure 1 depicts spectral source levels, not source levels, for discrete sources and spectral levels for diffuse sources.

[5] The terms, high-, mid- and low-frequency are associated by different stakeholders with rather different frequency ranges. Whenever using these terms, their definition should be provided for clarification. Here we follow the classification used by Hildebrand (2009) anthropogenic and natural sources of ambient noise in the ocean. Mar Ecol Prog Ser 395, 5–20.

marine vibrators emit minute-long sounds, while broadband sounds from storms and ships are audible for hours if not ***continuously*** for days to weeks.

Of similar variability is the duration of activities responsible for the sound generation. Anthropogenic activities might be rather ***short-term*** (e.g. a ship shock test or detonation of a naval mine), or last for an hour, like the passage of a ship. Other activities are ***long-lasting***, spreading over days (naval manoeuvres or ramming of a single wind farm foundation) to weeks and months (seismic surveys or ramming foundations of an entire wind park). Conglomerations of such activities might expose some regions to such sounds for the greater part of a year.

An important feature of seawater is its frequency-dependent absorption coefficient, allowing low frequency sounds in particular to remain discernible against the overall acoustic environment at rather large distances from the source. The frequency dependent nature of sound propagation thereby modifies the spectral composition of the propagating sound, similar to a lighting strike having a sharp, crisp characteristic when nearby but changing to a mere rumble when perceived from a distance. In addition to simple spreading loss and attenuation, the propagation of underwater sound is influenced by the characteristics of the bounding surfaces: depth, structure and composition of the seafloor, sea-state and ice cover as well as interior ocean stratification. Together these might promote (sound channels and sound ducts) or impede (e.g. sonar termination (Chambers and James 2005) and shadowing (Federation of American Scientists 2016)) the propagation of sound. All these aspects might be included in numerical sound propagation models, to obtain detailed predictions of sound levels around a given source.[6]

Underwater sound may be generated either ***intentionally*** or ***unintentionally*** (Table 24.1). Intentionally generated sounds (referred to as ***signals*** hereinafter) may be of biotic (e.g. echolocation clicks from toothed whales) or anthropogenic (e.g. chirps from naval sonars) origin. Unintentionally generated sound (referred to as ***noise***[7] hereinafter) can be of abiotic (e.g. breaking waves) or anthropogenic (ship noise) origin. The distinction is highly significant, as *anthropogenic signals* usually cannot be diminished without compromising their very purpose, while reduction of *anthropogenic noise* might be achievable without impairing the respective activity.

[6] However, overly ambitious efforts to provide precise sound level for risk assessments are often futile, as error estimates of even simple sound propagation estimates are dwarfed by the order of magnitude(s) bigger uncertainties associated with the estimation of probability and severity of contingent risks to the marine fauna.

[7] Alternatively, the term "***noise***" might also bear the connotation of being disturbing, however this is a rather subjective perception: Signals generated by marine animals may be experienced as distraction by a submarine's sonar operator, while the sonar pings of a submarine might disrupt the underwater communication of marine mammals. Additionally, noise sometimes is understood as all sounds of anthropogenic origin or it can bear special meanings in the context of measurement techniques.

Table 24.1 Characteristics of acoustic sources in the ocean

Acoustic source	Intention/application	Signal characteristics					
		Dominant frequency	Directionality	Signal type	Annual prevalence	Daily pattern	Acoustic footprint
Intentional, biotic							
Toothed whales	Echolocation	MF, HF	Forward	Broadband clicks	Year-round	Continuous	Local, mesoscale
Baleen whales (vocalizations)	Communication	LF, MF	Omni	Tonal (fm, am)	Seasonal/ year-round	Intermittent	Basin scale
Baleen whales (slapping, breaching)	Communication	LF, MF	Omni	Broadband pulses	Seasonal	Intermittent	Regional
Dolphins (whistles)	Communication	MF	Omni	Whistles	Year-round	Continuous	Local, regional
Snapping shrimps		MF	Omni	Broadband pulses	Seasonal	Diel cycle	Regional
Fish sounds	Communication, navigation	LF	Omni	Pulses, am-tonals	Seasonal	Diel cycle	Local, regional
Intentional, anthropogenic							
Fishing net pingers	Scare off marine mammals, position fishing net	MF,HF	Omni	Chirps, pings	Seasonal	Continuous	Local
(Simple) Echosounders	Navigation	MF, HF	Down	Ping, chirps	Year round	Continuous	Local
Fish finding sonars	Detecting fish	MF, HF	Down or sector	Ping, chirps	Seasonal	Intermittent	Local
Multibeam echosounders	Seafloor mapping	MF	Down	Pings, chirps	Occasional	Continuous	Local

(continued)

Table 24.1 (continued)

Acoustic source	Intention/application	Signal characteristics					
		Dominant frequency	Directionality	Signal type	Annual prevalence	Daily pattern	Acoustic footprint
Airguns	Hydrocarbon exploration	LF	Down	Pulses	Seasonal to year round	Quasi continuous	Regional to basin scale
Marine vibrators	Hydrocarbon exploration	LF	Down	Sweeps	Not yet in use		
Military sonars	Underwater reconnaissance	MF	Horiz.	Fm sweeps	Days to weeks	Intermittent	Regional
Unintentional, abiotic							
Precipitation	–	MF	Omni	Broadband pink noise	Occasional to year round	Intermittent	Regional
Breaking waves/surf	–	MF	Omni	Broadband pink noise	Seasonal to year round	Continuous	Local to regional
Lightning strikes	–	LF/MF/HF	Omni	Broadband	Seasonal	Sporadic	Local to regional
Marine earthquakes, volcanic eruptions	–	LF	Omni	Rumble, tremors	Year round	Intermittent	Basin scale to global
Sea ice and iceberg motion	–	LF, MF	Omni	Rumble	Seasonal	Intermittent	Regional to basin scale
Calving ice shelfs	–	LF	Omni	Cracking, rumble	Seasonal	Sporadic	Local to regional
Grounding and colliding ice bergs	–	LF, MF	Omni	Tremors, tonal sweeps	Occasional	Sporadic	Regional to basin scale

Shipping	–	LF, MF	Omni	Broadband, tonal	Year round	Continuous	Regional to global
Blasting of naval mines	–	LF, MF	Omni	Blast	Year round	Intermittent	Regional
Marine construction (ramming, vibrators)	–	LF, MF	Cylindric.	Pulses, tonal	Seasonal	Continuous	Regional
Marine renewable energies (operational phase)	–	LF, MF	Omni	Tonal	Year-round	Continuous	Regional
Small boats, jet skis	–	LF, MF	Omni	Broadband, tonal	Seasonal	Intermittent	Local to regional
Naval shock tests	–	LF, MF	Omni	Blast	Occasional	Rare	Regional to basin scale

Parameters given illustrate the typical range in areas of occurrence. Partially based on Hildebrand (2004a, b, 2009). LF (low frequency): 10–500 Hz; MF (mid-frequency) 500 Hz to 25 kHz; HF (high frequency) >25 kHz. A ping is a short, tonal pulse, a click is a broad-band pulse
fm frequency-modulated, *am* amplitude-modulated, *omni* omni-directional, *horiz* horizontal, *cylindric* cylindrical in horizontal plane

24.3 Impacts of Underwater Sound on Marine Life

Matching the diversity of sound sources, the potential impacts of sound are similarly manifold. Underwater sound is assumed to contingently affect the entire breadth of marine fauna, i.e. ***marine mammals, fish*** (including their larvae)***, sea turtles, birds, crustaceans, cephalopods and bivalves*** (including their larvae) at all levels, i.e. ***individuals***, ***populations*** and the ***ecosystem*** (Fig. 24.2), yet with widely varying severity and consequences. Unfortunately, while standing to reason, scenarios of specific consequences are mostly based on speculation or anecdotal reports and often are counterbalanced by no fewer reports noting a lack of observable effects. Quantitative assessments of a given scenarios likelihood and impact are, by contrast, sparse. Only recently, statistically robust descriptions of the effects of sound on individuals or populations have emerged (e.g. Solan et al. 2016), yet more than once revealing that further co-variates need to be included to fully understand the findings.

Exposure to sound may affect an individual's ***health***, ***hearing, fitness*** and ***behaviour***. Generally, it was assumed for long that the more distant the source, the less malign the impact: Exposure to sounds from high-intensity localised sources were

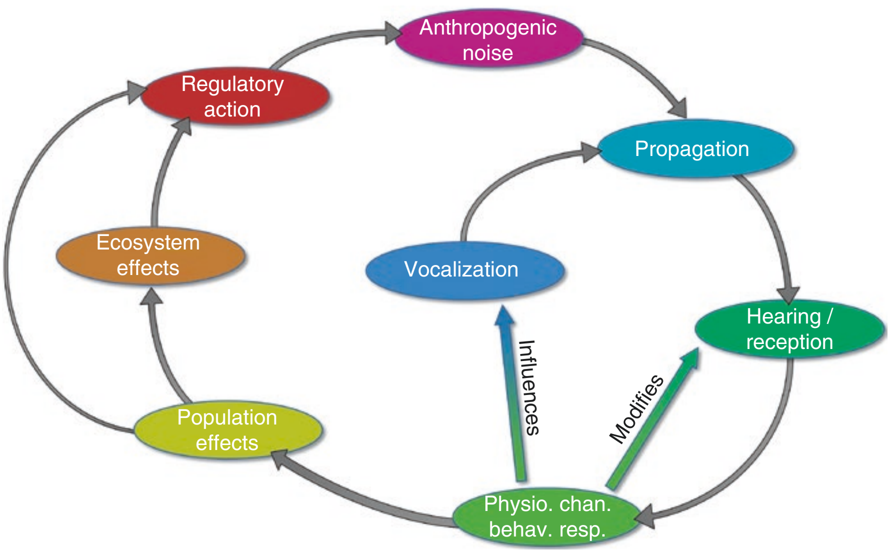


Fig. 24.2 Conceptual diagram of the contingent effects of (anthropogenic) sound on the marine fauna, including feedback mechanisms. Anthropogenic noise (top ellipse) is propagated to the receiving individual (hearing/reception), where it might elicit physiological changes (affecting hearing capabilities) or behavioural responses (motoric or vocal reactions such as louder or lesser vocalization). Individual responses may result in population effects when large numbers or critical members are affected, possibly resulting in ecosystem effects. Prudent regulatory action will modify anthropogenic emission as to avoid or at least minimize changes to populations and the ecosystem

presumed to result in acute effects such as mortal or recoverable injuries to individuals, while heightened diffuse sound levels were thought to elicit mainly transient behavioural interruptions. However, recent findings suggest that for some species/sound combinations initially merely behavioural responses may bear lethal consequences, requiring more differentiated evaluations.

Furthermore, types of sound that might affect health or hearing may not affect behaviour, and vice-versa, or they might elicit different responses amongst different individuals or contexts, necessitating independent assessments of the affiliated risks. Systematic listing off all these aspects/co-variates (e.g. species, sex, level, impact type, sound characteristics, and behavioural context) would result into thousands of scenarios, each of which requiring dedicated experiments to obtain quantitative measures of their severity and probability. Noting the impossibility of such undertaking, the common approach is to use generalized categories to provide a conceptual framework facilitating discussion:

24.3.1 Effects of Sound on Individuals

Effects of sound on individuals may be classified into four categories (arranged below in order of decreasing sound levels as needed for their elicitation). It should be emphasized however, that only few scenarios have in fact been observed in the field and that some, such as seals fleeing under the ice shelf and drowning are mere speculation.

1. ***Primary injury:*** This category comprises mortalities and acute (mortal or recoverable) injuries caused directly by the energy of the acoustic wave, including barotrauma, permanent threshold shifts (PTS), lesions of interior tissues and clogging of blood vessels by bubbles. Such injuries might lead directly or indirectly to death, e.g. by starvation or disorientation when hearing is permanently compromised.

   Such effects require, probably for all species, exposures to the highest of physically possible sound levels as generated by nearby (order of tens to lower hundreds of meters) discrete sources, such as underwater blasts or ramming.
2. ***Significant auditory impairment***: This category describes temporary threshold shifts (TTS) of the hearing apparatus, i.e. the animal can hear less well for a certain (minutes to days, depending on severity) amount of time. TTS is most likely to be caused by sound from discrete sources, yet already at larger (order of hundreds to thousands of meters) radii than those at which primary injuries might occur. For marine mammals, TTS onsets have experimentally been determined by several studies, which are compiled systematically in e.g. Southall et al. (2007b).
3. ***Secondary injury***: This category comprises (potentially lethal) injuries triggered by the behavioural response of the animal to the sound. For marine mammals, an individual's behavioural response to sound has been suggested to possibly trigger

interior bubble formation (Jepson et al. 2003) or result in hyperthermia leading to cardiovascular collapse (Cox et al. 2006). Interior gas bubbles might also result in disorientation with possibly lethal consequences.

This class of effects has, in fact, been linked almost exclusively to beaked whales exposed to sound from naval mid-frequency sonars (D'Amico et al. 2009). Surprisingly, it appears to occur already at relatively low exposure levels, which implies a great impact range of tens of kilometres around the source. Dedicated experiments showed that the severity of elicited (behavioural) responses are influenced by signal characteristics, species and context.

4. ***(Significant) behavioural response***: This category includes motoric and acoustic responses of variable duration, ranging from mere startle effects to obvious flight response, yet without secondary injuries. Responses might be short term (evasion of noise source) or long term (abandonment of habitat), probably related to the duration of the stimulus. Responses usually have no immediately apparent effect on individual fitness. Whether or not they result in significant changes to animal fitness in the long term strongly depends on the behavioural context. Behavioural responses also include acoustic responses, such as modification of vocalizations (cessation, amplification, frequency shifts).

   Attempts to link occurrences and severity of behavioural responses to sound levels have with few exceptions not yet produced robust dose-response relationships. For example, fish responded more pronounced to an approaching quiet vessel than to a loud vessel (Ona et al. 2007; De Robertis and Handegard 2013). However, levels eliciting behavioural responses are generally assumed to be much lower than those causing primary injury or auditory impairment. This entails that not only discrete, loud sources, but also increased diffuse sound levels may cause behavioural responses.

24.3.2 Effects of Sound on Populations

Effects of sound on populations do, of course, not manifest themselves on their own, but are the consequence of the effects of underwater sound on individuals. Some population effects might relate linearly to the number of individuals affected, but others, such as population productivity, may exhibit more complex relationships, involving feedbacks resulting in non-linear responses. A comprehensive, quantitative assessment of population level effects would require a thorough understanding of how population parameters such as growth and reproduction are affected by underwater noise. This would require a complete mechanistic ecological model of the target species and its environment, a level of expertise far from the current level of knowledge for virtually all aquatic animals. Additional complications arise from the fact that many of the higher marine species are highly mobile and migratory, impeding predictions on potential local effects of underwater sound exposure as animals may abandon or circumvent affected areas.

A conceptual model of population effects of acoustic disturbance (PCAD) was developed under the auspices of the National Research Council (2005) and experiences continuous improvement and refinement by ongoing research (E & P Sound and Marine Live Programme 2016; Office of Naval Research 2016). The PCAD model links acoustic exposure of individuals to potential population effects via three intermediate stages, using transfer functions to relate a given stage to its consecutive stage. However, whether PCAD is the ultimate method for use in acoustic risk assessments across all species is a matter of debate, as its predictive power depends on a substantial level of knowledge on the species in question (e.g. habitat use, physiological parameters). Maybe simpler models, such as Productivity-Susceptibility Analysis, PSA (Milton 2001; Patrick et al. 2009; Stobutzki et al. 2001), might, by themselves or in combination with PCAD, serve to obtain at evaluations of acceptable robustness with much less detailed knowledge.

24.3.3 Effects of Sound on the Environment and Ecosystems

Effects of sound on the environment may occur directly through modifying the acoustic environment itself or indirectly via impacts on the region's (acoustic) ecology. Four categories are identified to facilitate discussion:

5. ***Masking effects*** consider the subjective ability of the receptor (listener) to discriminate a signal of relevance against the overall acoustic environment (Erbe et al. 2016). Usually, masking effects are considered as detrimental for the listener, when for example prohibiting timely detection of a predator (Simpson et al. 2015), but they also might redound to another species' advantage, when, for example, baleen whale mother-calf communication is masked from detection by waylaying killer whales. Scenarios of the effects of chronically increased acoustic background levels are highly speculative. In some cases increases might not even be perceived by the animals, while in other contexts changes to the level of the acoustic environment might significantly reduce the range over which marine mammal vocalizations are audible. Ranges at which masking occurs are most variable across species and contexts, depending on e.g. frequency and signal characteristics and directionality, with numerous mechanisms by which relieve from masking can be achieved.
6. The ***acoustic ecology*** of a region might alter due to changes to the acoustic environment. Biotic use of acoustic time-frequency space is believed to be the result of an evolutionary process attempting to optimize the use of acoustics for each species (Van Opzeeland 2010). For example, seal vocalizations in the Antarctic are so unique in their characteristics that calls from different species remain recognizable even if concurrent. Introducing new sounds into this acoustic environment might change biotic usage patterns, similar to songbirds changing frequencies and source levels of their calls when residing in cities or next to highways (Brumm and Slabbekoorn 2005).

7. ***Biological services*** may alter through population effects with consequences for the (local) ecosystem. The great whales have been proposed to act as lateral (North/South) and vertical biological pumps, redistributing nutrients from the polar to the subtropical and from deep to shallow realms (Roman et al. 2014). Should acoustic exposure lead to changes in habitat usage, entire ecosystems might restructure. Behavioural responses of sediment-dwelling invertebrates to sound, on the other hand, have been shown to bear the potential to affect benthic nutrient recycling (Solan et al. 2016).
8. ***Prey distribution*** and ***predator pressure*** might change to a species' advantage or disadvantage due to the prey's or predator's response to acoustic exposure (Slabbekoorn et al. 2010), presumably shifting their habitat to less exposed locations.

24.4 Anthropogenic Sources and Emission Trends

Underwater sound is produced by nearly all anthropogenic marine activities. Emitters include, amongst others, the shipping industry, oil and gas producers, renewables, navies and marine research. While Hildebrand (2004b) already provides a comprehensive description of anthropogenic sound sources, the most notable sound emitters, along with their key features, are listed hereinafter.

Shipping, with the advent of steam engines, was probably the first human activity to introduce notable levels of noise into the ocean (see also Chap. 6). Source levels increased with growing numbers of ships which mainly followed tracks between major ports. Shipping noise is mainly caused by machinery and cavitating propellers. Both contributions increase with ship size, yet efforts to minimize fuel consumption for economic reasons instigated optimized propeller designs which reduce cavitation and hence noise levels (Chekab et al. 2013). Shipping is presumed to primarily elicit (significant) behavioural responses, as sound levels of ships are considered relatively benign. The near continuous chain of ships along some shipping routes imply a quasi-permanent broadband increase of sound levels in their vicinity. Shipping is, with regard to its noise emissions, currently unregulated.

Marine seismic exploration started with refraction and reflection surveys in the 1960 (Sternlicht 1999) and grew in momentum in the wake of the digital revolution and the development of non-explosive seismic sources. Today, seismic surveying is carried out on a regular basis mostly on the shelves and along the continental margins, with nearly 140 open-ocean going ships (Kliewer 2014) being operated by some 30 companies worldwide. In some areas, seismic operations are audible for much of the year. Airguns emit high acoustic level with the potential to cause primary injuries and auditory impairment in their direct vicinity. Marine seismic exploration is regulated under a number of jurisdictions, yet regulations vary widely between different states.

Naval activities since long introduced significant levels of underwater noise through explosions (torpedoes, water bombs) and the naval vessel's machinery, particularly during wartime. Interestingly though, in spite of the increased marine noise levels during World War II (WW II), whale stocks recovered notably during the concurrent decline in whaling (Muscolino 2012), putting the potential negative effects of noise into perspective. Today, controlled underwater detonations of lost mines and bombs from WW II occur regularly throughout the Baltic and North Sea.

Regular use of SONAR (SOund Navigation And Ranging) in submarine warfare started with WW II, and has received continuous advancement ever since. Currently, tactical mid-frequency sonars are deployed on order of 100 ships (Hildebrand 2004b), while low frequency sonar is used only in experimental settings.[8] While wartime activities are usually not subject to environmental regulations, use of sonars during naval exercises received increasing regulatory attention, particularly after the atypical strandings of beaked whales in the Bahamas (Jepson et al. 2003) was associated with the concurrent use of tactical mid-frequency sonars.

Marine construction includes a wide breath of noise sources: Dredging, ramming and vibrating of piles and runners (sheet piles) has originally been confined to coastal and estuary settings but now moved offshore with the construction of offshore windfarms, deep oil and gas installations and deep-sea mining (see also Chaps. 8, 9 and 11). Deep-sea mining requires operation of machinery on the sea-floor for extended periods of time, emitting sound levels comparable to those of large ships. Noise of highest levels is produced during the construction phase of structures (but drop by order of magnitude during the operational phase), with the potential to inflict primary injuries and significant auditory impairment. Some activities (ramming) are already subject for regulation based on noise emissions, yet others (e.g. dredging), where primary injury from noise exposure is less likely, are currently not.

Nautical safety and sovereign responsibilities require detailed knowledge of the sea-floor topography (bathymetry), which is obtained using multi-beam echosounders and side-scan sonars. Regions along coastal shipping lanes require continuous monitoring, as sediments are constantly repositioned, particularly in tidal seas. Delineation of exclusive economic zones under the United Nations Convention on Law of the Sea (UNCLOS) as based on e.g. the "foot of the slope" criteria recently led to increasing numbers of bathymetric surveys seaward of the continental shelves, particularly in regions of dispute between neighbouring states. So far, these activities remain unregulated, raising little concern of posing risks of primary injury or auditory impairment.

Commercial fishing employs sound to both find and track fish (fish sonars), to control the position of their fishing gear and to deter marine mammals (acoustic deterrent and harassment devices) from (drift-) gillnets. Fishing is unregulated with regard to noise, in fact use of sound producing marine mammal deterrence devices is encouraged in some countries.

Recreational boating, particularly motorboats and jet skis, might subject coastal settings to extended periods of noise, however, activities so far have not been regulated on basis of their sound pollution. Underwater noise related regulations may exist locally, yet are not known to the authors.

[8] Note that the terms "low" and "mid" frequency are used differently by different navies, creating ambiguities. Discussion should specify the frequency range in Hertz.

24.5 Current Management and Mitigation Approaches

Protective goals vary both with regard to target species as well as ecosystem level, i.e. whether individual animals, populations, or the ecosystem is to be protected. While facing great gaps in understanding on existence, type and magnitude of effects of sound on these various ecosystem levels, recommendations regarding management of sound have nevertheless been sought and developed throughout the past two decades. Two mitigation approaches have developed: ***operational*** and ***strategic***.

Operational management is primarily used to mitigate against primary injuries and significant auditory impairment, which may occur – probably across all taxa with acoustic perception – in the proximity of loud, discrete sources such as marine seismic, naval activities and marine construction: within tens to low hundreds of meters for primary injuries and hundreds to low thousands of metres for auditory impairment. Suitable metrics to regulate such risks have been investigated extensively in the past years and were first summarized in the seminal paper by Southall et al. (2007a), building the basis for a recently issued technical memorandum on this issue by the National Oceanic and Atmospheric Administration (NOAA 2016a, b). Recent advances in operational mitigation technologies (e.g. Zitterbart et al. 2013) facilitate an effective 24/7 implementation of mitigation measures.

Strategic management aims at alleviating risks caused by distant, discrete sources, i.e. secondary injuries and significant behavioural responses (which both are presumed to possibly occur up to tens of kilometres from the source), but also of diffuse sources which may change a region's (acoustic) environment and ecology including prey and predator distribution, and biological services rendered by resident species. While currently still a rather uncommon approach, the EU Marine Strategy Framework Directive aims at achieving a coherent management approach for European waters across national boundaries, also with respect to underwater sound, employing acoustic monitoring and registration of major noise emitters (Tasker et al. 2010). Further guidance on how to address managing these risks might also be taken from regulatory approaches concerning persistent substantial pollutants.

Managing diffuse sources, however, is difficult as it requires tracking a large number of dispersed sources, eventually located in different or even outside regulatory regimes. Contrasting the management options for persistent substantial pollutants, the underlying principle here is to shift anthropogenic activities – if possible – to areas and times when relevant marine fauna is less likely to be present. This approach requires *a priori* knowledge of species distribution and habitat use and/or operational mesoscale surveying. While implementation of the latter operational capabilities are rather costly, *a priori* information on habitat suitability is more easily obtained and might already provide reasonable guidance to at least avoid activities being conducted during peak presence (e.g. Bombosch et al. 2014).

24.5.1 Shortcomings of Current Implementations

Currently, a broad variety of regulatory procedures exists. Depending on the regulatory regime, mitigation requirements during seismic surveys range, for example, from none at all to continuous visual and passive acoustic observations for marine mammals and shutdown of sources should an animal enter a rather large mitigation zone. Such discrepancies likely reflect more on the subjectivity of the respective guideline than on underlying scientific uncertainties, particular when guidelines and regulatory documents make use of ambiguous terms. Unspecified legal terms, such as “harassment”, “molestation”, “disturbance” or “injury” allow for a wide range of interpretation when trying to determine whether such incidents might manifest themselves or not, resulting in rather divergent assessments of potential risks and hence mitigation requirements.

The situation worsens when documents are translated in different languages, e.g. during the national ratification of international agreements. Then, even presumably objective technical terms might attain ambiguity as manifest in the EU parliament’s resolution (European Parliament 2016) on the environmental effect of “*high intensity active naval sonars*”. The latter, i.e. the subject of the resolution, was translated as “sonars navals actifs à haute intensité” in the French and “*hochleistungsfähige[r] active[r] Unterwassersonare*” in the German versions of this resolution, terms of the trade which pertain to rather different types of sonar systems and stakeholders affected.[9]

Hence the use of unspecific terms in legal and regulatory documents, together with an imprecise use of the terms of the trade particularly in the “grey” literature on this topic, currently allows for a wide range of interpretation when trying to employ these terms in concrete assessments of risks as caused by specific activities, a shortcoming that future documents and discussions urgently need to resolve.

24.6 Challenges and Requirements of Prudent Management

Prudent management requires a solid understanding of the impacts it attempts to mitigate and the ability continuously adjust regulations to changes in our current state of scientific knowledge. This will require sustained science-based stakeholder dialogues as well as a management model governed by dynamic processes which continuously adapt and update regulations whenever scientific progress is made.

[9] “Naval” in English implies “belonging to the Navy”, i.e. a military context, whereas the French “naval” implies “nautical”, i.e. all seagoing activities including civil. The German text version simply refers to highly powerful (or efficient, the German term is ambivalent in this regard) active underwater sonars, including e.g. fishing sonars.

Future management of ambient noise should also employ a holistic approach, involving knowledge on ecoacoustics, i.e., how sounds reflect ecosystem processes. By increasing the awareness that acoustic environments are dynamic systems and products of adaptation, this can lead to alternative strategies to manage anthropogenic sound sources. The goal would be to minimize anthropogenic noise input particularly at times and frequencies relevant to the marine fauna. The temporal dimension hereby includes seasonal and diel cycles as well as call shapes, different temporal scales which all may be employed to minimize interference.

Mariners, on the other hand, will perceive regulatory requirements only as reasonable if implemented with a sense of proportion. Regulation of anthropogenic underwater sound is likely to impact considerably on marine anthropogenic activities: Activities will be prolonged (e.g. less wind farms built per year, longer seismic surveys due to shut downs, longer shipping routes), or involve higher risks for personnel and gear (e.g. longer times at sea or lack of situational awareness due to shutdowns of hydroacoustic sensors systems). Such consequences of mitigation measures, which might counter the original conservation goal, require careful balancing against the requirements' presumed benefits. Effects of sound also need to be put into perspective with other, potentially cumulative, anthropogenic disruptions (fishing, bycatch, ship-strikes) to allocate effort and funds to those mitigation measures benefitting the marine ecosystem most. For marine mammals, bycatch, whaling and ship strikes by far exceed the number of immediate mortalities (or takes) known to have been caused by sound exposure, and similar ratios apply in all likelihood for fishing versus acoustically mediated lethal takes of commercial fish.

Hence, to come to effective while at the same time economically viable, socially desirable, environmentally prudent and operationally realistic mitigation, regulations need to heed the insights and expertise of different scientific and societal actors and incorporate their knowledge bases. Flexibility will need to be an inherent and key feature of management for it to be truly effective, continuously facilitating implementation of new scientific insights into existing regulation. Some of the necessary prerequisites for an effective management are discussed hereinafter.

24.6.1 Understanding the Natural Environment

Guidance regarding a prudent setting of thresholds, e.g. for acceptable ambient noise levels, may be derived from an understanding of the natural levels and their variability (NOAA 2016a, b), as it can be assumed that species have evolved under like conditions and hence are capable of coping with them. Pristine areas, like the Southern Ocean, might serve to establish the *status quo ante*[10] acoustic state. As

[10] With recovering whale stocks, acoustic levels are expected to rise in their respective vocalization bands. For Antarctic Blue Whales, which already produce the most powerful signal in the Southern

many natural signals wax and wane on seasonal time scales, baseline acoustic recordings should be continuous and broadband, covering at least one, preferably multiple years for a meaningful analysis.

Proper calculations of sound levels are essential when aiming for an evaluation of long-term trends. While decadal trends between the sixties and nineties are estimated for some locations to be on the order of 3 dB per decade, this growth apparently stalled or reversed since the mid-nineties (Andrew et al. 2011). However, measurement uncertainties are of similar magnitude as the observed decadal changes. Hence thorough pre- and post-calibration for each recorder is mandatory to allow attaining robust results. Resolving long term trends furthermore requires multiple, successive recorder deployments which in most cases will employ different instruments, necessitating cross-recorder calibrations and meticulous management of recorder meta-data (Roch et al. 2016).

24.6.2 Understanding the Effects of Sound

Research questions are structured according to risk type (see above) and of course by the species concerned. They are hence at least as multifaceted as the number of categories listed under "effects of sound" times the number of species. Studies on the direct impact of sound on the organism (e.g. Kastelein et al. 2012; Mulsow et al. 2014) appear most advanced, whereas those concerning behavioural responses of individuals (e.g. Cato et al. 2013; Southall et al. 2012) are only emerging. Particularly, questions concerning the consequences of potential stress responses are difficult to address, at least for marine mammals, as monitoring biochemical levels and physiological changes in a meaningful, natural setting, is rather difficult for this group of species. Finally, studies of population and ecosystem level effects are the least progressed due to their complexity.

It is difficult to develop a universal ranking of research needs, as advancement is needed on all levels. However, among researchers there is a general consensus, that studies in a natural environment involving wild and unconfined animals will provide the most meaningful results, while, at the same time, being with few exceptions the most complex and expensive approach. At the same time, scientific progress is urgently needed regarding our understanding the impacts of chronic noise exposures on population and ecosystem health, which likely involves studying large sample sizes to attain statistically robust results (Boyd et al. 2011).

Ocean at 27 Hz when estimated at only about 1–2% of their pre-whaling population, acoustic levels might rise by up to 20 dB should the population fully recover. Estimates of natural levels should hence be based on the pre-whaling (*status quo ante)* acoustic state of the ocean.

24.6.3 Understanding Acoustic Metrics and Terms of the Trade

Creation of a judicious regulatory framework requires correct and unambiguous use of technical terms. However, the field of marine/hydro acoustics has not yet quite settled on an unambiguous language. Fortunately, recent efforts to standardize metrics (and language to some extent), are advancing rapidly (ISO 2014, 2016). One particular complication arises from the common use of "***levels, L***" together with the pseudo-unit "***decibel (dB)***" when describing acoustic properties. In fact, "deciBel" does not represent a physical metric (unambiguously traceable to SI units), but merely indicates that the preceding numerical number is proportional to the decadal logarithm of the ratio of the property and a reference value (Table 24.2). Hence, any proper use of levels requires declaration which field or power quantity is being considered, which frequently happens only implicitly by indicating the reference value. Equally often reference values are missing or incomplete and it is left to guessing to relate the numeric values to the physical property they describe. Particularly when measurements are compared between different stakeholders, this difficulty becomes evident.

Two further particular pitfalls need to be emphasized. Firstly, the definition of "root-mean-square sound pressure levels" needs to be augmented by the period and frequency band over which the acoustic signal is averaged, particularly when used in the context of pulsed sounds. This length should be chosen in accordance with the (biological) effect that is to be regulated through this metric, e.g. if behavioural responses are to be described, the averaging time should relate to the time period at which the auditory system processes sounds. Secondly, the definition of sound exposure levels requires the integration period over which sound levels are accumulated and/or the definition of an effectively quiet sound pressure level. Otherwise, even the lowest natural levels would accumulate to SELs exceeding any threshold. Currently, a comprehensive international standard is in preparation by the International Organization for Standardization, providing a catalogue of underwater acoustics terms, definitions and concepts (ISO 2016). It is highly advisable that terminology and standards as described therein are adopted stringently throughout all legal and regulatory proceedings.

No less important is the realization of obscured differences in the use of biological terms by different communities when formulating regulatory threshold levels. For example, the marine mammal scientific community considers a threshold shift of 40 dB to be prone of eliciting a permanent noise-induce hearing loss (National Oceanic and Atmospheric Administration (NOAA) 2016a, b). Recent studies on mice applied similar threshold shifts of up to 40 dB to study the long-term consequences of what they term initially "*moderate, but completely reversible threshold elevation*" (Kujawa and Liberman 2009). Hence, what is still considered a TTS (temporary threshold shift) in lab-based experiments with mice, is already considered the onset of PTS (permanent threshold shift) by the marine mammal community.

Table 24.2 Examples of metrics expressed in terms of the pseudo-unit "dB", including ancillary parameters as needed for their proper definition

"Unit"	Metric	Reference	Reference value	Ancillary parameters	Applications
dB	• Mean-square sound pressure level;	ISO/DIS 18405.2	1 µPa² (sic!)	Averaging time, frequency range	Characterizing pings in sonar technology
	• Sound pressure level	2.2.1.1			
	• SPL				
dB	• Peak sound pressure level	ISO/DIS 18405.2	1 µPa	Time interval and frequency range	Description of pulsed sounds in geophysics; evaluate impact of sound on marine mammal hearing (dual criteria in NOAA 2016a, b)
	• Zero-to-peak sound pressure level	2.2.2.1			
dB	• Peak to peak sound pressure level		1 µPa	Time interval and frequency range	Description of pulsed sounds in bioacoustics
dB	• Mean-square sound pressure spectral density level	ISO/DIS 18405.2 2.2.1.10	1 µPa² Hz⁻¹	Averaging time, frequency range	Description of broad band sounds, e.g. from airguns
dB	• Band averaged sound pressure level		1 µPa²	Time duration and frequency range	Description of acoustic emissions of ships
	• Band level				
dB	• Band averaged sound pressure level per Hertz	ICES 209	1 µPa (1 Hz band)	Time duration and frequency range	Description of acoustic emissions of ships
dB	• Sound exposure level	ISO/DIS 18405.2	1 µPa² s	Time duration and frequency range	Metric used to evaluate impact of sound on marine mammal hearing (dual criteria in NOAA 2016a, b)
	• Sound pressure exposure level	2.2.1.5			
	• SEL				
dB	Frequency weighted sound exposure levels	NOAA (2016a, b)	1 µPa² s	Weighting function, integration time	Metric used to evaluate impact of sound on marine mammal hearing (dual criteria)
dB	• Source level	ISO/DIS 18405.2	1 µPa² m²	Time interval and frequency range	A nominal value used as descriptor of sound source characteristics
	• SL	2.3.2.1	1 µPa² @ 1 m		

24.6.4 Promoting Technical Progress

With shipping being a major contributor of anthropogenic sound to the acoustic environment, regulations and technical solutions should be sought for this industry with priority. Currently, most ships lack equipment to monitor their acoustic state. At comparably little cost such systems could be integrated in the hull during construction of new vessels, allowing crews to observe and control their acoustic state. Setting design goals (ICES 1995) and requiring independent verification of acoustic emissions for newly launched ships, maybe coupled to financial incentives (e.g. like the Port of Los Angeles Environmental Ship Index Program to reduce airborne emissions), could provide an incentive for shipbuilders and shipping companies to develop, acquire and implement quieter propulsion systems and codes of conduct to reduce their acoustic footprints.

24.7 Further Reading

Apart from the comprehensive *in-depth* reviews listed in the Foreword, www.dosits.org provides an illustrative background on the issue, with their "Facts and Myths" page (http://www.dosits.org/factsandmyths/) giving informative examples of common misconceptions and pitfalls. JASCO Applied Sciences published a most helpful booklet (http://oalib.hlsresearch.com/PocketBook%203rd%20ed.pdf) for the practicing acoustician. Glossaries of terms are provided by a number of institutions, with examples given below. However, in case of conflict, preference should be given to the documents provided by ISO.

- Appendix F of the NOAA DRAFT Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing.
- The Journal of Cetacean Research and Management's guide to authors providing a list of recommended keywords and species names.
- HTI, providing a web page with terms related to sonar technology—http://htisonar.com/glossary.htm
- The list of terms and abbreviations in the recent paper by Erbe et al. (2016) on masking.
- Several stakeholders have initiated dedicated research programs, funding independent, scientifically sound studies. Calls for proposals and publications of current results may be accessed via their webpages:
  - http://www.onr.navy.mil/Science-Technology/Departments/Code-32/All-Programs/Atmosphere-Research-322/Marine-Mammals-Biology.aspx
  - http://www.lmr.navy.mil/Preproposals.aspx
  - http://www.soundandmarinelife.org/
  - http://www.esrfunds.org/abopro_e.php

Acknowledgement The authors would like to thank Michael Ainslie, René Dekeling and the editors of this book for their most helpful comments on the manuscript as it evolved.

References

Ainslie MA (2015) A century of sonar: planetary oceanography, underwater noise monitoring and the terminology of underwater sound. Acoustics Today 11:12–19

Andrew RK, Howe BM, Mercer JA (2011) Long-time trends in ship traffic noise for four sites off the North American West Coast. J Acoust Soc Am 129:642–651

Bombosch A, Zitterbart DP, Van Opzeeland I, Frickenhaus S, Burkhardt E, Wisz MS, Boebel O (2014) Predictive habitat modelling of humpback (Megaptera novaeangliae) and Antarctic minke (Balaenoptera bonaerensis) whales in the Southern Ocean as a planning tool for seismic surveys. Deep Sea Res Part 1 Oceanogr Res Pap 91:101–114

Brumm H, Slabbekoorn H (2005) Acoustic communication in noise, advances in the study of behavior. Academic Press, San Diego, pp 151–209

Boyd IL, Frisk G, Urban E, Tyack P, Ausubel J, Seeyave S, Cato D, Southall B, Weise M, Andrew R, Akamatsu T, Dekeling R, Erbe C, Farmer D, Gentry R, Gross T, Hawkins A, Li F, Metcalf K, Miller JH, Moretti D, Rodrigo C, Shinke T (2011) An International Quiet Ocean Experiment. Oceanography 24:174–181

Cato DH, Noad MJ, Dunlop RA, McCauley RD, Gales NJ, Kent CPS, Kniest H, Paton D, Jenner KCS, Noad J, Maggi AL, Parnum IM, Duncan AJ (2013) A study of the behavioural response of whales to the noise of seismic air guns: design, methods and progress. Acoustics Australia 41:88–97

Chambers S, James RN (2005) Sonar termination as a cause of mass cetacean strandings in Geographe Bay, south-western Australia. In: Society AA (ed) Acoustics 2005. Acoustics in a changing environment, Busselton, pp 391–398

Chekab MAF, Ghadimi P, Djeddi SR, Soroushan M (2013) Investigation of different methods of noise reduction for submerged marine propellers and their classification. Am J Mech Eng 1:34–42

Cox TM, Ragen TJ, Read AJ, Vos E, Baird RW, Balcomb K, Barlow J, Caldwell J, Cranford T, Crum L, D'Amico A, D'Spain GL, Fernandez A, Finneran J, Gentry RL, Gerth W, Gulland F, Hildebrand J, Houser D, Hullar T, Jepson PD, Ketten DR, MacLeod CD, Miller P, Moore S, Mountain DC, Palka D, Ponganis P, Rommel S, Rowles T, Taylor B, Tyack P, Wartzok D, Gisiner R, Mead J, Benner L (2006) Understanding the impacts of anthropogenic sound on beaked whales. J Cetacean Res Manag 7:177–187

D'Amico A, Gisiner RC, Ketten DR, Hammock JA, Johnson C, Tyack PL, Mead J (2009) Beaked Whale strandings and naval exercises. Aquat Mamm 35:452–472

De Robertis A, Handegard NO (2013) Fish avoidance of research vessels and the efficacy of noise-reduced vessels: a review. ICES J Mar Sci 70:34–45

E & P Sound & Marine Live Programme (2016) http://www.soundandmarinelife.org/research-categories/behavioural-reactions-and-biological-significant-effects/projects-related-to-the-population-consequences-of-acoustic-disturbance-pcad-model.aspx. Accessed 04 Aug 2016

Erbe C, Reichmuth C, Cunningham K, Lucke K, Dooling R (2016) Communication masking in marine mammals: a review and research strategy. Mar Pollut Bull 103:15–38

European Parliament (2016) http://www.europarl.europa.eu/sides/getDoc.do?type=TA&reference=P6-TA-2004-0047&language=EN&ring=B6-2004-0089. Accessed 4 Aug 2016

Federation of American Scientists (2016) http://fas.org/man/dod-101/navy/docs/es310/SNR_PROP/snr_prop.htm. Accessed 4 Aug 2016

Hildebrand JA (2004a) Impacts of anthropogenic sound on cetaceans. International Whaling Commission, IWC/SC/56/E13

Hildebrand JA (2004b) Sources of Anthropogenic Sound in the Marine Environment, in: Marine Mammal Commission, Joint Nature Conservaton (eds), International Policy Workshop on Sound and Marine Mammals, London, p 16

Hildebrand JA (2009) Anthropogenic and natural sources of ambient noise in the ocean. Mar Ecol Prog Ser 395:5–20

ICES (International Council for the Exploration of the Seas) (1995) Ices Cooperative Research Report No. 209: Underwater Noise of Research Vessels. http://www.ices.dk/sites/pub/Publication%20Reports/Cooperative%20Research%20Report%20%28CRR%29/crr209/CRR209.pdf#search=Report%20underwater%20noise%20209

ISO (2014) ISO 12913-1:2014(E) Acoustics—Soundscape—Part1: Definitions and conceptual framework

ISO (2016) ISO/DIS 18405.2:2016(E) DRAFT international standard Underwater acoustics—terminology

Jepson PD, Arbelo M, Deaville R, Patterson IAP, Castro P, Baker JR, Degollada E, Ross HM, Herraez P, Pocknell AM, Rodriguez F, Howie FE, Espinosa A, Reid RJ, Jaber JR, Martin V, Cunningham AA, Fernandez A (2003) Gas-bubble lesions in stranded cetaceans. Nature 425:575–576

Kastelein RA, Gransier R, Hoek L, Macleod A, Terhune JM (2012) Hearing threshold shifts and recovery in harbor seals (Phoca vitulina) after octave-band noise exposure at 4 kHz. J Acoust Soc Am 132:2745–2761

Kliewer G (2014) Seismic vessel survey is expanded to include additional vessel types. Offshore Magazine, pp 52–57

Kujawa SG, Liberman MC (2009) Adding insult to injury: cochlear nerve degeneration after "temporary" noise-induced hearing loss. J Neurosci 29:14077–14085

Milton DA (2001) Assessing the susceptibility y to fishing of populations of rare trawl bycatch: sea snakes caught by Australia's northern prawn fishery. Biological Conserv Biol 101:281–290

Mulsow J, Houser DS, Finneran JJ (2014) Aerial hearing thresholds and detection of hearing loss in male California sea lions (Zalophus californianus) using auditory evoked potentials. Marine Mammal Science, n/a-n/a

Muscolino MS (2012) Fishing and whaling. In: McNeill JR, Mauldin ES (eds) A companion to global environmental history. Wiley Blackwell, Oxford, pp 279–296

National Oceanic and Atmospheric Administration (NOAA) (2016a) Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing: Underwater acoustic thresholds for onset of permanent and temporary threshold shifts. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, NOAA Technical Memorandum NMFS-OPR-55 July 2016

National Oceanic and Atmospheric Administration (NOAA) (2016b) https://www.st.nmfs.noaa.gov/feature-news/acoustics. Accessed 4 Aug 2016

National Research Council (2003) Ocean noise and marine mammals. The National Academies Press, Washington, DC

National Research Council (2005) Marine mammal populations and ocean noise—determining when noise causes biologically significant effects. The National Academies Press, Washington, DC

Office of Naval Research (2016) Marine Mammal Programme. http://www.onr.navy.mil/en/Science-Technology/Departments/Code-32/All-Programs/Atmosphere-Research-322/Marine-Mammals-Biology/Marine-Mammal-Biology-Thrusts.aspx. Accessed 4 Aug 2016

Ona E, Godø OR, Handegard NO, Hjellvik V, Patel R, Pedersen G (2007) Silent research vessels are not quiet. J Acoust Soc Am 121:EL145–EL150

Patrick WS, Spencer P, Ormseth O, Cope J, Field J, Kobayashi D, Gedamke T, Cortés E, Bigelow K, Overholtz W, Link J, Lawson P (2009) Use of Productivity and Susceptibility Indices to Determine Stock Vulnerability, with Example Applications to Six U.S. Fisheries: NOAA Technical Memorandum NMFS-F/SPO-101 U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service

Popper AN, Hawkins AD, Fay RR, Mann DA, Bartol S, Carlson TJ, Coombs S, Ellison WT, Gentry RL, Halvorsen MB, Loekkeborg S, Rogers PH, Southall BL, Zeddies DGN, Tavolga W (2014) Sound exposure guidelines for fishes and sea turtles: a technical report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI. ASA S3/SC1.4 TR-2014. Springer, New York

Port of Los Angeles (2016) https://www.portoflosangeles.org/environment/ogv.asp. Accessed 4 Aug 2016
Richardson WJ, Greene CRJ, Malme CI, Thomson DH (1995) Marine mammals and noise. Academic, San Diego
Roch MA, Batchelor H, Baumann-Pickering S, Berchok CL, Cholewiak D, Fujioka E, Garland EC, Herbert S, Hildebrand JA, Oleson EM, Van Parijs S, Risch D, Širović A, Soldevilla MS (2016) Management of acoustic metadata for bioacoustics. Eco Inform 31:122–136
Roman J, Estes JA, Morissette L, Smith C, Costa D, McCarthy J, Nation JB, Nicol S, Pershing A, Smetacek V (2014) Whales as marine ecosystem engineers. Front Ecol Environ 12:377–385
Simpson SD, Radford AN, Nedelec SL, Ferrari MCO, Chivers DP, McCormick MI, Meekan MG (2015) Anthropogenic noise increases fish mortality by predation. Nat Commun 7:10544
Slabbekoorn H, Bouton N, van Opzeeland I, Coers A, ten Cate C, Popper AN (2010) A noisy spring: the impact of globally rising underwater sound levels on fish. Trends Ecol Evol 25:419–427
Solan M, Hauton C, Godbold JA, Wook CL, Leighton TG, White P (2016) Anthropogenic sources of underwater sound can modify how sediment-dwelling invertebrates mediate ecosystem properties. Sci Rep 6:20540
Southall B, Bowles A, Ellison W, Finneran J, Gentry R, Greene C, Kastak D, Ketten D, Miler J, Nachtigall P, Richardson W, Thomas J, Tyack P (2007a) Marine mammal noise exposure criteria: initial scientific recommendations. Aquat Mamm 33:411–521
Southall BL, Moretti D, Abraham B, Calambokidis J, DeRuiter SL, Tyack PL (2012) Marine mammal behavioural response study in Southern California: advances in technology and experimental methods. Mar Technol Soc J 46:48–60
Sternlicht DD (1999) Looking back: a history of marine seismic exploration. Potentials IEEE 18:36–38
Stobutzki I, Miller M, Brewer D (2001) Sustainability of fishery bycatch: a process for assessing highly diverse a nd numerous bycatch. Environ Conserv Biol 28:167–181
Tasker ML, Amundin M, Andre M, Hawkins A, Lang W, Merck T, Scholik-Schlomer A, Teilmann J, Thomsen F, Werner DMZ (2010) Marine Strategy Directive Framework Task Group 11 Report Underwater noise and other forms of energy in: ICES, E.U.A. (ed)
Van Opzeeland I (2010) Acoustic ecology of marine mammals in polar oceans, Alfred-Wegener Institute for Polar & Marine Research, Bremerhaven Ocean Acoustics Lab Germany & University of Bremen Germany. University of Bremen and Alfred—Wegener Insitute Bremerhaven, p 427
Zitterbart DP, Kindermann L, Burkhardt E, Boebel O (2013) Automatic round-the-clock detection of whales for mitigation from underwater noise impacts. PLoS One 8:e71217

Chapter 25
Introduction of Non-indigenous Species

Ralph Kuhlenkamp and Britta Kind

Abstract With the commencement of anthropogenic transcontinental movements followed by a continually increasing global traffic and intentional transfer of organisms, a diverse array of human-mediated pathways appeared responsible for transporting numerous marine species between different eco-regions. World-wide shipping increased dramatically over the last centuries emerging now as the most important vector for un-intentional artificial range-extensions of marine organisms thereby causing a steady raise in the introduction rate of non-indigenous species to most coastal regions of all oceans. Such neobiota pose a high functional risk if they develop stable populations and turn invasive with often detrimental effects on diversity and foodwebs of the indigenous ecosystems, even imposing high social-economic damage. Science is advancing in the attempt to understand the mechanisms of introduction and invasiveness which are crucial for further management approaches on national as well as international levels. Non-indigenous species have to be understood as a major pollution problem connected to every-day activities on all levels of society. Since the establishment of invasive species is nearly irreversible and attempts to eradicate populations of invasive organisms are mostly futile, a stringent prevention management on a global scale has to be anticipated.

Keywords Introduction • Invasiveness • Marine • Neobiota • Non-indigenous • Pathway • Vector

25.1 Introduction

Distribution ranges of marine species shifted throughout life's history according to environmental changes, most prominently climate fluctuations, and as a consequence diversity in ecosystems varied due to extinctions and introductions of species. Geographical and environmental barriers with strong gradients in temperature,

R. Kuhlenkamp (✉) • B. Kind
PHYCOMARIN, Hamburg, Germany
e-mail: ralph.kuhlenkamp@phycomarin.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_25

salinity, light and nutrients, as well as those based on biotic interactions like predator-prey combinations, evidently limit range shifts due to inherent physiological and ecological constraints of the expanding species. Performance in range extensions might change over time, either phenotypically or by altered genotypes modified through evolutionary processes, providing another variable in the ability of species to perform range extensions and create viable or even dominant populations in a new region. Dispersal of species or their propagation stages occurs either as active movement or in a passive way facilitated mostly by drifting with ocean currents, transport by other species, and rafting on various substrata (wood, seeds, pumice) or organisms like floating algae (Kuhlenkamp and Kind 2013). Incidences of natural range extension to non-contiguous biotic regions are generally rare events. All mechanisms of immigration do not automatically imply a successful foundation of a species in the new region unless its abundance and most of all the environmental and biotic conditions are suitable for the establishment of a viable, self-propagating population. Several successive introduction events might be necessary in order to establish a species in the recipient area. Range extensions are a continuous natural phenomenon and pre-eminent for the colonisation of newly opened marine regions as seen in the recent populating of the Baltic Sea after the influx of seawater had started just 8000 years ago (Helcom 2009).

With the commencement of human transcontinental movements, however, a new and very effective vector appeared responsible for transporting species between eco-regions, often unintentionally. An increasing array of human-mediated pathways and transportation vectors was generated proportionately to the development of societies and their mobility, by now far more relevant for range-extensions of marine species than natural means (Carlton 1987). Species introduced through anthropogenic activities are called neobiota (but also aliens, non-native or non-indigenous) and might subsequently become established in the foreign ecosystem to which they were transferred. Marine neobiota often travel with ships, either attached to their hulls (fouling) or more indiscernible in tanks when inadvertently taken in during uptake of ballast water at the port of leave for stabilizing empty cargo ships (Bailey 2015). During the last centuries, large scale introductions of foreign species reached a global magnitude and neobiota were established in nearly all regions of the world oceans (Carlton 1985). Depending on their impacts, which can range from being unnoticed to severe disturbance of the ecosystem ecology with negative influence on socio-economics, they constitute an important pollution factor particularly in view of the soaring introduction rates over the last decades due to an ever-increasing national and global shipping effort (Galil et al. 2014). Since about 90% of the world trade is estimated to be carried by ships (Kaluza et al. 2010), it is not surprising that the global shipping network is the dominant vector for translocating organisms via ballast water and responsible for most of the global introductions of non-indigenous species (Gollasch et al. 2002; Molnar et al. 2008). Intake of ballast water from the surrounding water body naturally gathers many different organisms ranging from viruses and bacteria to numerous planctonic species and larval stages up to invertebrate species and even fish (Carlton 2003). For the subsequent survival it is a prerequisite that biological requirements of the transferred species correspond to the conditions during transport and at the release area. Of the numerous marine species transported, only very few are able to sustain a long-term reproductive population outside their original native range and just a fraction of them become invasive (Mack et al. 2000). This small contingent of invasive non-indigenous species, however, presents the world with an increasing pollution problem.

25.2 Baseline

Between 1970 and 1985, many national and global conventions explicitly mentioned non-indigenous species (NIS) as a pollution problem including the United Nations Convention on the Law of the Sea (1982) or various European initiatives. Later, two regional conventions, HELCOM for the Baltic Sea, and OSPAR for the North Atlantic, recognized neobiota as a severe impact factor and provided many studies and information on introductions. Already in the 1970s, the International Council for the Exploration of the Sea (ICES 2005) pointed to the risks of neobiota and promoted the annual National Reports which created a common framework on information about global records of NIS (Gollasch 2007). Regardless of these efforts declaring NIS as a pollution problem for nearly 50 years, the problem has accelerated substantially during the last decades. Although treated scientifically to a greater extent since about 1940 (Lockwood et al. 2007), neobiota and their impacts are still not a concern of the public. It is crucial in the communication either on a scientific level or in general discussions about neobiota including their introduction mechanisms and impacts to set definite terms in order to avoid confusion in terminology. In this respect, the characterization of NIS will have to be more elaborate and comprise functional as well as qualitative aspects.

25.2.1 Terminology

Since the definitions used in connection with non-native species vary greatly in scientific literature, legal documents or popular writings, the basic terms are defined in short in Table 25.1 according to the information by the European portal DAISIE (Delivering Alien Invasive Species Inventories for Europe, Pysek et al. 2009) and by Carlton and Ruiz (2005).

25.2.2 Criteria Applying to NIS

Due to the widespread and numerous introduction events with high impact probability, IAS are recognized as one of the main anthropogenic threats to biological systems (Costello et al. 2010) dominating already marine communities in many major

Table 25.1 Basic definitions of terms with examples

Term	Abbreviation	Definition	Examples
Non-indigenous species	**NIS**	Taxa introduced outside of their natural range (past or present) and outside of their natural dispersal potential including any part that might survive and subsequently reproduce	Red macroalga *Bonnemaisonia hamifera*
			Crustacean *Hemigrapsus takanoi*
			Molluscan *Mya arenaria*
Invasive alien species	**IAS**	Subset of established NIS with potential to spread and with adverse effect on biological diversity, ecosystem functioning, socio-economic values and/or human health in the invaded regions	Green macroalga *Caulerpa taxifolia*
			Brown macroalga *Sargassum muticum*
			Molluscan *Crassostrea gigas*
			Crustacean *Carcinus maenas*
			Crustacean *Caprella mutica*
			Ascidian *Styela clava*
Cryptogenic species		Species of unknown origin and often undetected taxonomically, difficult to be ascribed as being native or non-indigenous	Green macroalga *Ulva californica*
			Ship boring molluscan: *Teredo navalis*
Vector		Transport mechanism or physical means by which NIS are translocated	Shipping: ballast water, hull-fouling
			Aquaculture: translocation of cultured species
			Recreational boating
			Floating objects
			Rafting on macroalgae
Route, pathway		Geographic path over which a species is transported from donor to target area	Main shipping lines
			Pathway of spat for mussel and oyster aquacultures
			Driftpath by ocean currents
Corridor		Artificial infrastructure connecting previously unlinked water bodies	Suez Canal between Red Sea and Mediterranean Sea
			Nord-Ostsee Kanal, Germany

ecosystems (Cohen and Carlton 1998). Although IAS are the main pollution factor, the introduction paths and invasion process is the same for all NIS. It cannot be excluded upfront if a species will become only a minor component of the recipient community or if it will become invasive and cause damage in various ecological and socio-economic ways. Hence, the concept of invasion is based on the steps taken

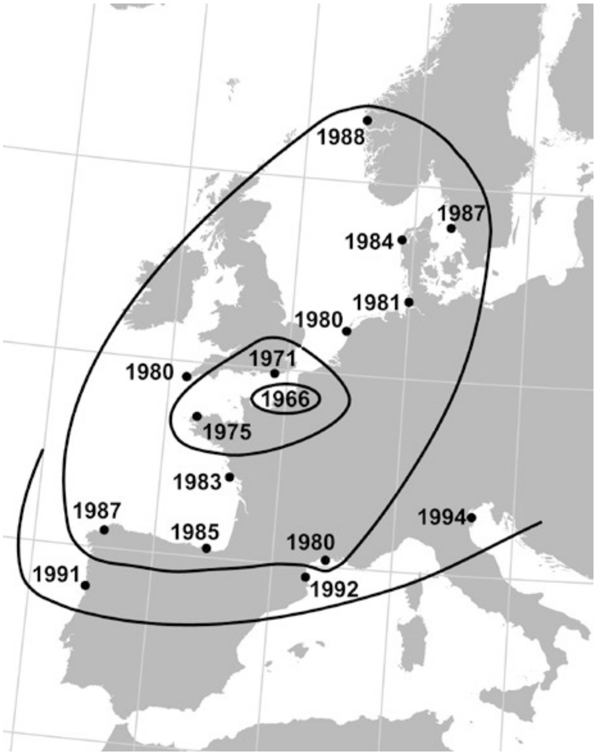


Fig. 25.1 Example of secondary, stepwise, natural or human-mediated expansion of a NIS from its point of introduction: temporal scale of the spread of the seaweed *Sargassum muticum* to several European coasts after its un-intentional introduction in France (modified after Ribera and Boudouresque 1995)

during introduction of any NIS and regulative measures need to consider every introduced organism as potentially invasive. Every species translocated by anthropogenic means is non-indigenous in a disparate region to its original range if it is exhibiting subsequently a disjunct distribution with highly separated ranges. In most cases, introductions occur suddenly and very localized whereas the subsequent spread follows mostly a step-wise process over an extended period involving several natural and human-mediated vectors (Fig. 25.1).

NIS are mainly characterized by features pertaining to the recipient distribution range. First of all, the species has to be new in the region and anthropogenic transportation means are the basic introduction vector without natural dispersal involved in the initial invasion. Geographically it is separated from its original range and occurs mainly in harbours, enclosures, protection barriers etc. or aquaculture sites. Local distribution during initial stages of the introduction is often followed by a sudden population increase and a step-wise expansion from there. NIS are found in all marine species groups from higher plants to unicellular algae, from vertebrates to even bacteria and viruses. Benthic invertebrates represent the main group of NIS among which Mollusca provide the most numerous taxa, followed by Arthropoda, Chordata, and Annelida (Gollasch 2006; Streftaris et al. 2005; Galil 2008). Well represented as NIS are macroalgae with globally 277 species (Williams and Smith 2007) including some of the well-known cases with high negative impacts like

Caulerpa taxifolia and *Sargassum muticum*. Many are transported via hull-fouling not only on commercial vessels (Hewitt et al. 2007; Mineur et al. 2007), but also with recreational craft (Mineur et al. 2008). Due to the capacity of the brown seaweed *Sargassum muticum* to establish large populations in a wide-range of environmental regimes including all temperate zones, it became now the most widespread macroalgal NIS (Engelen et al. 2015). Despite the essential requirement for correct species identification, continuing loss of taxonomic expertise or the lack of harmonised standard taxonomic procedures is accountable for many small sized taxa remaining unrecognised (Terlizzi et al. 2003) and microorganisms are still highly underrepresented in neobiota assessments (Ojaveer et al. 2015), although ballast water contains a large proportion of them, some of even pathogenic nature (Ruiz et al. 2000). Distinguishing NIS from native species can be difficult when they share very similar taxonomic features. With molecular studies, however, the non-indigenous status of several cryptogenic species and the origin of some common NIS formerly assumed to be native were confirmed (McIvor et al. 2001; Provan et al. 2008).

25.3 Mechanisms and Drivers

25.3.1 Framework of the Invasion Process

Deliberate or un-intentional introductions of organisms through anthropogenic activities and the subsequent invasion of an ecosystem follow an invasion process characterised by different barriers and drivers (Fig. 25.2), generally proceeding in three major successive steps:

1. Introduction from the native range
2. Establishment in the recipient system
3. Proliferation and expansion to other regions

It is essential to define the phases and drivers of these key steps as a prerequisite for understanding the process of introduction and for evaluating its inherent risks. Colautti and MacIsaac (2004) linked the stepwise invasion levels of NIS to different filters which regulate transition to the next stage. The invasion process will only continue if species are able to pass them. Obstruction of the process might fail the initial introduction or subsequent invasion especially if it occurs during the initial levels (Lockwood et al. 2007). In the first step, ballast water transfer and artificial corridors (e.g. Suez Canal) are the main transport vectors indicating the translocating phase, which is only successful if the transported species or its stages survive the transport conditions. After extraction from its original range and subsequent release in its new environment, the establishment phase follows in which the species must be able to cope with the existing environmental conditions and is forced to interact with other components of the ecosystem (enemies, food sources, food webs etc.). For many species, environmental conditions at the entry location and a low initial population size will be the main barriers for a continued establishment.

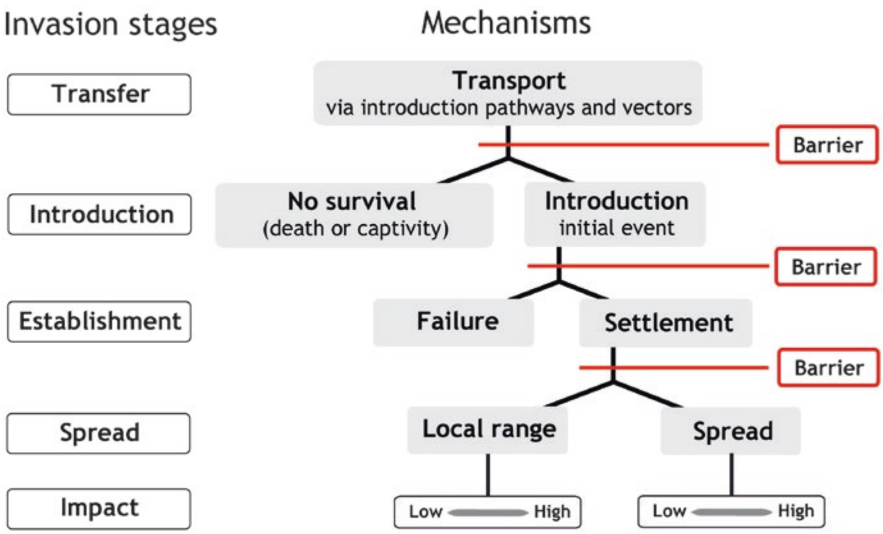


Fig. 25.2 Conceptual model depicting the discrete stages of the invasion process. Alternative outcomes are included at each stage and the sites of possible physiological/physical barriers between stages are indicated (modified after Lockwood et al. 2007)

Human activities (alteration of habitats due to construction, harvesting, fishing etc.) which generally hamper establishment of native species, especially facilitate settlement of NIS in this phase (Mineur et al. 2012). In the third phase, NIS either remain a minor component of the recipient ecosystem without any harm or benefit to it by sustaining a low abundance, or turn invasive by increasing population size and markedly extend the distribution range. At this stage, secondary spread is provided by natural dispersal and anthropogenic distribution activities identical to the human-mediated vectors acting in the primary introduction phase, only now within the recipient region. Finally, the strength in population size and the ability to continue the spread regulate invasiveness and further impacts by the introduced species. Invasions of deliberately translocated species and their co-introduced NIS proceed different due to the fewer and less severe barriers between steps. For aquaculture purposes, usually large quantities of the preferred species are transferred with the aim to enhance survival and support settlement. Such species are in a favourable situation during transport and introduction, with the consequence of a high propensity for further spread and invasion (see case of the Pacific oyster).

25.3.2 Natural Dispersal

Although natural dispersal is not regarded per se as a vector in primary introductions of NIS, it is very important during the subsequent spread. The intensity of the vector depends on the inherent capabilities of the species to grow and reproduce in the recipient ecosystem. Many macroalgae can re-grow from fragments of their thalli, which represents one of the means for natural dispersal, but also for human-mediated transport when fragments are entangled in nets and other ship-related devices. Human activities over the last centuries, however, indirectly caused natural dispersal to be included as a primary vector by adding numerous floating objects to the marine environment like timber, plastics, garbage or discarded fisheries equipment, thereby significantly raising the opportunities for rafting (Wolff 2005).

25.3.3 Human-Mediated Vectors and Routes

Numerous different pathways and vectors based on anthropogenic activities (Table 25.2) exist as drivers for introductions of NIS (Carlton 2009), of which trade and shipping are present already for thousands of years, but increased exceptionally during the last century (Hewitt et al. 2009).

Table 25.2 Major pathways and vectors important in introductions of marine NIS

Pathway or route	Vector
Commercial shipping: ships, floating structures	Transport of ballast water, sediments, solid ballast
	Fouling of hulls and all parts which come into contact with surrounding sea (anchors etc.)
Corridors	Natural dispersal and ship-mediated transport through canals
Recreational activities	All kind of boating (similar vector to shipping in general)
	Fishing and Angling: transport of live bait, accidental/intentional transport and release of angling catch, stocking for angling
	Sport equipment (diving, angling gear)
Aquaculture activities	Intentional releases and movement of stock associated water
	Unintended or unauthorized releases of species
	Transport of equipment or discarding any of it
	Distribution of live feed
Aquarium and live food trade	Intentional and accidental release from aquaria and similar compartment
Wild fisheries	Untreated material formerly used in aquaria and their waste discharge
	Unauthorised release of imported living foods
	Discharge live packing materials and release of transported water
Artificial structures, habitat management	Artificial protection structures, reclamation and protection activities moving rock or sediments from or to places far away from original sites
Research and education	Field experiments
	Accidental release
	Movement of experimental equipment
	Escapes of caged organisms used for monitoring
Biological control	Release of certain species for control of invasive species or pests

25.3.3.1 Commercial Shipping

Shipping is the major vector of global marine invasions, either through ballast taken onboard or through fouling of the hull (Leppäkoski et al. 2002a). The historically used solid ballast was more and more displaced since 1800 by using water in special tanks. Ballast water was already suspected in 1908 as a factor in the introduction of a non-native planctonic diatom to Europe (Ostenfeld 1908). Based on estimates for global shipping activities, 8–10 billion tonnes of ballast water were transported per year carrying 3000–4000 species daily (Carlton and Geller 1993; Gollasch et al. 2002) indicating the enormous potential for introductions of NIS to any harbour in the world. Harbours were defined as a more appropriate habitat for tolerant introduced species than for native ones, because NIS and cryptogenic species were found in higher numbers and abundances than native species (López-Legentil et al. 2015). Additionally, transport connectivity between ports and marinas as hotspots of NIS contribute to the spread of NIS but less for native species. Hull-fouling is the second most important vector even with numerous anti-fouling methods applied (Gollasch 2002; Hewitt et al. 2007; Mineur et al. 2007). Recruitment to the surface of vessels is either through secondary attachment of NIS directly from adjacent populated surfaces and from drifting specimens including fragments e.g. of macroalgae, or as planctonic stages of the life-history. Especially macroalgae are very capable of hull-fouling (Schaffelke et al. 2006) and in some species even very large thalli are able to withstand the drag during a long voyage (see case of *Undaria pinnatifida*).

25.3.3.2 Corridors

Corridors like the Nord-Ostsee Canal in Germany, the Suez Canal in Egypt and the Panama Canal in Central America offer ample opportunities for fast transfer of NIS between very different biotic regions (Gollasch et al. 2006). About half the NIS in the Mediterranean Sea are supposed to have been introduced through the Suez Canal, a corridor without barriers, which supports ship-mediated translocation as well as intense natural migration (Zenetos et al. 2012).

25.3.3.3 Recreational Activities

Small craft shipping is the most important vector responsible for introductions due to recreational activities and is especially effective in the secondary spread of NIS between ports, and between ports or marinas and nearby coastal sites (Minchin et al. 2009; Mineur et al. 2012; Bishop et al. 2015). Recreational boating functionally resembles commercial shipping, except that hull fouling is the dominant vector and transport distances are much shorter (Wasson et al. 2001; Davidscon et al. 2010). Long residence times of boats at their harbour or mooring site increases fouling of hulls and subsequently the introduction risk at sites approached by the vessels (Marchini et al. 2015a).

25.3.3.4 Aquaculture Activities

Introductions of economically valuable species for cultivation purposes, especially mussels, oysters and fish (Wolff and Reise 2002; Ribera-Siguan 2003; Wolff 2005), were the basis for an expansion of the aquaculture industry providing much of the worlds seafood products albeit with numerous negative side-effects (Cook et al. 2008). Several of the intentionally introduced species posed a high risk as NIS, often changing into invasive species like the Pacific oyster in Europe. As a secondary cause of such introductions, but with similar consequences as the intentional transfer, introduced aquaculture species turn into a significant vector due to the numerous organisms attached to or 'hitchhiking' with the organisms or their shells (Ribera-Siguan 2003; Hewitt et al. 2007). Macroalgae have also been imported for aquaculture purposes of which the Pacific *Undaria pinnatifida*, transferred to a French Mediterranean lagoon and from there to the French Atlantic coast, started to spread to nearby regions due to natural dispersal and transport via hull-fouling (Floc'h et al. 1996). Despite some constraints during transfer and at the culture site, the negative effects on transported aquaculture species, including their attached or 'hitchhiking' organisms, is certainly limited since the main incentive is to keep them alive at all stages of transport and fit for growth and reproduction afterwards.

25.3.3.5 Aquarium and Live Food Trade

Either for amateur or for commercial use, the trading of species poses a high risk to the environment due to inadvertently (escapes) or intentionally released organisms of all taxonomic groups (Calado and Chapman 2006). Trades for aquarium species are getting more into focus due to their increasing commercial value and because they are seen as one of the five major causes of introductions with sometimes very negative impacts on aquatic ecosystems (Padilla and Williams 2004). Discarding of any unwanted or unused life material such as live packaging material (mostly seaweeds) or discards from fish markets directly into adjacent coastal areas might also contribute to introductions (Hewitt et al. 2007).

25.3.3.6 Artificial Structures, Habitat Management

Increased construction activities over the last century led to numerous artificial structures in coastal environments (harbour facilities, barriers, marinas etc.) providing various hard substrata for the attachment of macroalgae and sessile benthic invertebrates directly in the vicinity of NIS introductions (Mineur et al. 2012; Marchini et al. 2015a). Coastal structures are often placed in estuaries or regions with little hard substrata thereby enhancing fouling with NIS since conditions in these biotic systems provide suitable habitats for a larger proportion of neobiota than open coastal areas (Preisler et al. 2009; Buschbaum et al. 2012; Marchini et al. 2015b). NIS frequently establish first in major nodes within the shipping network (Carlton 1996; Minchin et al. 2006) where artificial structures represent the primary receivers of NIS. At the same time, these structures function as a donor in the further spread of NIS constituting important stepping stones in the invasion process and facilitate the recruitment of NIS onto other vessels for further ship-mediated transfer (Marchini et al. 2015a).

25.3.4 The Main Driver Shipping and Risk Evaluation

The shipping network is the dominant vector for translocating organisms responsible for most of the world-wide introductions of NIS (Gollasch 2006; Molnar et al. 2008; Hewitt et al. 2007; Seebens et al. 2013). In a first step of analyzing invasion patterns, the network in international shipping traffic was identified with recent data (Fig. 25.3) providing basic information on possible invasion routes of NIS (Kaluza et al. 2010; Kölzsch and Blasius 2011). Adequate representation of the actual risk involved in the invasion flow required the inclusion of several additional factors like the dynamics of the uptake and subsequent release of ballast water, species survival during transport, propagule pressure, the environmental factors temperature and salinity at the donor site, and interactions between species and transport substrata (Seebens et al. 2013, Xu et al. 2014). It was predicted that the greatest risk of new introductions was involved with medium-range shipping distances of 8000–10,000 km between ports. Organisms are less likely to survive longer journeys. The invasion risks are concentrated at a few major ports located in South East Asia, the Middle East and the USA, while most harbours exhibited a low risk.

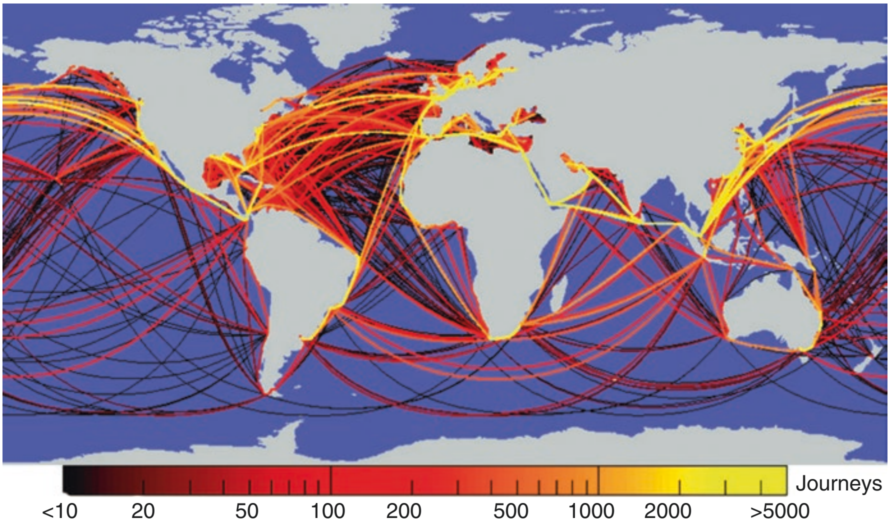


Fig. 25.3 Trajectories of all cargo ships larger than 10,000 GT during 2007. The *colour scale* indicates the number of journeys along each route. Ships are assumed to travel along the shortest (geodesic) paths on water (Kaluza et al. 2010)

25.3.5 Introduction Rate

It is generally accepted that regions with an elevated proportion of NIS are at greater risk of future invasions. The number of introductions or invasions is therefore an important basic indicator addressing anthropogenic pressures. Despite the multitude of global aspects on NIS as a pollution problem, the general focus in all chapters was placed on the situation in Europe justified by the fact that most worldwide introductions happened in European seas (Galil et al. 2014). Until 2012, about 1230 marine NIS were recorded for Europe (Katsanevakis et al. 2013) of which about 57% are assumed to occur in self-sustaining populations, indicating their stable situation in the recipient systems (Gollasch 2006). The highest numbers of NIS were found along the Mediterranean coasts of Israel, Egypt, Turkey, Greece, Italy and France with 430 species in Israel alone. Each sub-region of the Mediterranean Sea is affected by different introduction pathways (Galil and Zenetos 2002). While aquaculture imports are the most important vector for the western region, the connection of different water-bodies through a corridor is responsible for introductions in the eastern part (Galil et al. 2015) where the Suez Canal facilitated the influx of tropical species from the Indian and Pacific Ocean since its opening in 1869 (Zenetos et al. 2012). For that reason, the eastern Mediterranean coastline is worldwide the marine biogeographical region most severely affected by NIS and exhibits the highest rate of introductions and the highest number of NIS (Raitsos et al. 2010; Occhipinti-Ambrogi et al. 2011; Zenetos et al. 2012). There is a constant acceleration in the introduction rate within Europe since global transfer of species intensified around 1900 (Fig. 25.4).

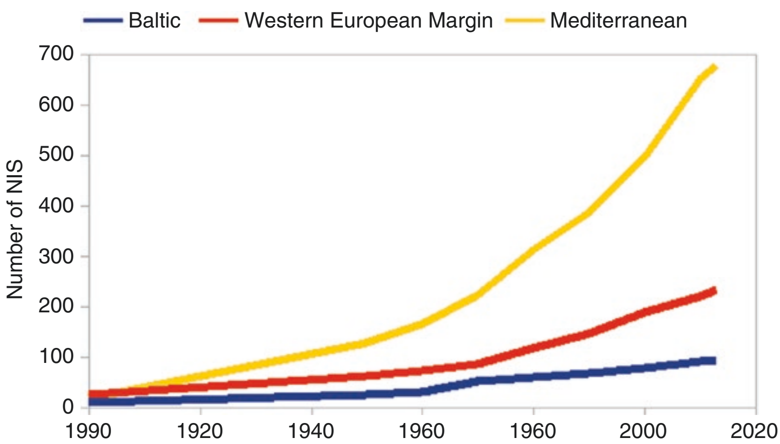


Fig 25.4 Cumulative number of NIS recorded in the Baltic Sea, Western European Margin and Mediterranean Sea (Galil et al. 2014, based on information from AQUANIS, a pan-European aquatic non-indigenous and cryptogenic species information system)

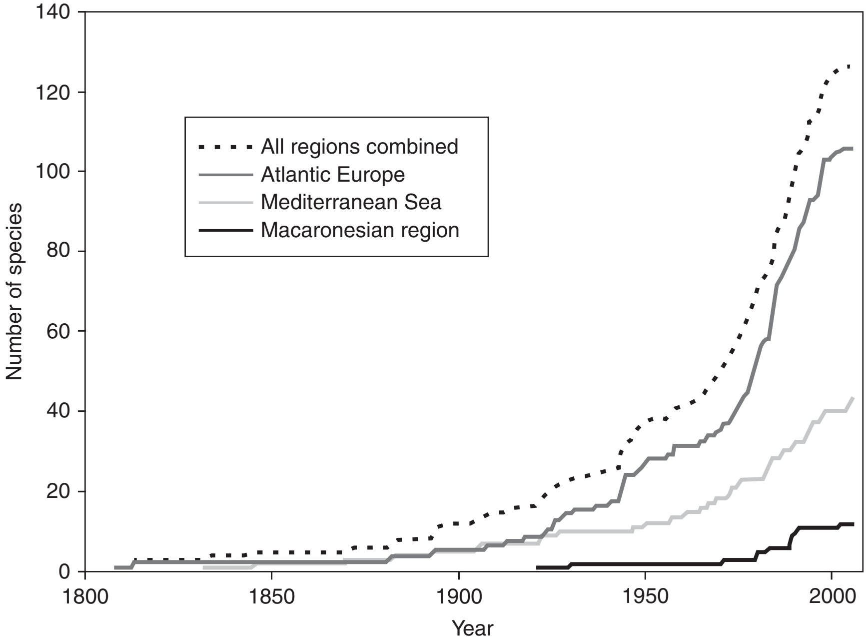


Fig. 25.5 Cumulative number of all introduced seaweed species observed on Atlantic coasts of Europe, the Mediterranean Sea, the Azores and Canary Islands from 1800 to 2005 (Mineur et al. 2015)

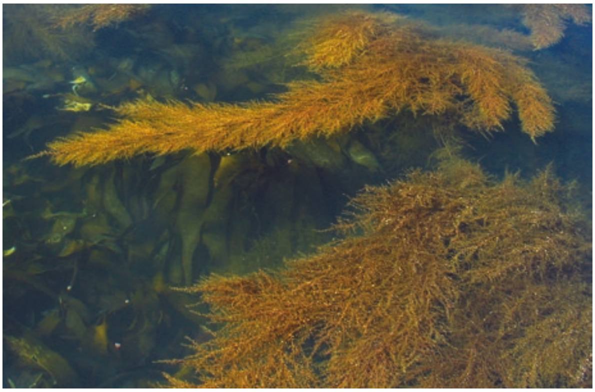


Fig. 25.6 *Sargassum muticum*: thallus floating at the surface above the *Laminaria* canopy in the subtidal of Helgoland, Germany

Macroalgae represent a very large portion of NIS which increased after 1900 to more than 125 species in Europe alone (Mineur et al. 2015), most of them occurring in the Mediterranean Sea (Fig. 25.5). About half of those species spread further and are considered invasive (Mineur et al. 2010). Like in *Sargassum muticum* (Fig. 25.6), any potential floating ability might greatly fascilitate the natural distribution of macroalgae.

25.3.6 Factors Supporting the Invasion Process

Certain ecological or environmental conditions and especially human disturbances were identified to increase introduction rates and invasion success of NIS like existing vulnerability of the recipient community, sediment pollution, artificial constructions and effluents (Schaffelke et al. 2006; Valentine et al. 2007). In some studies, the absence of natural enemies and competitors in the recipient region are seen as the main reason for the invasion success of NIS (Blumenthal 2006). Alternatively, multiple factors act simultaneously, like favourable environmental conditions for NIS and anthropogenic infrastructure or activity (Colautti et al. 2004). Selection for an advantageous genotype and positive interactions with other species were also identified. Low native cover, vacant space and low species numbers supported natural settlement of the IAS *Sargassum muticum* during its spread in Europe (Fernández et al. 1990). NIS introductions contribute to a mixing of species assemblages from different marine regions. In the case of the Mediterranean Sea, the so-called 'tropicalization' was attributed to the combination of four factors, the natural Atlantic influx through the Straits of Gibraltar, the invasion through the Suez Canal, aquaculture and climate warming (Raitsos et al. 2010). Future scenarios about NIS and their impacts certainly need to consider an on-going climate warming as one of the major interacting factors increasing introduction rates and rendering biological tropicalization in many regions inevitable (Occhipinti-Ambrogi 2007). High risks are even attributed to polar regions where an increased influx of neobiota with a warming climate and expanding tourism is predicted (Ware et al. 2014; Hughes and Ashton 2016). In the case of the Pacific oyster, which was introduced numerous times to Europe in order to restock the existing cultures, a positive feedback loop was described by Mineur et al. (2014) in which as part of the attached organisms introduced with the oyster spat specific diseases (parasites and viruses) were imported which posed a direct threat to the established aquaculture of oysters with sometimes detrimental impacts on the commercial yield.

25.4 Impacts

25.4.1 Overview

Marine IAS are known to exert numerous impacts, some with serious consequences for coastal ecosystems as well as for economics and society (Katsanevakis et al. 2014b; Vaz-Pinto et al. 2015). They are defined by the European Commission (EC 2014) as a factor of significant impact on environmental quality caused by adverse effects on the biological, chemical and physical properties of marine ecosystem, and the recent Marine Strategy Framework Directive (EC 2008) recognises NIS as a major threat to biodiversity required to be considered as a relevant descriptor of the Good Environmental Status (GES). IAS act as vectors for diseases, alter ecosystem processes, disrupt cultural landscapes, reduce the value of land and water for human

Table 25.3 Major impacts through introductions of marine non-indigenous species

Biological impacts	Economic impacts	Social impacts
Change and loss of native biodiversity: preying on native species, displacement of native species (competition for space and food), parasites and disease, overgrowth of existing communities, degradation of ecosystems, hybridization, genetic dilution	Interference with resources for fishing and mariculture (fish or shellfish-stocks): collapse of stocks, decreased yield through smothering of cultured populations, pathogen invasion into aquaculture	Competition with native species used for subsistence harvesting
Changes of ecosystem function	Direct interference with fisheries (fouling, clogging or tearing of nets)	Degradation of culturally-important habitats and resources
Changes in nutrient cycles	Damage to infrastructure (through fouling of pipes, wharves, buoys etc.)	
Decreased water quality	Decreased recreational opportunities: massive growth in coastal areas used by humans	
Impacts to human health and wellbeing	Expenses for cleaning, control and eradication measures	
Habitat changes due to mass-occurrence or eco-engineers altering substrate conditions (oysters etc.)		

activities and cause negative socio-economic impacts (Table 25.3). Recognized as one of the five main pressures directly causing loss in marine biodiversity, IAS eliminate sensitive or rare species, alter native communities, cause mass proliferations, modify habitat conditions through changes in substrata, and reduce native species numbers and abundance (Bax et al. 2003). Eventually there might be unexpected and irreversible consequences for native communities and economically valuable resources in fisheries (Occhipinti-Ambrogi and Savini 2003). Impacts may vary in magnitude ranging on temporal scales from sporadic or short-term to permanent effects, and on a spatio-functional scale from low abundances in a very limited range with no measurable adverse effects up to mass proliferations in a large region or ecosystem with marked influence on native communities, habitats and ecosystem functioning. Predicting invasion events is very difficult since it is uncertain which species will become invasive. Introduced species might exist in the recipient system for a long time with a small, non-invasive population until conditions change. Either environmental shifts or introductions of additional species might trigger its population increase and finally lead to the invasion by this formerly 'harmless' introduction (see Chap. 27). Human activity distinctly shaped biodiversity patterns in the Mediterranean Sea with differences in taxonomic composition between regions depending on the dominant vectors, either ship traffic and natural dispersal through the Suez corridor intensifying invertebrate NIS or imports for aquaculture purposes which enhanced macroalgal introductions (Katsanevakis et al. 2014a). Biodiversity changes can occur at a very high rate as seen in the Mediterranean Sea where one non-indigenous species is expected to arrive every 10–11 days (Zenetos 2010). Sheltered coastal areas and estuaries, harbours and canals show the highest proportion of changes in biodiversity with ratios for non-native to native species of 1:40 in the majority of European marine waters, 1:20 at open coasts and 1:5 in estuaries or lagoons (Reise et al. 1999; Leppäkoski et al. 2002b; Wolff 2005). Increasing the number of species by additions from other regions implies not only changes on a local scale, but serious impact is seen in the systematic homogenization of biota over large regions since species are transported between different oceans (Mineur et al. 2015). Although Europe and Australia are major recipient region for introductions, one has to keep in mind that they are also automatically donor sites for NIS to other regions for instance North America, since ship traffic is a two-directional vector. In the following chapters we describe some key impacts relevant on a global scale based on prominent invasion cases as a function of their underlying introduction framework and the main vectors involved.

25.4.2 Unintentional Introductions

25.4.2.1 Historic Case or Cryptic Species

It is assumed that the ship boring clam, the so-called shipworm *Teredo navalis* probably appeared in western Europe around 1700 (Gollasch et al. 2009). Within a short period it caused enormous damage to wooden structures in the Netherlands and even in recent years, its damage to wooden constructions along the coast of the western Baltic was estimated to cost 25–50 million Euros (DAISIE 2006). There is no competition with other species since it occupies a special ecological niche. It is difficult, however, to ascertain its origin and if it was introduced to Europe or not. It is therefore seen as a cryptic species.

25.4.2.2 NIS as Indirect Vector for Other Introductions

With the intentional importation of species, unintentional introductions of accompanying NIS occur on a global scale already for centuries (Ruesink et al. 2005). Besides invertebrate and macroalgal species, also pathogens or parasites can be transported which can infect and damage native and commercial species, or even show a health risk to humans.

25.4.2.3 Synergistic Factors in the Success of IAS

The green crab *Carcinus maenas*, a very common native of European shores, is believed to have been introduced to many areas worldwide. Evidently it was transported inside the holes bored by shipworms into wooden ships and first recognized in North America in 1817 (Carlton and Cohen 2003). It is believed to be partly responsible for destroying the soft-shelled clam fisheries during the 1950 by expanding along the coastline of the USA which affected thousands of people besides changing the biological situation of the ecosystem. Feeding on many seashore organisms, particularly bivalve molluscs such as clams, oysters and mussels, the green crabs are faster and can open shells more easily than the native crab species. After their introduction to the Pacific side of North America, the green crab started to reduce the native clams due to its food-selection and ability to feed on larger shells than the local crab species. Biological characteristics of the native species were playing an important additional role in this case. Most of the specimens of the affected clams transform into females when they are large, which is the preferred food size of the green crabs. This caused the removal of mainly reproductive individuals, enhancing the eradication process even more. Native clams were not only reduced due to the increased grazing pressure, but another clam species present as a small non-invasive population since its un-intentional introduction by oyster-transports from the Atlantic shores of North America, switched to invasive and expanded significantly (Grosholz 2005). As a consequence, the ecological balance was severely disturbed illustrating a major impact by positive interactions or feedback between NIS causing an accelerated decline in native species.

25.4.2.4 Introduction with Ballast Water: Interference of NIS with Existing Food Web

Originally from the Atlantic estuaries of North America, the ctenophore *Mnemiopsis leidyi*, a carnivorous predator, was introduced in the early 1980s to the Black Sea by ballast water of cargo ships (Ghabooli et al. 2011; Costello et al. 2012). Without natural predators it rapidly established a population of an estimated 1 billion tonnes in the food-rich Black Sea. While feeding on fish larvae or eggs, but also on zooplankton which was the main food-source of the local fish population, the impact was tremendous culminating in the collapse of the fish-stocks only a decade after its introduction, causing annual losses in commercial fisheries of at least US$ 240 million with subsequent social implications. Introduced as a harmless species with regards to its original range, this NIS became invasive extremely fast, reaching very high densities and completely disrupting the food chain of the invaded area impacting all trophic levels. It tolerates a wide range of temperature and salinity and did not face any immediate predators or parasites. After *M. leidyi* devastated the ecosystem and fisheries, another NIS, introduced incidentally in 1997 to the Black Sea, turned out to be its native predator *Beroe ovata* and started to prey heavily on *M. leidyi*, finally causing the recovery of the Black Sea ecosystem.

25.4.3 Intentional Introductions

25.4.3.1 Aquaculture Imports and Co-introductions: Complex Multi-Factorial Impact by Non-native Oysters

Most oyster species were used intensively as a food source for a long time before aquaculture started as compensation for depleted native oyster populations. In many countries, commercial production was initiated from repeatedly introduced oysters dating back as far as the seventeenth century. Large oyster cultures are now present in coastal regions of all oceans (Ruesink et al. 2005) and provide the basis for a sizable economy like the Pacific *Crassostrea gigas* which is one of the most farmed marine species accounting for over 90% of the world oyster production (about 4.4 million tonnes in 2003, www.fao.org/fishery/culturedspecies/Crassostrea_gigas/en). The fact that an enormous biomass of *C. gigas* was imported over decades to foreign countries (about 10,000 t of spat from Japan to France between 1971 and 1977 alone) is reason enough to expect an impact in the recipient systems. *Crassostrea gigas* was finally introduced to at least 48 countries and spread into coastal estuarine regions of 17 countries (Stiger-Pouvreau and Thouzeau 2015) thereby substantially increasing its actual distribution range (Fig. 25.7).

In most of the invasive wild populations, biomass now surpasses by far that of aquaculture. Despite its high spawning temperature of 18–21 °C, the species is spreading intensively in northern Atlantic areas as far as Norway (Wrange et al. 2010). It is certain that often the combination of natural and human factors substantially enhanced the invasion capabilities of *C. gigas* (Molnar et al. 2008; Troost 2010). Intentional transport and multi-vectorial routes were providing excellent conditions for the secondary spread of *C. gigas*, like direct imports of juvenile oysters from nearby countries and within countries, non-intentional spread with shipping (ballast water and hull-fouling), recreational activities (mainly boating) or artificial structures, and even natural dispersal and propagation on a regional scale. As a negative side-effect, multi-vectorial spreading is obscuring invasion routes and hampers preventive measurements or the search for the initial introduction process. Although oyster aquaculture represents a high economic value, introductions of non-native *C. gigas* caused numerous major impacts (Stiger-Pouvreau and Thouzeau 2015).

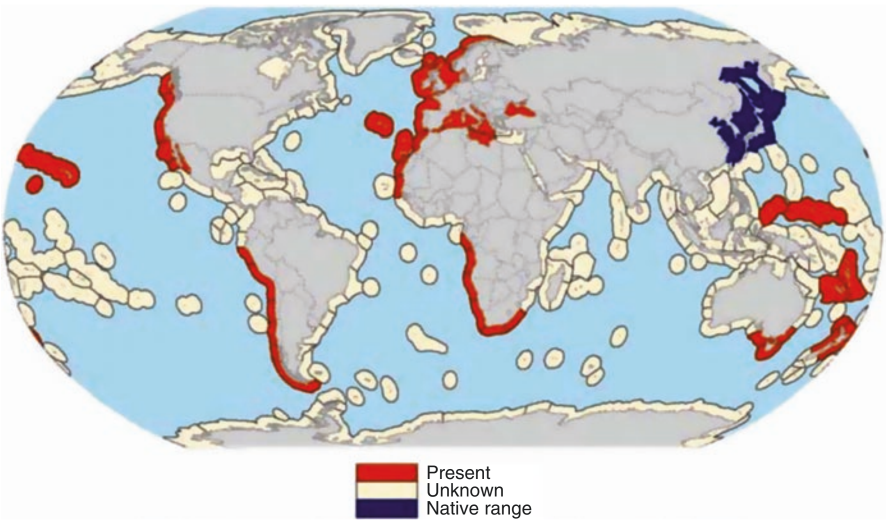


Fig. 25.7 Global distribution range of the Pacific oyster: non-indigenous range indicated in *orange*, native range in *blue* (Molnar et al. 2008)

The species might compete successfully with residential or native species and as a prolific ecosystem-engineer it has the capacity within a short time to create new habitats due to its large biogenic reef structure. Economic damage is caused by fouling harbours and numerous artificial structures or clogging pipes. Regarding biodiversity, species are displaced or relative abundances of taxonomic groups are modified. Large oyster reefs influence several trophic levels when their density is so high that filtration rates reduce phytoplankton to the point where a cascade of impacts is initiated with a top-down control of the ecosystem which is finally affecting the highest trophic levels (Troost 2010). European intertidal coastal areas with soft sediments are highly dynamic and preferred ecosystems for NIS (Reise et al. 2006) providing also *C. gigas* with appropriate conditions for establishing prolific reefs (Reise 1998; Troost 2010). During the 1990s, the continuous increase in oyster populations and the concomitant disappearance of the large native mussel beds in the German Wadden Sea first indicated a direct competition by the non-indigenous *C. gigas*. Subsequent research, however, presented evidence for a coincidental situation of very low mussel recruitment and high reproduction rate of *C. gigas*, both caused by warm seasonal temperatures over several years (Diederich et al. 2005) which supported the theory that dominance of this NIS was a result of climate conditions (Nehls et al. 2006). As an alternative viewpoint, new oyster reefs were discussed as a significant gain for the ecosystem (Reise et al. 2006) since they well compensate for habitat and biodiversity loss in estuarine environments formerly depleted by mussel and oyster exploitation and may serve as sediment traps and protection of tidal flats against further erosion which might become more important under the aspect of future sea level rise due to global warming (Troost 2010).

The complex situation of oyster introductions provides an additional example how impacts are reinforced by the combination of simultaneous anthropogenic pollution factors. Climate warming and increased introduction rates of neobiota, therefore, need to be jointly implicated in scenarios of future environmental impacts. Under this aspect, the particularly high number of up to 78 un-intentionally introduced NIS associated with live *C. gigas* transports certainly represent an enormous potential for further impacts (Ruesink et al. 2005). Of these species, several became invasive and spread to other regions contaminating many ecosystems around the world. In the Netherlands, *C. gigas* is the single most important vector for NIS (Wolff 2005). The foreign slipper limpet *Crepidula fornicata*, or the seaweeds *Sargassum muticum* and *Undaria pinnatifida* (see this chapter) are only few of the most prominent examples of IAS well established in Europe due to oyster imports (Stiger-Pouvreau and Thouzeau 2015).

25.4.3.2 Natural Dispersal as Secondary Vector in the Spread of Introduced IAS

The brown seaweed *Undaria pinnatifida* is native mainly to Japan and harvested for food throughout Pacific Asia. *Undaria* has no specific requirements for settlement on hard surfaces and can grow on natural bottoms and shells, but shows also a preference for many artificial substrates like buoys, vessel hulls, floating pontoons, ropes and all sorts of drifting material including plastics. It is tolerating a wide range of conditions, but prefers temperate waters (Floc'h et al. 1996). It was first detected in the French Thau-Lagoon of the Mediterranean Sea, a hot-spot for introductions, obviously imported from the Pacific with seed oysters for aquaculture purposes (Perez et al. 1981). In 1983, an intentional introduction of *Undaria* to the Atlantic coast of Brittany, France, was undertaken in order to establish viable cultures for future commercial harvest as a food source. Only a few years later, the seaweed had already proliferated and spread around the initial introduction sites in large numbers (Floc'h et al. 1996), despite the scientific confirmation of the responsible institution that *Undaria* would not reproduce in Atlantic waters due to environmental constraints. From then on, *Undaria* was spreading to all coastal regions of France and further south to Portugal and northward to Northern Ireland and The Netherlands, efficiently assisted by its natural dispersal ability and high preference in attachment to artificial structures like hulls, harbour walls, pontoons and protection barriers (Minchin and Nunn 2014). Negative effects of the *Undaria* invasion were evident in the influence on biodiversity, habitat structure and interference with marine farming by attaching to cages and ropes or displacing cultured species. When growing on hulls, large *Undaria* might decrease speed efficiency of vessels. This invasion case illustrates how the combination of human-mediated transport vectors and natural dispersal cabablities enhances the secondary spread of NIS. And it emphasizes the need to draw more attention to attached or hitchhiking species transferred unintentionally with imports of any kind of species or products, since every NIS is potentially invasive as long as the contrary is proven. Based on the spreading activity in *Undaria*, Mineur et al. (2015) proposed future extension of this species into the North Sea, an assumption which was now verified by the fact that attached *Undaria* was reported in summer 2016 for the German Wadden Sea island of Sylt (D. Lackschewitz, pers. com).

25.4.3.3 Escapes and Intentional Discharge

The aquarium trade is responsible for a large number of accidental and intentional releases of which the case of the green seaweed *Caulerpa taxifolia* became not only one of the most infamous examples for macroalgal introductions, but for all cases of invasions. Introduction of *C. taxifolia* to the marine environment occurred through wastewater of the Oceanographic Museum at Monaco during its use as aquarium decoration. Only the use of molecular tools finally identified the source of this IAS (Jousson et al. 1998), emphasising the need for modern methods in the study of invasion ecology. Once established, the species rapidly became invasive due to the vegetative propagation capabilities of the particular strain formerly obtained by the aquarium from the commercial dealer. Spreading rapidly through the Mediterranean Sea (Meinesz et al. 2001), *C. taxifolia* started displacing native species by overgrowing and shading seaweeds and the ecologically very important seagrass meadows by producing up to 14,000 blades per m^2 (Galil 2007), finally affecting the fauna which relied on the existing ecosystem. Sessile fauna like mussels were easily overgrown while loss of seagrass resulted in reduction of former spawning or nursery grounds and of fish populations feeding on benthic invertebrates shielded now by the thick *Caulerpa* cover (Galil 2007; Schaffelke and Hewitt 2007). Additionally, *C. taxifolia* is well protected against grazing by producing a toxin. The disastrous effect on the ecosystem had also a negative effect on commercial interests like tourism and fisheries. This case vividly demonstrates the immense risk potentially inherent in any trade for aquarium species and since acquisition of foreign species became much easier with global internet trade, transfer routes become obscured rendering control mechanisms less effective (Hewitt et al. 2007).

25.5 Research Requirements and Management

Scientific, regulative and socio-economic actions on NIS introductions require fast access to data and updated information on status, range and population size, invasion cases, pathways and impacts as provided by more than 250 websites (see list in Gatto et al. 2013, Olenin et al. 2014). Additionally, comprehensive regional lists of neobiota are needed containing supplementary species information similar to the national German list of marine neobiota (Lackschewitz et al. 2014) or those on a European scale (Gollasch 2006). The information needs, however, might not always be supported since a fundamental bias in data is evident due to inconsistencies in updates and taxonomic expertise, to variable monitoring efforts and data quality, and to different scopes between databases (Gatto et al. 2013). Within Europe, the European Alien Species Information Network (EASIN) was initiated to serve as a platform for political institutions (Katsanevakis et al. 2012) to fascilitate management on national and global scales which has to focus primarily on mitigation of existing problems and prevention of any future introductions. Science seems to be still in its early stages in providing the required substantial evidence and strategies needed, despite extensive outlines presented previously (Schaffelke et al. 2006) and authorities often react to existing cases instead of executing strict prevention management. While long-term studies are needed for understanding the ecology of invasions in order to evaluate future risks, rapid assessment methods already represent an appropriate monitoring approach for immediate actions like eradication measures before NIS become established and spread, especially in containable areas (Buschbaum et al. 2012; Lehtiniemi et al. 2015). Most promising is the combination of methods involving different aspects of invasion analysis, from historic data to species inventories, from taxonomic expertise to genetic studies, and from rapid assessments to models of invasion processes (see Mathieson et al. 2008). Database management has to be improved and acquisition of updated information facilitated on an international scale. Impacts and underlying mechanisms are often not fully substantiated through quantitative results in order to support general ecological patterns which could help in understanding invasion processes and predicting future risks (Schaffelke and Hewitt 2007). Data are even lacking (Davidson and Hewitt

2014) or impacts are not well enough described and mechanisms misinterpreted (Molnar et al. 2008). Several cases depend on studies with low statistical evidence or insufficient sample size, and comparisons between regions for categorizing impacts are generally impossible (Davidson et al. 2015). One of the alternatives is modelling strategies for managing ballast water invasions in the global shipping network (Drake and Lodge 2004). A major framework for action plans and management based on international agreements is the European Marine Strategy Framework Directive which defines descriptors of the environmentally good status and outlines categories with core values for evaluating neobiota and their impacts (Ojaveer et al. 2015). If member states fulfil their obligations, this framework could be the first step in a proper management of invasion risks and future prevention of introductions in Europe. Science and management have to consider the fundamental differences between impacts of IAS and other pollution forms which often can be diminished by appropriate measures at the source. Once established, it is nearly impossible to eradicate IAS and their tendency to continuously expand by multifactorial pathways circumvents control mechanisms. The only effective strategy for reducing future impacts is a consequent prevention of introductions of any NIS by intercepting or removal of pathways with strict entry regulations (Carlton and Ruiz 2005). Ballast water treatment and inhibition of hull-fouling are the major prevention methods against ship-mediated introductions (David and Gollasch 2008), but are only effective if strictly implemented, similarly to the control of imports for aquaculture purposes and trade of live organisms. It is, however, impossible to control every vessel, every import and trade, so efforts have to concentrate on high-risk vessels and their pathways and entry regions. The assessment of IAS impacts has to involve different temporal and spatial scales. Locations with high numbers of NIS and those with stepping stone characteristics like all artificial structures (harbours etc.) and aquaculture installations represent the local scale and require the primary focus before further evaluations are extended to ecosystems and whole regions. According to the purpose of the assessments and the taxonomic groups involved, it is essential to consider also temporal scales. Rapid assessment monitoring has to be done in a high frequency and very effectively, albeit encompassing as much area as possible, while ecological studies will be done in more detail with long-term aspects becoming more important in order to predict invasion risks of regions and invasion pressure through traits of NIS. Successful assessment of the ecological situation of an introduction requires a sound basis in species identification. Once a newly introduced species is detected and identified by classic taxonomic procedure, it is often critical to use molecular methods. There might be cryptic species formerly overlooked or the NIS constitutes a specific strain of its source population with ecological traits increasing its invasiveness like enhanced vegetative propagation. Valuable information for future predictions in the invasion process is acquired with studies on potential genetic changes, genetic differentiation, hybridization, phenotypic variation, interactions between species-genes and the environment, and on possible genetic adaptations in NIS after their invasion (Booth et al. 2007). Most pollutants usually follow a typical degradation gradient which can be monitored and assessed by descriptors of the Good Environmental Status (GES) and corrective actions might be taken accordingly. IAS, on the contrary, often represent an integral part of the ecosystem with ecological implications difficult to assess. Continuing impacts despite any remedial actions like eradication efforts, obstruct any effective and long-term management. Absolute prevention and extensive control of introduction vectors has therefore top priority in a sustainable management. All intentional introductions need substantial examination and official authorisation with a comprehensive risk assessment of invasiveness. Vectors and pathways have to be constantly controlled and early detection and rapid response need to be essential parts of baseline surveys. Additionally, community participation and awareness have to be acknowledged as an integral basis for a successful management.

25.6 Perspectives

Identification of the relative importance of invasion factors is a prerequisite for future management purposes and requires integration of additional stressors in ecosystem functioning which likely induce a positive response in invasion rates like global warming, reclamation of land, construction activities along coastlines, sediment extraction, harvesting of natural resources, habitat modification, overgrazing and eutrophication (Raitsos et al. 2010; Mineur et al. 2015). Introductions of NIS are a continuing and increasing pollution problem which has to be tackled on a broad scale ranging from individual responsibilities to scientific excellence and global regulative measures (Ojaveer et al. 2014). Science started to advance beyond the assessment of introductions or species lists and even critical aspects were issued warning against bias about NIS and urging to focus instead on sound ecological science which need to be extended (Reise et al. 2002). Similarly, international regulative measures and political management are now required to advance in accordance to the existing management options available at the various points within the introduction framework (Fig. 25.8).

Whereas shipping is recognized in regulative organisations as a major vector for introductions, recreational boating is mostly unregulated and like the trade with aquarium species, risks of introductions depend on the attitude and behaviour of amateur persons difficult to control (Clarke Murray et al. 2011). All the more there is the need for general education to enhance awareness of individuals in their daily activities and on socio-economic levels. It is the opportunity of everyone who is relying on worldwide trade for their consumption of goods to reduce the chance of neobiota introductions by selecting products which require only short transport distances and as little shipping from overseas countries as possible especially if adequate alternatives exist. If all risks and socio-economic costs attributable to invasive species are considered in a broader view, the consumption of local products and resources might be less costly in the long term. Nevertheless, there is the obligation of regulation authorities and the political management to support people in this aspect and to provide the necessary framework (Chap. 48). It is of paramount importance to consider the synergistic effects of human activity, pollution

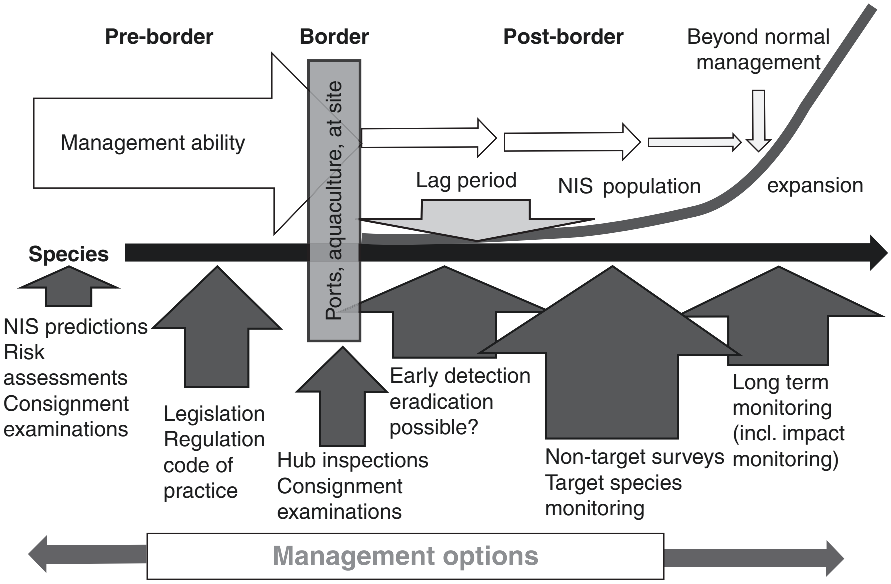


Fig. 25.8 Diagram of management and monitoring options at different phases of the introduction and during spread of NIS (Lehtiniemi et al. 2015)

and environmental factors, since invasions of IAS often occur in a multi-factorial context as stated in the case of global warming as one of the principal causes in the success of future introductions suspected of accelerating invasions by global shipping (Seebens et al. 2015).

References

Bailey SA (2015) An overview of thirty years of research on ballast water as a vector for aquatic invasive species to freshwater and marine environments. Aquat Ecosyst Health Manag 18:1–8

Bax N, Williamson A, Aguero M, Gonzalez E, Geeves W (2003) Marine invasive alien species: a threat to global biodiversity. Mar Policy 27:313–323

Bishop JDD, Wood CA, Yunnie ALE, Griffiths CA (2015) Unheralded arrivals: nonnative sessile invertebrates in marinas on the English coast. Aquat Invasions 10:249–264. doi:10.3391/ai.2015.10.3.01

Blumenthal DM (2006) Interactions between resource availability and enemy release in plant invasion. Ecol Lett 9:887–895

Booth D, Provan J, Maggs C (2007) Molecular approaches to the study of invasive seaweeds. Bot Mar 50:385–396. doi:10.1515/BOT.2007.043

Buschbaum C, Lackschewitz D, Reise K (2012) Non-native macrobenthos in the Wadden Sea ecosystem. Ocean Coast Manag 68:89–101

Calado R, Chapman PM (2006) Aquarium species: deadly invaders. Mar Pollut Bull 52:599–601

Carlton JT (1985) Transoceanic and interoceanic dispersal of coastal marine organisms: the biology of ballast water. Oceanogr Mar Biol Annu Rev 23:313–371

Carlton JT (1987) Patterns of transoceanic marine biological invasions in the Pacific Ocean. Bull Mar Sci 41:452–465
Carlton JT (1996) Pattern, process, and prediction in marine invasion ecology. Biol Conserv 78:97–106
Carlton JT (2003) Community assembly and historical biogeography in the North Atlantic Ocean: the potential role of human-mediated dispersal vectors. Hydrobiologia 503:1–8
Carlton JT (2009) Deep invasion ecology and the assembly of communities in historical time. In: Rilov G, Crooks J (eds) Biological invasions in marine ecosystems: ecological, management and geographic perspectives, Ecological studies, vol 204. Springer, Heidelberg, pp 13–56
Carlton JT, Cohen AN (2003) Episodic global dispersal in shallow water marine organisms: the case history of the European shore crabs *Carcinus maenas* and *C. aestuarii*. J Biogeogr 30:1809–1820
Carlton JT, Geller JB (1993) Ecological roulette: the global transport of nonindigenous marine organisms. Science 261:78–82
Carlton JT, Ruiz GM (2005) Vector science and integrated vector management in bioinvasion ecology: conceptual frameworks. In: Mooney HA, Mack RN, McNeely JA, Neville LE, Schei PJ, Waage JK (eds) Invasive alien species: a new synthesis. Island Press, Washington, DC, pp 36–58
Clarke Murray C, Pakhomov EA, Therriault TW (2011) Recreational boating: a large unregulated vector transporting marine invasive species. Divers Distrib 17:1161–1172
Cohen AN, Carlton JT (1998) Accelerating invasion rate in a highly invaded estuary. Science 279:555–558
Colautti RI, MacIsaac HJ (2004) A neutral terminology to define 'invasive' species. Divers Distrib 10:135–141
Colautti RI, Ricciardi A, Grigorovich IA, MacIsaac HJ (2004) Is invasion success explained by the enemy release hypothesis? Ecol Lett 7:721–733
Cook E, Ashton G, Campbell M, Coutts A, Gollasch S, Hewitt C, Liu H, Minchin D, Ruiz G, Shucksmith R (2008) Non-native aquaculture species releases: implications for aquatic ecosystems. In: Holmer M, Black KD (eds) Aquaculture in the ecosystem. Springer, Dordrecht, pp 155–184
Costello MJ, Coll M, Danovaro R, Halpin P, Ojaveer H, Miloslavich PA (2010) A census of marine biodiversity knowledge, resources, and future challenges. PLoS One 5:e12110. doi:10.1371/journal.pone.0012110
Costello JH, Bayha KM, Mianzan HW, Shiganova TA, Purcell JE (2012) Transitions of *Mnemiopsis leidyi* (Ctenophora: Lobata) from a native to an exotic species: a review. Hydrobiologia 690:21–46. doi:10.1007/s10750-012-1037-9
DAISIE (2006). *Teredo navalis*—species factsheet. http://www.europe-aliens.org/speciesFactsheet.do?speciesId=50276#. Accessed 8 Feb 2016
David M, Gollasch S (2008) EU shipping in the dawn of managing the ballast water issue. Mar Pollut Bull 56:1966–1972
Davidscon IC, Zabin CJ, Chang AL, Brown CW, Sytsma MD, Ruiz GM (2010) Recreational boats as potential vectors of marine organisms at an invasion hotspot. Aquat Biol 11:179–191
Davidson AD, Hewitt CL (2014) How often are invasion-induced ecological impacts missed? Biol Invasions 16:1165–1173
Davidson AD, Campbell ML, Hewitt CL, Schaffelke B (2015) Assessing the impacts of nonindigenous marine macroalgae: an update of current knowledge. Bot Mar 58:55–79. doi:10.1515/bot-2014-0079
Diederich S, Nehls G, Van Beusekom JEE, Reise K (2005) Introduced pacific oysters (*Crassostrea gigas*) in the Northern Wadden Sea: invasion accelerated by warm summers? Helgol Mar Res 59:97–106
Drake JM, Lodge DM (2004) Global hot spots of biological invasions: evaluating options for ballast-water management. Proc R Soc Lond B 271:575–580
EC (2008) Marine strategy framework. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field

of marine environmental policy (Marine Strategy Framework Directive). Off J Eur Union L164:19–40

EC (2014) Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species. Off J Eur Union 317:35–55

Engelen AH, Serebryakova A, Ang P, Britton-Simmons K, Mineur F, Pedersen M, Arenas F, Fernández C, Steen H, Svenson R, Pavia H, Toth G, Viard F, Santos R (2015) Circumglobal invasion by the brown seaweed *Sargassum muticum*. Oceanogr Mar Biol Annu Rev 53:81–126

Fernández C, Gutiérrez LM, Rico JM (1990) Ecology of *Sargassum muticum* on the north coast of Spain: preliminary observations. Bot Mar 33:423–428. doi:10.1515/botm.1990.33.5.423

Floc'h JY, Pajot R, Mouret V (1996) *Undaria pinnatifida* (Laminariales, Phaeophyta) 12 years after its introduction into the Atlantic Ocean. Hydrobiologia 326(327):217–222

Galil BS (2007) Loss or gain? Invasive aliens and biodiversity in the Mediterranean Sea. Mar Pollut Bull 55:314–322. doi:10.1016/j.marpolbul.2006.11.008

Galil BS (2008) Alien species in the Mediterranean Sea—which, when, where, why? Hydrobiologia 606:105–116

Galil BS, Zenetos A (2002) A sea of change: exotics in the eastern Mediterranean sea. In: Leppäkoski E, Gollasch S, Olenin S (eds) Invasive aquatic species of Europe: distribution, impacts and management. Kluwer Academic Publishers, Dordrecht, pp 325–336

Galil BS, Marchini A, Occhipinti-Ambrogi A, Minchin D, Narščius A, Ojaveer H, Olenin S (2014) International arrivals: widespread bioinvasions in European Seas. Ethol Ecol Evol 26:152–171

Galil BS, Boero F, Campbell ML, Carlton JT, Cook E, Fraschetti S, Gollasch S, Hewitt CL, Jelmert A, Macpherson E, Marchini A, McKenzie C, Minchin D, Occhipinti-Ambrogi A, Ojaveer H (2015) 'Double trouble': the expansion of the Suez Canal and marine bioinvasions in the Mediterranean Sea. Biol Invasions 17:973–976. doi:10.1007/s10530-014-0778-y

Gatto F, Katsanevakis S, Vandekerkhove J, Zenetos A, Cardoso AC (2013) Evaluation of online information sources on alien species in Europe: the need of harmonization and integration. Environ Manag 51:1137–1146

Ghabooli S, Shiganova TA, Zhan A, Cristescu ME, Eghtesadi-Araghi P, MacIsaac HJ (2011) Multiple introductions and invasion pathways for the invasive ctenophore *Mnemiopsis leidyi* in Eurasia. Biol Invasions 13:679–690. doi:10.1007/s10530010-9859-8

Gollasch S (2002) The importance of ship hull fouling as a vector of species introductions into the North Sea. Biofouling 18:105–121

Gollasch S (2006) Overview on introduced aquatic species in European navigational and adjacent waters. Helgol Mar Res 60:84–89

Gollasch S (2007) International collaboration on marine bioinvasions: the ICES response. Mar Pollut Bull 55:353–359. doi:10.1016/j.marpolbul.2006.11.009

Gollasch S, McDonals E, Belson S, Botnen H, Christensen JT, Hamer JP, Houvenaghel G, Jelmert A, Lucas I, Masson D, McCollin T, Olenin S, Persson A, Wallentinus I, Wetsteyn LPMJ, Wittling T (2002) Life in ballast tanks. In: Leppäkoski E, Gollasch S, Olenin S (eds) Invasive aquatic species of Europe: distribution, impacts and management. Kluwer Academic Publishers, Dordrecht, pp 217–231

Gollasch S, Galil BS, Cohen AN (2006) Bridging divides—maritime canals as invasion corridors, Monographiae Biologicae, vol 83. Springer, Berlin

Gollasch S, Haydar D, Minchin D, Wolff WJ, Reise K (2009) Introduced aquatic species of the North Sea coasts and adjacent brackish waters. In: Rilov G, Crooks J (eds) Biological invasions in marine ecosystems: ecological, management and geographic perspectives, Ecological studies, vol 204. Springer, Heidelberg, pp 507–528

Grosholz ED (2005) Recent biological invasion may hasten invasional meltdown by accelerating historical introductions. Proc Natl Acad Sci 102:1088–1091

HELCOM (2009). Biodiversity in the Baltic Sea—an integrated thematic assessment on biodiversity and nature conservation in the Baltic Sea. Baltic Sea Environment Proceedings 116B

Hewitt CL, Campbell ML, Schaffelke B (2007) Introductions of seaweeds: accidental transfer pathways and mechanisms. Bot Mar 50:326–337. doi:10.1515/9783110211344

Hewitt CL, Gollasch S, Minchin D (2009) Ballast water, sediments and hull fouling. In: Rilov G, Crooks J (eds) Biological invasions in marine ecosystems: ecological, management and geographic perspectives, Ecological studies, vol 204. Springer, Heidelberg, pp 117–129

Hughes KA, Ashton GV (2016) Breaking the ice: the introduction of biofouling organisms to Antarctica on vessel hulls. Aquat Conserv Mar Freshwat Ecosyst 27(1):158–164. doi:10.1002/aqc.2625

ICES (2005). ICES Code of practice on the introductions and transfers of marine organisms 2005. International Council for the Exploration of the Sea

Jousson O, Pawlowski J, Zaninetti L, Meinesz A, Boudouresque CF (1998) Molecular evidence for the aquarium origin of the green alga *Caulerpa taxifolia* introduced to the Mediterranean Sea. Mar Ecol Prog Ser 172:275–280

Kaluza P, Kölzsch A, Gastner MT, Blasius B (2010) The complex network of global cargo ship movements. J R Soc Interface 7:1093–1103

Katsanevakis S, Bogucarskis K, Gatto F, Vandekerkhove J, Deriu I, Cardoso AC (2012) Building the European Alien Species Information Network (EASIN): a novel approach for the exploration of distributed alien species data. Bioinvasions Rec 1:235–245. doi:10.3391/bir.2012.1.4.01

Katsanevakis S, Gatto F, Zenetos A, Cardoso AC (2013) How many marine aliens in Europe? Manag Biol Invasions 4:37–42. doi:10.3391/mbi.2013.4.1.05

Katsanevakis S, Coll M, Piroddi C, Steenbeek J, Ben Rais Lasram F, Zenetos A, Cardoso AC (2014a) Invading the Mediterranean Sea: biodiversity patterns shaped by human activities. Front Mar Sci. doi:10.3389/fmars.2014.00032

Katsanevakis S, Wallentinus I, Zenetos A, Leppäkoski E, Çinar ME, Oztürk B, Grabowski M, Golani D, Cardoso AC (2014b) Impacts of marine invasive alien species on ecosystem services and biodiversity: a pan-European critical review. Aquat Invasions 9:391–423. doi:10.3391/ai.2014.9.4.01

Kölzsch A, Blasius B (2011) Indications of marine bioinvasion from network theory. An analysis of the global cargo ship network. Eur Phys J B 84:601–612

Kuhlenkamp R, Kind B (2013) Arrival of the invasive *Watersipora subtorquata* (Bryozoa) at Helgoland (Germany, North Sea) on floating macroalgae (*Himanthalia*). Mar Biodivers Rec 6:e73. doi:10.1017/S1755267213000481

Lackschewitz, D., Reise, K., Buschbaum, C. & Karez, R. (2014). Neobiota in deutschen Küstengewässern. Eingeschleppte und kryptogene Tier- und Pflanzenarten an der deutschen Nord- und Ostseeküste. Report of the State Agency for Agriculture, Nature and Rural Areas (LLUR) of Schleswig-Holstein, Germany

Lehtiniemi M, Ojaveer H, David M, Galil B, Gollasch S, McKenzie C, Minchin D, Occhipinti-Ambrogi A, Olenin S, Pederson J (2015) Dose of truth—monitoring marine non-indigenous species to serve legislative requirements. Mar Policy 54:26–35

Leppäkoski E, Gollasch S, Olenin S (2002a) Invasive aquatic species of Europe: distribution, impacts and management. Kluwer Academic Publishers, Dordrecht

Leppäkoski E, Gollasch S, Gruszka P, Ojaveer H, Olenin S, Panov V (2002b) The Baltic—a sea of invaders. Can J Fish Aquat Sci 59:1175–1188

Lockwood JL, Hoopes MF, Marchetti MP (2007) Invasion ecology. Blackwell, Oxford

López-Legentil S, Legenti ML, Erwin PM, Turon X (2015) Harbor networks as introduction gateways: contrasting distribution patterns of native and introduced ascidians. Biol Invasions 17:1623–1638

Mack RN, Simberloff D, Lonsdale WM, Evans H, Clout M, Bazzaz FA (2000) Biotic invasions: causes, epidemiology, global consequences, and control. Ecol Appl 10:689–710

Marchini A, Ferrario J, Minchin D (2015a) Marinas may act as hubs for the spread of the pseudo-indigenous bryozoan *Amathia verticillata* (Delle Chiaje, 1822) and its associates. Sci Mar 79:355–365. doi:10.3989/scimar.04238.03A

Marchini A, Ferrario J, Sfriso A, Occhipinti-Ambrogi A (2015b) Current status and trends of biological invasions in the Lagoon of Venice, a hotspot of marine NIS introductions in the Mediterranean Sea. Biol Invasions 17:2943–2962

Mathieson AC, Pederson JR, Dawes CJ (2008) Rapid assessment surveys of fouling and introduced seaweeds in the northeastern Atlantic. Rhodora 110:406–478

McIvor L, Maggs CA, Provan J, Stanhope MJ (2001) rbcL sequences reveal multiple cryptic introductions of the Japanese red alga, *Polysiphonia harveyi*. Mol Ecol 10:911–919

Meinesz A, Belsher T, Thibaut T, Antolic B, Ben Mustapha K, Boudouresque CF, Chiaverini D, Cinelli F, Cottalorda J-M, Djellouli A, El Abed A, Orestano C, Grau AM, Ivesa L, Jaklin A, Langar H, Massuti-Pascual E, Peirano A, Tunesi L, De Vaugelas J, Zavodnik N, Zuljevic A (2001) The introduced green alga *Caulerpa taxifolia* continues to spread in the Mediterranean. Biol Invasions 3:201–210

Minchin D, Nunn J (2014) The invasive brown alga *Undaria pinnatifida* (Harvey) Suringar, 1873 (Laminariales: Alariaceae), spreads northwards in Europe. BioInvasions Rec 3:57–63

Minchin D, Floerl O, Savini D, Occhipinti-Ambrogi A (2006) Small craft and the spread of exotic species. In: Davenport J, Davenport JL (eds) The ecology of transportation, managing mobility for the environment. Springer, Berlin, pp 99–118

Minchin D, Gollasch S, Cohen AN, Hewitt C, Olenin S (2009) Characterizing vectors of marine invasions. In: Rilov G, Crooks J (eds) Biological invasions in marine ecosystems: ecological, management and geographic perspectives, Ecological studies, vol 204. Springer, Heidelberg, pp 109–115

Mineur F, Johnson MP, Maggs CA, Stegenga H (2007) Hull fouling on commercial ships as a vector of macroalgal introduction. Mar Biol 151:1299–1307

Mineur F, Johnson MP, Maggs CA (2008) Macroalgal introductions by hull fouling on recreational vessels: seaweeds and sailors. Environ Manag 42:667–676. doi:10.1007/s00267-008-9185-4

Mineur F, Davies AJ, Maggs CA, Verlaque M, Johnson MP (2010) Fronts, jumps and secondary introductions suggested as different invasion patterns in marine species, with an increase in spread rates over time. Proc R Soc B 277:2693–2701

Mineur F, Cook EJ, Minchin D, Bohn K, MacLeod A, Maggs CA (2012) Changing coasts: marine aliens and artificial structures. Oceanogr Mar Biol Annu Rev 50:189–233

Mineur F, Le Roux A, Verlaque M, Maggs CA (2014) Positive feedback loop between intensive aquaculture and marine introductions. Conserv Biol 28:1667–1676. doi:10.1111/cobi.12363

Mineur F, Arenas F, Assis J, Davies AJ, Engelen AH, Fernandes F, Malta E-J, Thibaut T, Van Nguyen T, Vaz-Pinto F, Vranken S, Serrão EA, De Clerck O (2015) European seaweeds under pressure: consequences for communities and ecosystem functioning. J Sea Res 98:91–108

Molnar JL, Gamboa RL, Revenga C, Spalding MD (2008) Assessing the global threat of invasive species to marine biodiversity. Front Ecol Environ 6:485–492

Nehls G, Diederich S, Thieltges DW, Strasser M (2006) Wadden Sea musselbeds invaded by oysters and slipper limpets: competition or climate control? Helgol Mar Res 60:135–143

Occhipinti-Ambrogi A (2007) Global change and marine communities: alien species and climate change. Mar Pollut Bull 55:342–352

Occhipinti-Ambrogi A, Savini D (2003) Bioinvasions as a component of global change in stressed marine ecosystem. Mar Pollut Bull 46:542–551

Occhipinti-Ambrogi A, Marchini A, Cantone G, Castelli A, Chimenz C, Cormaci M, Froglia C, Furnari G, Gambi MC, Giaccone G, Giangrande A, Gravili C, Mastrototaro F, Mazziotti C, Orsi-Relini L, Piraino S (2011) Alien species along the Italian coasts: an overview. Biol Invasions 13:215–237

Ojaveer H, Galil BS, Gollasch SA, Marchini A, Minchin D, Occhipinti-Ambrogi A, Olenin S (2014) Identifying the top issues of invasive alien species in Europe. Manag Biol Invasions 5:81–84. doi:10.3391/mbi.2014.5.2.01

Ojaveer H, Galil BS, Campbell ML, Carlton JT, Canning-Clode J, Cook EJ, Davidson AD, Hewitt CL, Jelmert J, Marchini A, McKenzie CH, Minchin D, Occhipinti-Ambrogi A, Olenin S, Ruiz G (2015) Classification of non-indigenous species based on their impacts: considerations for application in marine management. PLoS Biol 13:e1002130. doi:10.1371/journal.pbio.1002130

Olenin S, Narščius A, Minchin D, David M, Galil B, Gollasch S, Marchini A, Occhipinti-Ambrogi A, Ojaveer H, Zaiko A (2014) Making non-indigenous species information systems practical for management and useful for research: an aquatic perspective. Biol Conserv 173:98–107

Ostenfeld CHP (1908) On the immigration of *Biddulphia sinensis* Grev. and its occurrence in the North Sea during 1903–1907. Meddelelser Fra Kommissionen Fur Danmarks Fiskeri-og Havundersogelser. Serie Plankton 1:1–44

Padilla DK, Williams SL (2004) Beyond ballast water: aquarium and ornamental trades as sources of invasive species in aquatic ecosystems. Front Ecol Environ 2:131–138

Perez R, Lee JY, Juge C (1981) Observations sur la biologie de l'algue Japonaise *Undaria pinnatifida* (Harvey) Suringar introduite accidentellement dans l'Etang de Thau. Science et Péche 315:1–12

Preisler RK, Wasson K, Wolff WJ, Tyrrell MC (2009) Invasions of estuaries versus the adjacent open coast: a global perspective. In: Rilov G, Crooks J (eds) Biological invasions in marine ecosystems: ecological, management and geographic perspectives, Ecological studies, vol 204. Springer, Heidelberg, pp 587–617

Provan J, Booth D, Todd NP, Beatty GE, Maggs CA (2008) Tracking biological invasions in space and time: elucidating the invasive history of the green alga *Codium fragile* using old DNA. Divers Distrib 14:343–354

Pysek P, Hulme PE, Nentwig W (2009) Glossary of the main technical terms used in the handbook. In: DAISIE (ed) The handbook of alien species in Europe. Springer, Berlin, pp 375–381

Raitsos DE, Beaugrand G, Georgopoulos D, Zenetos A, Pancucci-Papadopoulou AM, Theocharis A, Papathanassiou E (2010) Global climate change amplifies the entry of tropical species into the Eastern Mediterranean Sea. Limnol Oceanogr 55:1478–1484

Reise K (1998) Pacific oysters invade mussel beds in the European Wadden Sea. Senckenberg Marit 28:167–175

Reise K, Gollasch S, Wolff WJ (1999) Introduced marine species of the North Sea coasts. Helgoländer Meeresuntershungen 52:219–234

Reise K, Gollasch S, Wolff WJ (2002) Introduced marine species of the North Sea coasts. In: Leppäkoski E, Gollasch S, Olenin S (eds) invasive aquatic species of Europe: distribution, impacts and management. Kluwer Academic Publishers, Dordrecht, pp 260–266

Reise K, Olenin S, Thieltges DW (2006) Are aliens threatening European aquatic coastal ecosystems? Helgol Mar Res 60:106–112

Ribera MA, Boudouresque CF (1995) Introduced marine plants, with special reference to macroalgae: mechanisms and impact. In: Round FE, Chapman DJ (eds) Progress in phycological research, vol 11. Bristol, Biopress Ltd, pp 187–268

Ribera-Siguan MA (2003) Pathways of biological invasions of marine plants. In: Ruiz GM, Carlton JT (eds) Invasive species: vectors and management strategies. Island Press, Washington, DC, pp 183–226

Ruesink JL, Lenihan HS, Trimble AC, Heiman KW, Micheli F, Byers JE, Kay MC (2005) Introduction of non-native oysters: ecosystem effects and restoration implications. Annu Rev Ecol Evol Syst 36:643–689

Ruiz GM, Rawlings TK, Dobbs FC, Drake LA, Mullady T, Huq A, Colwell RR (2000) Global spread of microorganisms by ships. Nature 408:49–50

Schaffelke B, Hewitt CL (2007) Impacts of introduced seaweeds. Bot Mar 50:397–417. doi:10.1515/BOT.2007.044

Schaffelke B, Smith JE, Hewitt CL (2006) Introduced macroalgae—a growing concern. J Appl Phycol 18:529–541

Seebens H, Gastner M, Blasius B (2013) The risk of marine bioinvasion caused by global shipping. Ecol Lett 16:782–790

Seebens H, Essl F, Dawson W, Fuentes N, Moser D, Pergl J, Pyšek P, van Kleunen M, Weber E, Winter M, Blasius B (2015) Global trade will accelerate plant invasions in emerging economies under climate change. Glob Chang Biol 21:4128–4140

Stiger-Pouvreau V, Thouzeau G (2015) Marine species introduced on the French Channel-Atlantic coasts: a review of main biological invasions and impacts. Open J Ecol 5:227–257

Streftaris N, Zenetos A, Papathanassiou E (2005) Globalisation in marine ecosystems: the story of non-indigenous marine species across European seas. Oceanogr Mar Biol Annu Rev 43:419–453

Terlizzi A, Bevilacqua S, Fraschetti S, Boero F (2003) Taxonomic sufficiency and the increasing insufficiency of taxonomic expertise. Mar Pollut Bull 46:556–561. doi:10.1016/S0025-326X(03)00066-3

Troost K (2010) Causes and effects of a highly successful marine invasion: case-study of the introduced Pacific oyster *Crassostrea gigas* in continental NW European estuaries. J Sea Res 64:145–165

United Nations Convention on the Law of the Sea (1982) UNTS 1833-A-31363

Valentine JP, Magierowski RH, Johnson CR (2007) Mechanisms of invasion: establishment, spread and persistence of introduced seaweed populations. Bot Mar 50:351–360. doi:10.1515/BOT.2007.040

Vaz-Pinto F, Rodil I, Mineur F, Olabarria C, Arenas F (2015) Understanding Biological Invasions by Seaweeds. In: Pereira L, Neto JM (eds) Marine algae—biodiversity, taxonomy, environmental assessment and biotechnology. Francis & Taylor, Boca Raton

Ware C, Berge J, Sundet JH, Kirkpatrick JB, Coutts ADM, Jelmert A, Olsen SM, Floerl O, Wisz MS, Alsos IG (2014) Climate change, non-indigenous species and shipping: assessing the risk of species introduction to a high-Arctic archipelago. Divers Distrib 20:10–19

Wasson K, Zabin CJ, Bedinger L, Diaz MC, Pearse JS (2001) Biological invasions of estuaries without international shipping: the importance of intraregional transport. Biol Conserv 102:143–153

Williams SL, Smith JE (2007) Distribution and impact of introduced marine plants around the world. Annu Rev Ecol Evol Syst 38:327–359

Wolff WJ (2005) Non-indigenous marine and estuarine species in the The Netherlands. Zoologische Mededelingen 79:1–116

Wolff WJ, Reise K (2002) Oyster imports as a vector for the introduction of alien species into northern and western Europe coastal waters. In: Leppäkoski E, Gollasch S, Olenin S (eds) Invasive aquatic species of Europe: distribution, impacts and management. Kluwer Academic Publishers, Dordrecht, pp 193–205

Wrange A-L, Valero J, Harkestad LS, Strand Ø, Lindegarth S, Christensen HT, Dolmer P, Kristensen PS, Mortensen S (2010) Massive settlements of the Pacific oyster, *Crassostrea gigas*, in Scandinavia. Biol Invasions 12:1145–1152

Xu, J., Wickramarathne, T. L., Chawla, N. V., Grey, E. K., Steinhaeuser, K., Keller, R. P., Drake, J. M. & Lodge, D. M. (2014). Improving management of aquatic invasions by integrating shipping network, ecological, and environmental data: data mining for social good. In: Proceedings of the 20th ACM SIGKDD international conference on knowledge discovery and data mining, New York, 24–27 August 2014, pp 1699–1708

Zenetos A (2010) Trend in aliens species in the Mediterranean. An answer to Galil, 2010 "Taking stock: inventory of alien species in the Mediterranean Sea". Biol Invasions 12:3379–3381

Zenetos A, Gofas S, Morri C, Rosso A, Violanti D, Garcia Raso JE, Cinar ME, Almogi-Labin A, Ates AS, Azzurro E, Ballesteros E, Bianchi CN, Bilecenoglu M, Gambi MC, Giangrande A, Gravili C, Hyams-Kaphzan O, Karachle PK, Katsanevakis S, Lipej L, Mastrototaro F, Mineur F, Pancucci-Papadopoulou MA, Ramos Espla A, Salas C, San Martin G, Sfriso A, Streftaris N, Verlaque M (2012) Alien species in the Mediterranean Sea by 2012. A contribution to the application of European Union's Marine Strategy Framework Directive (MSFD). Part 2. Introduction trends and pathways. Mediterr Mar Sci 13:328–352

Part V
Social Drivers, Developments, and Perspectives of Increasing Ocean Uses

Chapter 26
A Short History of the Use of Seas and Oceans

Sunhild Kleingärtner

Abstract The history of ships and shipping technologies reveals the history of use and perception of the sea by human beings. It also serves as an example to reveal a paradigm shift in terms of sustainable management of seas and oceans. Utilization of the sea has always been strongly motivated by the basic needs of human beings. People have been obtaining resources from the sea since the Stone Age, and beginning in the early Middle Ages and continuing especially in the early modern era, there has been increased frequency of trading contacts, at first limited to coastal areas and ultimately crossing oceans. If large sea battles that led to ships being used as floating "battle positions" can be said to have dominated the stage of the sea in the seventeenth and eighteenth centuries, in the late nineteenth century and especially the twentieth it was pleasure trips and research issues that turned ships into hotels and laboratories on the water. Ships and shipping have always operated in interaction with human benefits, technologies, and the environment.

Over the past four decades, there have been decisive discussions about how to deal with our seas and oceans in the context of finite natural resources. As seen from a larger historical perspective, concern about sustainable use occupies a comparatively brief interval in human history. Nevertheless, in what follows the current concerns are not interpreted as a passing fashion but rather as being representative of a new societal consensus borne through paradigm shift. In the field of shipping, this has been expressed internationally as "green shipping", i.e. environmental protection in maritime transportation. The goal of green shipping is to bring about a change in attitude in order to advance the sustainable use of seas and oceans as part of a responsible approach to nature despite similarly growing demands for greater economy, greater safety and adaptation to new tasks for transportation.

Keywords History of shipping • History of ocean uses and exploitation • Changing perceptions of the sea

---

(Translated by Steven Lindberg)

S. Kleingärtner
Deutsches Schiffahrtsmuseum, Leibniz-Institut für deutsche Schifffahrtsgeschichte, Bremerhaven, Germany
e-mail: Kleingaertner@dsm.museum

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_26

26.1 Introduction

We live in a connected world. In the wake of globalization and digital communication, geographical distances have been reduced and in some cases, eliminated altogether (Osterhammel and Petersson 2007). The world seems to have "moved closer together." The seven continents have digital links via the Internet and analogue ones via undersea cables (Holtorf 2013). Today, airplanes represent the fastest mode of conveyance between continents; at one time, however, ships were the only way to cross the world's seas.

The size and appearance of all watercraft depend on their purpose, their place of action, and not least the state of technology of their time. Navigation has always been part of the interaction with human benefits, environment, and technology. The history of the use and perception of the seas and oceans by human beings can thus be expressed in the history of ships and shipping.

The goal of the present essay is to use the example of ships to reveal in retrospect the paradigm shift in terms of sustainable management of seas and oceans—a relatively recent one within the Anthropocene epoch (see Ehlers 2008). Examples and aspects are highlighted without any claim to completeness. Human motives and behavior in relation to the environment and technology and the resulting consequences will be examined in the first section, while the second section will deal with some different forms of use as well as the intensification of sea and ocean use.

26.2 Human Beings

The human motives for using the seas and oceans are changing, diverse, and most of all dependent upon time and space. Though there are many practical motivations to make use of seas and oceans, many almost always seem linked with either adventure and the desire to travel or the drive to compete, and discover. In times when transoceanic voyages were still novel and infrequent, the foreign objects arriving in Europe by ship were considered significant purely by the fact that they had survived the difficult conditions of the crossing. This was especially so in regard to the "voyages of discovery," initially by the Portuguese and Spaniards in the early modern era, beginning in the fifteenth century, when these objects enduringly altered the image of the earth and knowledge about the world (Kollert 1997). The longer they had traveled and the fewer in number, the greater the value Europeans placed on the objects. Against that backdrop, it is hardly surprising that the rulers of Europe of the time surrounded themselves with exclusive and exotic objects that helped underscore their own special status and emphasized their power. In many cases, these objects formed the basis for the European museums of cultural and natural history (Minges 1998).

In addition to infusing objects with meaning, the act of seafaring itself, especially when people have successfully survived risky situations, often takes on a mythological quality. This applies of course to the famous "discoverers" of the early modern era (Henze 2011), but perhaps most of all to the nineteenth-century seamen on the freight ships sailing around the legendary Cape Horn—one of the most dangerous shipping routes in the world. The "Cape Horners", as they were called, were depicted with a mélange of adventure, masculinity, and danger—a portrayal which continues to this day (Feldkamp 2003) despite the fact that the last freight sailboat with no engine to pass Cape Horn was the *Pamir* in 1949 (Stark 2003). The same heroic romanticism can be observed, for example, in the perpetual appeal of the Blue Riband, or with the continued desire of some to sail solo around the world, where after risky and often sorrowful experiences at sea, the sailors are celebrated after a successful return. This feeling peaked in an undertaking that was not related to the true purpose of transportation but rather for the prospect of the "Blue Riband of the Ocean," an "imaginary trophy" and "purely symbolic award without material compensation" (Rook 1994: 17). It was merely bragging rights for the passenger ship that could travel the route between Europe and North America the fastest.

The Romantic artists recognized the sea as a source of inspiration and a place of yearning, as a site of self-reflection and finding oneself (Brenken and Spielmann 1997).

Finally, in much more recent years the sea has become associated with recreation. Popular recreational use started out with group travels in the form of cruises (König and Schabbing 2014) in which only an exclusive section of society participated, but today recreational activities are more individual and much more widespread. Such activities include sailing, surfing, diving, and even mini-submarines used in coastal areas for tourists to explore the underwater coast. This growth has led to a very high overall frequency of use, with many negative consequences for sea sustainability.

26.3 Environment

Since the Neolithic age human beings have always attempted to manipulate the world around them to the extent that their technology has allowed (Moetz 2014), first on land and then at sea. Initially, this meant the focused use of specific areas: for example, fishing by those who lived in coastal regions to meet dietary needs (Goldhammer and Hartz 2012). From the eleventh century at the latest, however, with the construction of dikes, humans were able to take power away from the erosive property of the sea and preserve a more permanent coastline (Peters 2015). With the flourishing of hydro-engineering in the eighteenth and nineteenth centuries, additional technical structures in the form of locks and dams were created with the intention to regulate tide-related environmental conditions. The installation of infrastructure for navigation, especially in the form of coastal facilities and canals, represented no small enduring intervention in the environment. Human beings thus expressed their desire to not simply use the conditions established by the environment but also to design the environment to suit their ideas. This was based primarily on economic considerations, although in many cases a potential for prestige was associated with it as well.

In addition to these deliberate interventions, however, humans indirectly affect the environment in negative ways. For a long time, people were not conscious of or simply did not care about the way they were affecting the world's seas. Garbage and things that had become useless onboard were thoughtlessly dumped on the high seas (Deutsches Umweltbundesamt 2010). The same was also done with unused munition after the Second World War, which was sunk at selected dump sites in the ocean (Böttcher 2014).

The use of ships, with its often far-ranging consequences for the environment, accounts for a large share of the pollution of the world's seas. Effects on the surface of the water that frighten sea creatures, the noise of engines under water, noxious emissions, and introduction of non-native species lead over the long term to infertility and resistance reduction of some sea animals. Dangers at sea from shallows, reefs and rocks, storm floods, and tsunamis can in unfortunate cases lead to shipwrecks with detrimental effects on the environment. Heavy oil (Diesel) and other fuels cause bird feathers and fish gills to stick together, causing agonizing deaths. The Russian nuclear submarine *Kursk*, which sank in the Barents Sea in 2000, impressively demonstrated the risks to the sea that nuclear-powered vessels can pose. (Mikes and Migdal 2014).

26.4 Technology

Engine technology and the associated range of ships have been crucial to how the sea is used. Whereas originally muscle power was the only way to move watercraft, wind power has been harnessed in northern Europe with the use of sails at least since the early Middle Ages. In the mid-nineteenth century, two innovations prevailed that still have effects today: the steam engine was used instead of sails, and steel replaced wood, which until then had been the sole as long-lasting material for constructing ships. These two crucial developments opened the way to modern developments in shipping. Steamships were less dependent on the wind and weather, and thus able to travel along canals which appeared soon thereafter. Most importantly, steam power led to greater reliability in terms of the duration of voyages.

With the introduction of steamships in the second half of the nineteenth century, the use of sails became less frequent in professional shipping. The Flettner rotors introduced in the 1920s, which provided aerodynamic propulsion by subjecting a rotating cylinder to airflow (Flettner 1926), remained a marginal phenomenon, just like the fully automated towing kites of the SkySails company, in which wind energy would supplement the engine power of large freight ships and fish trawlers (Elsner 2009). In the name of green shipping, electricity and liquefied natural gas are now occasionally used as alternatives to heavy oil (Diesel), making shipping cleaner and lowering emissions.

More broadly, the technological innovation of the ship opened up the use first of the surface of the water and then, with submarines, the area below the surface. Already in antiquity, people were thinking about how to spend extended periods under water despite their limited lung volume. The oldest drawings for diving boats and diving suits date from the fifteenth centuries, but it was not until the early seventeenth century that the first diving boat with a rudder was built. In the nineteenth century, the invention of the electric motor made it possible for the first time to build mechanised submarines, i.e., submarines that did not require muscle power. Their first practical use was in 1864 during the American Civil War. The *Sub Marine Explorer* was built a year later; it is regarded as the first functional submarine in the world, because it was the first that could surface again on its own. At the end of the nineteenth century, the world's navies recognized submarines as suitable to their ends, and they were first deployed in large numbers in the First World War, culminating in the very effective use of unrestricted submarine warfare. After being deployed with heavy losses in the Second World War due to the development of effective surface to underwater countermeasures, submarines once again resurfaced in the Cold War due to newfound strategic significance.

Beginning in the 1960s, submarines were increasingly used for research. Along with unmanned diving vessels equipped with cameras and grip arms, submarines were used for the systematic study of sea floors or sea currents to answer geological, biological, oceanographic, and archaeological questions. The use of the sea for oil extraction has led to the development of special submarines or diving robots with suitable grip arms and equipment to carry out repairs of drilling rigs, pipelines, and underwater cables.

As technology allowed ships to be increasingly less reliant on natural forces, their use has become an expression of the superiority of human beings over nature. The *Titanic* is the most prominent counterexample of the superiority of humanity over the environment and nature. The common view in the late nineteenth century that this ship could not be sunk was reflected in the limited number of lifeboats added to the ship, which turned out to be a fatal omission. That the ship was declared "unsinkable" has no doubt caused the sinking of the *Titanic* to linger in the popular consciousness to this day.

26.5 Seas and Oceans as a Place to Transport People, Goods, and Information

Ever since the invention of watercraft to transport human beings, coastal seas have also been used to transfer goods and information. In northern Europe during the Viking era (eighth to eleventh centuries), the intensity of trading along the coasts steadily increased and eventually resulted in the crossing of the Atlantic Ocean for the first time from the North Atlantic islands of Greenland to Newfoundland. This was made possible by narrow sailboats. Archaeological finds testify to an intense exchange of goods, technologies, fashions, and presumably information as well (Delgado 2015). By contrast, at the time of the medieval Hansa (twelfth to seventeenth centuries), a new type of bulbous ship with a much larger capacity was found to be practicable for a network of trading in the region of the North and Baltic Seas and as far as Iceland (Hammel-Kiesow 2004). Even though there were contacts in this period to the Italian maritime republics and to the Near East as a result of the Crusades, it was only the founding of the trading alliance of the *Vereenigde Oostindische Compagnie* (VOC; Dutch East India Company) in 1599 that began to regularly conduct long-distance trading and influence the Far East in particular. This historical trading company was founded through the merger of smaller trading companies that no longer wished to compete with one another, and it became one of the most important business enterprises in the world (Nagel 2007). The prerequisites for this long-distance trading, which went hand in hand with colonialism, were the overseas voyages of discovery in the fifteenth and sixteenth centuries, advances in monetary and credit systems and the resulting simplified procurement of capital, and especially the development of the caravel, a new type of ship that was characterized by improved maneuverability.

The preferred ships for the "trading goods" of the seventeenth and eighteenth centuries—ivory, gold, and slaves for the Americas—were older brigs and schooners, i.e. sailing ships with two or more masts. In keeping with their focus on profits in the slave trade, intermediate decks were added so that slaves could be "stored" below the waterline where the cargo was normally held. Unhygienic conditions onboard led to comparatively high mortality rates. The ships were also subjected to heavy cargo and the risk of shipwreck (Harms 2007).

Many people were shipped across the Atlantic as a result of the nineteenth-century immigration waves from Europe to the Americas, first on sailing ships and later on paddle steamers and other steamboats (Guillet 1963). As mentioned above, one consequence of the introduction of steam power was regular shipping times. This increased reliability benefited the postal service in particular, which therefore had an interest in subsidizing passenger ship travel. And this in turn made passenger transportation less expensive and hence attractive for large numbers of people. The mass of immigrants traveling by ship ensured a regular income for ships. In the case of slaves, immigrants, and refugees, the sea journeys that people have been forced to make for various reasons are often their first and only ones.

With the introduction of regularly scheduled intercontinental flights, however, passenger travel by ship has declined. The shipping of raw materials and goods has, by contrast, increased. Mass transportation of goods by water began in the 1860s. Initially, petroleum was transported in barrels on sailing ships. Twenty years later, true tankers were developed. It is interesting to note that steam-powered tankers built according to the same principle as the oldest ones from 1886—in which the oil is stored in the ship's hull itself—are still being used!

The relatively late introduction of container shipping in Europe, compared to the Americas, was associated with consequential changes on land as well (Levinson 2008). The standardization of containers went hand in hand with automated processes for loading and unloading. Today's harbor facilities, most of which are impressively large, are huge logistics centers. After the Second World War, shipping was the largest force behind globalization. Even today it is the largest mode of transportation in the world economy.

26.6 Seas and Oceans as Places for Resources

It is reasonable to assume that one of the oldest motives for using seas and oceans was the exploitation of marine resources for food and to obtain economic goods. Fishing implements found in northern Europe dating as far back as the Mesolithic era testify to this (Goldhammer and Hartz 2012). This sort of exploitation of marine resources is inconceivable without ships; it can be assumed that dugout canoes were already in use near coasts during the Stone Age.

Ships had to be equipped appropriately to exploit the materials of the sea. In many cases, special types of ships were developed over the course of time. For example, in the early days of whaling, small, powerful rudder boats, handheld harpoons, and lances were used. By the nineteenth century, however, whaling ships had harpoons mounted on deck. The driving force behind whaling in the seventeenth century was the pursuit of train oil as a fuel and industrial raw material. In the twentieth century, the driving force switched to the pursuit of raw materials for margarine and nitroglycerin (Ellis 1993). Encouraged by the self-sufficiency policy of the Third Reich to reduce the "fat gap," specialized factory ships for whaling were placed in service between 1936 and 1939. Factory ships, the first of which were produced in Germany in 1940–1941, were equipped to filet and freeze large quantities of fish to obtain a market-ready product directly on board. Whaling factory ships, too, followed this principle, with a tow for the whales on the stern and the deck used for slaughtering. The only whaling ships that can be inspected today, in Germany for example, are museum ships such as the *Rau IX* in the museum harbor of the *Deutsches Schiffahrtsmuseum* (DSM; German Maritime Museum) in Bremerhaven. Whaling, which is controversial internationally, is no longer permitted under EU law.

The enormous size of the ships and fishing fleets used for fishing today has made it necessary to regulate the use and construction of fishing equipment and to place specific quotas on catches. This is true of trawling ships as well as factory ships. In order to meet the world's needs for seafood in view of depleted fish populations and quotas on catches, aquaculture is becoming increasingly important (Nash 2011).

Extracting inorganic resources also requires special vehicles. Offshore oil rigs are often transported using semisubmersible ships, which carry cargo underwater (Spethmann et al. 2012). Installation vessels with heavy cranes, special motors, and jacking equipment are used to construct offshore wind turbines, though in many cases it is no longer necessary to anchor the turbines in the ground, since floating facilities are increasingly being employed (Hautmann 2012: 29).

The sand and gravel used as construction materials are extracted in coastal areas using dredging vessels. In addition, ships are constructed specifically to extract large quantities of raw materials (ores) for metals at deep sea, with all the consequences one would expect for the mechanical destruction of the ocean floor and the eco system therein (Halbach and Jahn 2015). Internationally binding, sustainable rules for such extraction are currently being established.

Ships themselves are considered resources of the sea in the broadest sense when they are removed from their original functional context—whether as the result of an accident or deliberately grounding. For example, ships that have sunk off the coast are scrapped to obtain the valuable wood or high-quality steel used in ship building. The right of salvage laws that applies in many countries enables people to use objects removed from the sea like newly extracted resources (Hansen 2001). Germany rescinded this right with a new law in 1990. According to this law of lost property, flotsam and jetsam can only be claimed when its legal owner cannot be determined.

Last but not least, there are recovery companies that search for sunken ships, such as Odyssey Marine Exploration (http://www.odysseymarine.com/), which are motivated in part by economic objectives. The expedition to find the *Titanic*, by contrast, was organized on the initiative of the Woods Hole Oceanographic Institution in Massachusetts and the *Institut français de recherche pour l'exploitation de la mer* (IFREMER; French Research Institute for Exploitation of the Sea) (http://www.huffingtonpost.de/norbert-zimmermann/vor-30-jahren-wurde-das-w_b_8059414.html).

26.7 Seas and Oceans as Territories

The uses of seas and oceans are to a large degree dependent on the political situation on land. In the seventeenth century, Hugo Grotius, who is regarded as one of the founding fathers of modern international law, formulated the principle of freedom of the seas (Mühlegger 2007). It states that the exercise of state power on the high seas is limited to ships flying that state's own flag, though piracy and other similar behaviours limit the full implementation of this principle. This was already the case with the so-called *Likedeelers* ("Equal Sharers"), buccaneers and pirates from the Hanseatic era, whose views probably became known historically as a result of their most prominent advocate of the time, Klaus Störtebeker (Zimmermann 2000). Similarly, there were other ship commanders who operated on their own initiative without authorisation from any state as well as those who had a letter of marque from a state or ruler and thus conducted a trade war for third parties.

With the United Nations Convention on the Law of the Sea (UNCLOS) of 1982, the signatory states agreed to work together to combat piracy. This has become all the more relevant as globalization and political revolutions have created new behavior in piracy that has been manifested repeatedly since the 1990s. From Southeast Asia, South America, and South Africa, ambushes with bazookas, grenades, machine guns, and other automatic weapons have been reported on ships involved in professional shipping, from small vessels like yachts all the way to huge freighters and supertankers. The first judicial inquiry into piracy by German prosecutors took place in Hamburg in 2008 and was related to the case of the tanker *Longchamp*, which was operated by a German shipping company prior to being seized off the coast of Somalia.

Additionally, there have been repeated attempts to establish physical boundaries at sea or to demonstrate maritime power by militarizing ships and positioning them in strategic places. For example, there is evidence of underwater barriers for ships since the Viking era, and blockades by warships or underwater mines have tried to control shipping or otherwise place strict limits on navigation. Whereas ship barriers and blockades have always occurred in relatively shallow waters, sea battles and skirmishes have often taken place on the open seas. Victory and defeat are usually decided by new technologies of shipbuilding or new tactics for naval warfare. During the Cold War skirmishes were avoided by equipping ships with sophisticated weapons systems and medium- to long-range missiles with nuclear warheads, as well as by the creation of nuclear-powered aircraft carriers (Duppler 1999). Today such arms are intended to deter by instilling fear and establishing distance.

26.8 Seas and Oceans as a Subject of Research

Seas and oceans play an important role in the research regarding worldwide climate change. Marine research is conducted with the goal of understanding the system of the ocean better in order to make life on land sustainable (Wefer et al. 2012). As a rule, such research is ship-based, that is to say, it is conducted on water using research ships as laboratories.

Modern oceanography began with the British HMS *Challenger* at the end of the nineteenth century. Surveys of the world's seas and oceans were conducted over several years and the first fundamental findings on their topographical, physical, chemical, and biological conditions were obtained (Thomas and Murray 1880).

Whereas modern research ships are tailored for specific applications and are distinguished by remote-controlled and autonomous watercraft and highly specialized measuring systems to collect data and probes, research ships in the nineteenth century instead were repurposed and adapted from previous uses prior to being used for research. For example, the yacht used by the geographer Dr. Petermann of Gotha for the first German polar expedition in April 1868 originally was a ship for seal hunting. The *Grönland* was converted for research by Captain Koldewey on behalf of the *Komitee für die Deutsche Nordpolarforschung* (Research Committee for the German Arctic) in Bremen, and is maintained today by a volunteer crew at the *Deutsches Schiffahrtsmuseum* in Bremerhaven.

Oceanography has thus always had a pioneering character, due to its extreme destinations. While that once meant journeys to the ice-covered regions of the Arctic and Antarctica, today it is the deep sea being explored, often with unmanned vehicles with suitable diving and imaging techniques. Germany now has more than 30 research ships used by geologists, oceanographers, and biologists for both observational and experimental oceanography (Wissenschaftsrat 2010).

26.9 Seas and Oceans as Places of Perception and Memory

Human beings attribute meaning to seas and oceans in a variety ways. Survivors of shipwrecks usually have especially vivid memories of the scenes experienced at sea. In addition to collective forms of memory, there are also individual ones, often expressed in diaries and letters. A sea journey from one cultural circle to another can be seen as a "rite of passage" into a new world and hence be perceived as very memorable, especially if it is the only journey by ship in a lifetime, and is associated with strong emotions such as bidding farewell, uncertainty, or the joy of anticipation.

Initially, and for a long time, life onboard was difficult and sea journeys were often dangerous and even fatal. Skepticism about sea travel changed as advances in technology enabled navigators to better predict wind and weather, and to adapt accordingly. Visual and literary evidence from the late nineteenth century documents the discovery of nature, including the sea, as a place of inspiration and beauty. The memories retained via images also include sea battles perceived as successful or traumatic (or sometimes both). Marine art especially keeps the memory of specific battles and warships alive.

As the hundredth anniversary of the outbreak of the First World War, 2014 was a good occasion to reflect on those who died in naval wars. Several European countries seized that historical moment of reflection to ratify the Convention on the Protection of the Underwater Cultural Heritage, which had been passed in 2001 but only signed by a few European countries. In the coalition agreement concluded in 2014, the German government defined the ratification of the convention as a goal to be achieved within that legislative term. Currently, all of the measures necessary for the law—in particular the legal ones—have been met. Ships thus become places of memory. This means a shift consciousness from perceiving submarines as weapons to memorials.

Another way to create sites of collective memory is to build museums. They too help to offer places to reflect on history. Against the backdrop of the structural change in professional shipping since the 1970s, museums are an important way to help reflect on this process of change that affects the whole of society. Processes that have changed as a result of automation, digitalization, increases in the quantities transported, and the associated growth of ships and ports have led to structural innovations which in turn have led to the rezoning of neighborhoods. Ports and transshipment areas for fish and goods have been converted into modern residential neighborhoods and tourist attractions with a maritime flair. The task of museums is to document, evaluate, and moderate knowledge about the past and its reflection as part of positioning within society.

The *Deutsches Schiffahrtsmuseum*, for example, uses research and communication to lend value and social significance to the subject of "human beings and the sea." Topical and socially relevant themes are addressed by scholars and research cooperatives. As an independent "third party," the *Deutsches Schiffahrtsmuseum* looks at current topics from a scientific perspective. It increases awareness of the historical dimensions of current and future problems, helps individuals position themselves within the society, and lends scientific, political, and emotional value to maritime themes.

26.10 Looking Forward

By using the seas and oceans for different purposes, human beings have shaped and influenced their space. The development of ships has resulted in a tension in the relationship between human beings, the environment, and the technology we use to interact with it. This tension is dynamic insofar that it varies with different uses and the intensity of the use of seas and oceans.

In order to maximize the use of seas and oceans, people observed nature, beginning locally and on the basis of knowledge acquired through experience. The increasing "surveying of the world" in the nineteenth century produced the foundations for an intervention in the environment that not only enabled humans to shape it but also to improve their use of it. Data recorded regularly now forms the basis for prognoses that can be used to guide modern strategies for use. The opportunities that result from digitalization make it possible to see and measure not only complex local conditions and connections but especially global ones.

Future-oriented calculations and assumptions have prompted a discussion of the finiteness of natural resources. The Club of Rome's report *The Limits to Growth* of 1972 led to international awareness of these themes (Meadows et al. 1972). Environmental organizations that helped make the negative consequences of tanker accidents known internationally by circulating photographs of birds that perished in oil spills have also contributed to increasing public awareness.

Very recently, seas and oceans have again become the focus of political and public interest as well. The flagship report "*World in Transition: Governing the Marine Heritage"* published by the *Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen* (WBGU; German Advisory Council on Global Change) in 2013, revealed the scale of global changes in living conditions (WBGU 2013). Renewing political and public interest was also the objective of the *Bundesministerium für Bildung und Forschung* (BMBF; Federal Ministry of Education and Research) when they selected "Meere und Ozeane" ("Seas and Oceans") as the theme of the *Wissenschaftsjahr* ("Science Year") 2016–2017. By making funds available through competitions, governments can provide stimuli for research and educational institutions to use participatory events to sensitize the public to the precautionary principle when dealing with seas and oceans. The goal of higher public awareness and engagement is also demonstrated by UNESCO's efforts to protect water across international boundaries.

Especially given the background of anthropogenic interventions with worldwide effects, connections and dependencies that are by nature global must be solved with international strategies. Moreover, the example of carbon dioxide emissions shows that maritime and terrestrial factors have to be observed together, and the plastic trash that has been fished from the world's seas as part of research projects confronts us with a visible consequence of a globalized and networked world that is the hallmark of the Anthropocene epoch.

It is up to human beings to use centuries of experience and present knowledge about the relationship of human beings, nature, and technology to help guide decisions with regard to the intensity and frequency of human interventions in nature. Under the slogan "green shipping," the first steps toward changes in shipping that are urgently necessary to minimize environmental pollution and improve environmental project have already been identified (Müller 2012). The next essential action is for them to be rigorously implemented.

References

Böttcher C (2014) Munitionsbelastung der deutschen Meeresgewässer: Entwicklungen und Fortschritt. Landesregierung Schleswig-Holstein, Kiel

Brenken A, Spielmann A (1997) Maler am Meer: Auf den Spuren der Brücke in Schleswig-Holstein. Ellert und Richter, Hamburg

Delgado JP (2015–2016) Maritime archaeology in the 21st century. In sea history: the art, literature, adventures, lore and learning of the sea. Official Journal of the World Ship Trust, 153, 16–22

Duppler J (ed) (1999) Seemacht und Seestrategie im 19. und 20. Jahrhundert. Mittler, Hamburg

Ehlers E (2008) Das Anthropozän. Die Erde im Zeitalter des Menschen. Wissenschaftliche Buchgesellschaft, Darmstadt

Ellis R (1993) Mensch und Wal: Die Geschichte eines ungleichen Kampfes. Droemer Knaur, Munich

Elsner R (2009) Testergebnisse des SkySails-Systems. Schiff & Hafen 1:36–43

Feldkamp U (ed) (2003) Rund Kap Hoorn: Mit Frachtseglern zur Westküste Amerikas. Hauschildt, Bremen

Flettner A (1926) Mein Weg zum Rotor. Köhler & Amelang, Leipzig

Goldhammer J, Hartz S (2012) Steinzeitliche Siedlungsreste am Ostseegrund: Ein endmesolithischer Fundplatz in der Kieler Bucht. Archäologische Nachrichten aus Schleswig-Holstein 18:26–29

Guillet EC (1963) The great migration: the atlantic crossing by sailingship since 1770. University of Toronto Press, Toronto

Halbach PE, Jahn A (2015) Metalle aus der Tiefsee: Aussichtsreiche Quelle oder Illusion? Schiff und Hafen 2:36–41

Hammel-Kiesow R (2004) Hanse. C. H. Beck, Munich

Hansen N (2001) Strandrecht und Strandraub: Bemerkungen zu einem Gewohnheitsrecht an den schleswig-holsteinischen Küsten. Kieler Blätter zur Volkskunde 33:51–78

Harms R (2007) Das Sklavenschiff: Eine Reise in die Welt des Sklavenhandels. Goldmann, Munich

Hautmann D (2012) Die Windkraft schwimmt sich frei. Technol Rev 4:29

Henze D (2011) Enzyklopädie der Entdecker und Erforscher der Erde. Wissenschaftliche Buchgesellschaft, Darmstadt

Holtorf C (2013) Der erste Draht zur Neuen Welt: Die Verlegung des transatlantischen Telegrafenkabels. Wallenstein, Göttingen

Kollert G (1997) Der Gesang des Meeres: Die portugiesischen Entdeckungsfahrten als Mythos der Neuzeit. Edition tertium, Ostfildern

König N, Schabbing B (2014) Risikobetrachtung für Kreuzfahrten: Eine systematische Risikoanalyse und -bewertung der Urlaubsform Kreuzfahrt am Beispiel von Clubschiffen und Megalinern. ISM-Schriftenreihe 28. Monsenstein und Vannerdat, Münster

Levinson M (2008) The box: how the shipping container made the world smaller and the economy bigger. Princeton University Press, Princeton

Meadows D, Meadows L, Randers J, Behrend WW (1972) The limits to growth. Universe Books, New York
Mikes A, Migdal A (2014) Learning from the Kursk Submarine Rescue Failure: the case for Pluralistic Risk Management. HBS Working Paper Series, 15-003
Minges K (1998) Das Sammlungswesen der frühen Neuzeit. Kriterien der Ordnung und Spezialisierung. Reihe Museen—Geschichte und Gegenwart 3. LIT, Münster
Moetz FK (2014) Sesshaftwerdung: Aspekte der Niederlassung im Neolithikum in Obermesopotamien. In: Universitätsforschungen zur prähistorischen Archäologie 244. Habelt, Bonn
Mühlegger F (2007) Hugo Grotius: Ein christlicher Humanist in politischer Verantwortung—Arbeiten zur Kirchengeschichte 103. De Gruyter, New York
Müller S (2012) Green Shipping als Konzept zur Bewältigung des Problems knapper Ressourcen—eine Ist-Aufnahme. Schriftenreihe des Institut für Logistikmanagement 4. BA-Arbeit, Bremen
Nagel JG (2007) Abenteuer Fernhandel: Die Ostindienkompagnien. Wissenschaftliche Buchgesellschaft, Darmstadt
Nash C (2011) The history of aquaculture. Wiley-Blackwell, Ames, IA
Osterhammel J, Petersson NP (2007) Geschichte der Globalisierung: Dimensionen, Prozesse, Epochen. C. H. Beck, Munich
Peters K-H (2015) 1000 Jahre Deichbau und Sturmfluten. In Oldenburger Landesverein für Geschichte, Natur- und Heimatkunde e.V (ed) Die Jade: Flusslandschaft am Jadebusen—landes- und naturkundliche Beiträge zu einem Fluss zwischen Moor, Marsch und Meer. Oldenburg, Isensee, pp 374–87
Rook H-J (1994) Die Jagd ums Blaue Band: Reeder, Rennen und Rekorde. Gondrom, Bindlach
Spethmann K, Holbach G, Ritz S (2012) Halbtaucher-Serviceschiffe für den Offshore-Einsatz: das SWA-Konzept. Jahrbuch der Schiffbautechnischen Gesellschaft 106:169–179
Stark WF (2003) Das letzte Mal ums Horn: Das Ende einer Legende, erzählt von einem, der dabei war. Piper, Munich
Thomas CW, Murray J (1880) Report on the scientific results oft he Voyage of H.M.S. Challenger during the years 1873–76. Eyre & Spottiswoode, London
Umweltbundesamt (2010) Abfälle im Meer: Ein gravierendes ökologisches, ökonomisches und ästhetisches Problem. http://www.umweltbundesamt.de/publikationen/abfaelle-im-meer. Accessed 4 Juli 2016
WBGU (2013) World in transition: governing the marine heritage. WBGU, Berlin. http://www.wbgu.de/fileadmin/templates/dateien/veroeffentlichungen/hauptgutachten/hg2013/wbgu_hg2013_en.pdf
Wefer G, Schmieder F, Freifrau von Neuhoff S (2012) Tiefsee: Expeditionen zu den Quellen des Lebens. Begleitbuch zur Sonderausstellung im Ausstellungszentrum Lokschuppen Rosenheim 23. März bis 4. November 2012. MARUM, Bremen
Wissenschaftsrat (ed) (2010) Empfehlungen zur zukünftigen Entwicklung der deutschen marinen Forschungsflotte. Wissenschaftsrat, Lübeck. http://www.wissenschaftsrat.de/download/archiv/10330-10.pdf
Zimmermann D (2000) Die Hanse. Störtebeker & Co. Verlag, Hamburg

Chapter 27
Factors Behind Increasing Ocean Use: The IPAT Equation and the Marine Environment

Troels J. Hegland

Abstract This chapter provides an introduction to the main factors behind increasing ocean use, which—more often than not—tend to lead to increasing pressure on the marine environment. In this way, it aims on a very general level to account for the root causes of the different developments that have led to the need for specific management and governance intended to protect the marine environment. With reference to a few selected examples related to fishing, which is one of the main anthropogenic stressors of the marine environment, it is illustrated how increasing ocean use—and associated pressure on the marine environment—can be seen as rooted in a combination of increasing population and human development. In doing so, the chapter departs from the IPAT equation, which is a classic way to explain changes in the environmental impacts of human activities as a product of three factors: population, affluence and technology.

Keywords IPAT equation • Environmental impact • Marine environment • Fishing • Technology • Population • Affluence

27.1 Introduction

This chapter provides an introduction to the main factors behind increasing ocean use. Increasing use—more often than not—tends to lead to increasing pressure on the marine environment, given that use of the marine environment is generally associated with some sort of (bigger or smaller) impact.

Historically, Western scientific interest in the human impact on the environment is argued to date back to the eighteenth century, where the French natural scientist Count Buffon contrasted inhabited and uninhabited lands (Goudie 2013). However,

T.J. Hegland
Department of Planning, Innovative Fisheries Management – an Aalborg University Research Centre, University of Aalborg, Rendsburggade 14, Aalborg DK-9000, Denmark
e-mail: tjh@plan.aau.dk

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_27

compared to the focus on the terrestrial impacts, the awareness of, interest in, and ability to study the human impacts on the marine environment have been trailing somewhat behind. This is neatly exemplified by this Handbook being the first of its kind.

There are likely multiple explanations for this delay, including the mere size of the oceans and the relative inaccessibility of large parts. Similarly, compared to terrestrial impacts, a relatively larger share of what goes on in the marine environment is not immediately visible. As such, there seems to be some truth to the saying *'out of sight, out of mind'* in relation to the marine environment. In recent years, there appears, however, to be increasing focus on the oceans, as scientists discover how profoundly humans are affecting the marine environment, even in the most remote parts. Similarly, interest seems to have increased as the overall scientific (and perhaps political, one might hope) paradigm is shifting towards more holistic approaches, such as for instance ecosystem based management. Despite the differences between land and oceans, this chapter will argue that the factors that drive increasing human impacts on the environment remain at a general level the same in the two settings.

In Part I of this Handbook, the anthropogenic impacts of relevant marine and land-based activities, as well as what was referred to as 'diffuse sources', on the marine environment have been reviewed in significant detail. The reviews document that the impacts are not negligible but, on the contrary, significant and in many cases increasing. This has also been documented elsewhere, e.g. by Halpern et al. (2008, 2015), reporting on a large-scale project monitoring the cumulative human impacts on the marine eco-systems by means of combining individual impacts of a range of stressors related to human influence, such as for instance fishing and climate change. Halpern et al. (2015) conclude that over the 5-year study span (2008–2013) a little less than 66% of the ocean was subject to increases in cumulative impacts and only 13% of the ocean experienced decreases. The North Sea and the South and East China Seas are highlighted as particularly impacted seas where almost all stressors are present. Notably, no part of the ocean remains unaffected by human influence.

Here in Part II, the Handbook addresses governance and management aspects related to the protection of the marine environment; in other words: what actions is humanity as a society taking to control and limit the adverse effects of our activities? In this chapter, attention is directed at providing a simple reference for understanding the factors behind of increasing ocean usage and associated environmental impact. We hereby take a step back from the discussion of specific impacts, stressors and activities and simply ask the question: *what are the basic factors that drive environmental impacts and how does that apply to the marine environment?*

In the following section, the so-called 'IPAT equation' will be presented as a possible answer to the first half of the question above. Hereafter, the equation will be discussed *vis-à-vis* the marine environment primarily through examples related to fishing, which is considered one of the main anthropogenic stressors of the marine environment.

27.2 Factors Behind Environmental Impacts

Providing a brief introduction to the main factors behind increasing ocean use and associated pressure on the marine environment is complicated. It is easy to become buried in detail due to the diverse nature of human use of the marine environment and the shape of the associated impacts. Nevertheless, the *IPAT equation* has shown to be resilient as a conceptual approach for exactly that purpose.

The IPAT equation, which is an attempt from the early 1970s to provide a simple expression of the factors that lead to human impacts on the environment, was originally developed in a debate between environmental thinkers Barry Commoner, Paul Ehrlich, and John Holdren. In its original form it explained that impact (I), in the shape of, for example, use of and/or depletion of resources and pollution, equals the product of population (P), affluence (A) and technology (T) (Chertow 2000; Goudie 2013):

$$I = P \times A \times T.$$

'Population' refers to the size of the human population (at the scale of interest in the specific case), the assumption being that increasing population in itself leads to increased human impacts on the environment. Hence, a larger population places increasing demands on land and resources as well as increases pollution. This happens even if the individual person does not on average consumes or pollutes more than before and the technologies used remain the same, i.e. the 'per capita impact' is constant.

'Affluence' refers to the level of consumption of the population in question, the assumption being that as consumption grows so does the demand on resources, and—in turn—the environmental impact. A measure for economic wealth is often used as a proxy for affluence (in practice this proxy is often gross domestic product (GDP) per capita, although this is a measure of production rather than consumption).

'Technology' refers to the technologies employed to produce affluence, the assumption—at the time of the development of the IPAT equation—being that technological development leads to increased environmental pressure (which seemed particularly true in the 1970s when the environmental impacts of technological developments in production after World War 2 became visible).

Arguably, the IPAT equation is a (maybe too) simple way to present complex relationships, and some of the original, underlying assumptions have over the years been questioned and/or abandoned. Technology (and technological development), as an example, was originally seen as more or less solely a driver of environmental degradation, whereas today it is recognized that technology can also be employed to reduce environmental impacts. In fact, 'environmental' or 'green' technology is considered a crucial factor in reducing human impacts on the environment, through for instance technologies for renewable energy and waste treatment etc. Similarly, it has also been discussed whether it is reasonable to assume that it is affluence (wealth) that is the source of environmental degradation, or if it is in fact in some cases rather poverty that leads to degradation (Chertow 2000; Goudie 2013).

However, as stated by Chertow (2000: 20),

> "[t]*here really has been no underlying disagreement that each of the terms belong to the equation in some way and so, as a conceptual analytical approach, IPAT provides readily identifiable common ground"*.

Consequently, for the purpose of this sub-chapter, the equation provides considerable structure and a point of departure for understanding the factors behind impacts on the marine environment.

Before we proceed, a word of caution might be in its place, though. In the following, we look at population, affluence and technology as factors behind marine environmental impact/degradation. However, as also briefly discussed in Chertow (2000), from a social science perspective it might be more interesting to look behind these elements; in other words: *what influences the three driving factors?* Doing so would highlight attention on a much more complex range of political, social and cultural issues, which might more or less directly influence population, affluence or technology at various scales—and thereby influence impact on the marine environment. The following chapters of the Handbook contain on illustrative examples of these complexities.

27.3 IPAT and the Marine Setting

In the following, population, affluence and technology will be briefly discussed *vis-à-vis* the marine setting and examples related to fishing will be presented. However, initially a few words on the concept of 'impact' in relation to fishing.

Impact—the 'I' in the IPAT equation—comes in a variety of shapes. From fishing the environment is impacted directly through the removal of targeted fish from the marine eco-system though fishing operations (see Chap. 4). However, there are also a number of other (direct and indirect) impacts from fishing. One example is unwanted by-catch, which is either discarded at sea (often dead or dying) or landed. By-catch is often unwanted fish but can also include sea mammals, turtles or other sea creatures. The removal of fish and other organisms can potentially have serious effects, most directly by depleting the fish stocks targeted (or sea mammals or turtles unintentionally caught) but also by, for instance, alteration of food webs (because fishing operations often target specific species with specific roles in the food web). Another direct impact, which comes with a number of fishing practices, is alteration of the physical environment, the typical example being the impact of bottom trawling on the seafloor. Similarly, fishing also results in indirect impacts on the marine environment. As an example, most fishing operations are associated with the burning of fossil fuels and thereby emissions of CO_2, which contribute to climate change (cf. rising sea levels and increasing sea surface temperatures).[1]

[1] For further consideration of impacts of fishing, please consult Thrane (2004). A noticeable conclusion by Thrane is that many negative impacts of fishing seem correlated to energy consumption (burning of fossil fuels) of the fishing practice in question.

27.3.1 Population (P)

Although maybe not as directly observable as on land, it seems intuitively true that some sort of link exists between the size of the population and the environmental impacts of that population on the marine environment; and that this link does not seem to be for the better of the environment. Like on land, we would—presuming that affluence and technology is kept constant—expect that population growth leads to increased pressure on the marine environment, be that in the form of different uses of the marine space, extraction of various marine resources, or marine pollution in its various shapes. Arguably, one would likely not expect that a 10% increase in the population would necessarily lead to a 10% increase in the environmental impact. However, it appears in most cases unlikely that an increase in the population in itself would deliver stable or reduced pressure on the environment.

The global population has increased dramatically over the last few centuries. From year 0, the world population increased slowly from around 300 million to 1 billion in 1800 (threefold over a span of 1800 years). However, from 1800 until 2015, the world population increased (or maybe rather exploded) from around 1 billion to over 7 billion, that is sevenfold over only 200 years (United Nations 2015). According to the most recent estimates from the United Nations, the world population will most likely continue to grow from around 7.3 billion in 2015 to 8.3 billion in 2030, 9.7 billion in 2050, and eventually 11.2 billion in 2100; the further into the future, the larger uncertainty. Although the world population seems to be on its way to stabilize or even begin to fall (with a 23% chance that this will happen before 2100), the most likely scenario is that the world population will continue to grow for the foreseeable future (United Nations 2015). Although the future increase in the world population is not as dramatic as the historical, the coming century's increase in the world population will happen at a time when the environment, including the marine environment, is in many ways already pushed to its limits.

As an example, the global fishing catch (as opposed to aquaculture production) in marine areas grew consistently from around 20 million tons in the early 1950s until the end of the 1980s, after which the catches have been fluctuating around 80 million tons. According to the United Nations' Food and Agricultural Organization (FAO), part of this increase in the catches/consumption can—more or less—directly be attributed to the increase in the world population, which has created a greater demand for fish as a source of necessary nutrition, in particular protein (FAO 2014).

FAO figures also show that the wild stocks have not been able to keep up pace with the increasing demand, as the development has resulted in a number of stocks being overfished (and a huge increase in marine and freshwater aquaculture). For 2011, FAO estimates that only 9.9% of the stocks monitored by FAO were underutilized. In contrast, the gain from rebuilding the overfished stocks (28.8% of the stocks) could result in an extra annual production of 16.5 million tons (FAO 2014). Consequently, due to the natural limits of fish stocks to provide evermore yield, the link between population growth and catch of marine fish has been broken.

Nevertheless, if we include marine aquaculture, which has been growing to the extent that it now represents around a quarter of the total fish production from marine areas (up from around 5 million tons around 1990 to 25 million tons in 2012) (FAO 2002, 2014), the association is maintained. Obviously, it is very difficult to isolate how much of the increases in production that should be attributed to the increase in world population, rather than changes in affluence and/or technology. However, undoubtedly production would have increased—driven by the increase in population alone—even if affluence and technology had remained at 1950s level.

27.3.2 Affluence (A)

As described earlier, affluence refers to the level of consumption and the associated use of resources; the simple indicator often being GDP per capita. The GDP per capita of the world has been steadily increasing, and—like in the case of population—it seems intuitively reasonable to assume that increasing affluence, as a general rule, will lead to some degree of increase in the different uses of the oceans.

Compared to increase in population, which would as a general rule be expected to lead to increasing pressure on resources rather than the opposite, the situation with affluence may not be as clear-cut in the case of fishing, however. Something that could on a more general level be taken as an indication that compared to population and technology, affluence may be more intangible and complex (see also Chertow 2000).

Arguably, higher per capita GDP indicates that each person is presented with the possibility to consume more, which should intuitively mean greater pressure on the fish resources. On the other hand, being a food product, there is also a physiological limit as to how much fish each person can consume. According to FAO (2014), the average annual fish consumption per capita has increased from around 10 kg in the 1960s to 18.9 kg in 2012. Similarly, according to for example York and Gossard (2004), there is a clear association between GDP per capita and fish consumption: the higher GDP per capita, the higher average fish consumption. The explanation primarily being that, as the GDP per capita increases, people tend to shift to animal sources of protein, which includes fish.

Moreover, fish is generally associated with a healthy diet, and as this information becomes available to people, other, less healthy animal sources of protein will to a certain extent be substituted with fish (if it is economically feasible). In general, knowledge of the health benefits of a diet with a higher share of fish can be expected to be more widespread in developed countries with highly developed health systems (FAO 2014). Similarly, some fish products are considered luxury products, taste particularly good or are well-marketed and fetch high prices for those reasons. As a consequence, people may turn towards these fish products when they have the economic capacity to do so. To the extent that increasing GDP per capita makes people shift from other sources of protein to fish or simply in general increase their intake of fish, this will, in principle, create additional pressure on the fish resources. Consequently, increasing affluence can be related to increasing pressure on the fish resource with direct and indirect impacts as a result.

On the other hand, it is also possible to argue that affluence might lead to lower consumption of fish—or at least lower environmental impact at the same level of consumption. This is for instance the case when 'ethical consumers' choose environmentally certified products over non-certified. The dominating eco-label in relation to fisheries products is the label of the Marine Stewardship Council (MSC). The intention of the MSC is to give consumers the possibility to navigate between well-managed and (maybe) not so well-managed fish products. For the privilege of carrying the certificate on their products the producers pay a fee to the MSC, the idea being that the producer can fetch a higher price in the market, which compensates for the cost of being certified. Some studies seem to document that certified stocks do appear to be better managed (e.g. Selden et al. 2016); however, others add that certification is not without caveats (e.g. Hadjimichael and Hegland 2016). On average, it seems reasonable to expect that increasing GDP per capita will allow more people to afford 'paying for the protection of the environment' and decide to choose the pricier certified products. This may not reduce or increase the direct pressure on the resources (as the amount of fish consumed per capita may remain the same), but it may well change consumption patterns from fish products with significant environmental impacts (in the form of for instance by-catch of sea mammals, stock overfishing etc.) to fish products associated with lower environmental impacts.

In the previous section on population, we dealt with fish more or less exclusively as a source of nutrition, which made it obvious that more people would lead to higher pressure on the resource. Here, in connection with affluence, social issues such as culture and tradition become of much more importance. Consequently, analyzing the change in consumption of fish products as affluence increases is more complex and dependent on the case in question. As FAO (2014: 63) puts it, dissimilarities in the consumption of fish products across countries and regions:

> *depend on the availability and cost of fish and other alternative foods, disposable income and the interaction of several socio-economic and cultural factors. These factors include food traditions, tastes, demand, income levels, seasons, prices, health infrastructure and communication facilities.*

Although the examples show that increased affluence is not necessarily only a driver for increased pressure on the fisheries resource, on a more general level, history has shown that decoupling economic growth from environmental degradation is extremely difficult.

27.3.3 Technology (T)

The perception of the technology-factor in the IPAT equation has changed somewhat over the years. Originally it was perceived as a factor that would lead more or less unidirectionally to increasing impact, but it is increasingly recognized as a factor that can lead both to increasing and decreasing impact. In the light of the inevitable increase of the world population, as well as all the complexities related to affluence (and the very legitimate wish of large parts of the world population to increase their standard of living and the perhaps not so legitimate insistence of a different part of the world population to maintain a very high level of consumption), technology may in fact appear as the most viable way to reduce impacts.

Examples of some of the relatively recent technological advances that have resulted in significant impacts of the marine environment may include such things as off shore oil installations, marine windfarms and marine aquaculture; upcoming technologies may include such things as the ability to carry out deep-sea mining, as an example.

In relation to commercial fisheries, Eigaard et al. (2014: 159) operate with four drivers of technological development (which can be sudden as well as incremental):

> *"(i) to increase revenue by catching more, (ii) to increase revenue by raising the value of the catch, (iii) to reduce the costs of fishing, and (iv) to enhance comfort and safety on-board."*

The value of the catch can for instance be increased by: better handling of the catch to increase the price of the product, increasing the catch of the target-species/making the catch of it more efficient or developing technologies enabling fishers to target 'new' resources. To the extent that these developments lead to increased catch of fish etc., this would constitute an increased environmental impact of fishing. Valdemarsen (2001) highlights the employment of pelagic trawl and the purse seine in industrial fishing fleets from the 1960s and 1970s as a particularly significant example of technological development, which has led to increased impact of fishing.

An example of technological development, which has enabled the targeting of new resources, is deep-sea fishing. This has resulted in new fisheries for several species, such as for instance *orange roughy* and *pelagic armourhead* (Roberts 2002; Norse et al. 2012). However, deep-sea fishing is subject to a number of concerns in relation to stock sustainability, habitat destruction and by-catch. Most importantly, deep-sea species tend to be slow reproducers and there is as such a very real risk that intentional, directed fishing on deep-sea stocks might be difficult (or impossible) to manage sustainably, as they can only be fished at a very low rate (for orange roughy in the southern ocean maybe as low as 1.5% of the biomass (Roberts 2002)) even though they seem to congregate in specific areas. Similarly, we know comparatively little about the eco-systems and habitat at these depths and we may not be fully aware of what unintentional consequences such fisheries might have (Roberts 2002; Norse et al. 2012).

However, more and more focus is today directed towards technological advances directed at reducing the unintended environmental impacts of fishing. In practice, reducing the unintended impacts of fishing may in fact allow fishermen to continue fishing in cases where they would otherwise be stopped by management intended to curb negative impacts from fishing (see beneath).

As an example, significant efforts are going into for instance the development of selective fishing gear, which is gear that allows fishermen to avoid specific sizes or species that might be overfished or deemed worthy of protection for other reasons. As an example, by studying the behavior of different fish species or different sizes of the same species, it is to a certain extent possible to design trawls which for instance allow unwanted species and small sizes of the target species to escape while retaining the appropriate sizes of the target species. In this way the fishers reduce—through technology—the unintended impacts on the environment. For an example, see for instance Madsen et al. (2006).

In fisheries management (research), technological development remains an important issue. Some (input-oriented) fisheries management systems builds on the idea of putting a cap on for instance fleet size or days-at-sea—as opposed to directly limiting the catch (output-oriented systems) (see Chap. 33). If technological development is not properly handled in input-oriented systems, catches will tend to increase over time, even though the same number of vessels is fishing the same number of days. There is no consensus about the rate of 'technological creep', as it is often referred to in the literature. Recent estimates by Eigaard et al. (2014) seem to indicate that increases in 'capture efficiency' related to technological developments are 3.2% per year on average based on data from a number of selected European fisheries (the rate varies considerably from fishery to fishery, though). As mentioned, in the absence of properly designed management, this efficiency gain can be translated into increased catch.[2] However, when discussing technological creep it is important to keep in mind that this relates to the '*intended* environmental impact' of fishing, namely the removal of target-species from the marine ecosystem. Technological development will oftentimes make the vessels more effective in producing intended impacts (catches) while, at the same time, other advances (i.e. selective gear) might result in lower unwanted impacts.

27.4 Concluding Remarks

As illustrated, at a generic level the IPAT equation provides a useful conceptual framework for understanding the different factors behind ocean use and the often associated negative marine environmental impacts: population, affluence and technology. However, it is equally clear that the IPAT equation does not present solutions or a clear guide on how to reduce impacts, although it does highlight that there are different basic factors.

As discussed in the example of marine fishing, increases in the world population has clearly contributed to driving up the consumption of fish—but so has affluence (at least for some species), as more people are now in a financial position to buy healthy 'luxury' fish products. On the other hand, increasing affluence may also provide consumers with a real option to choose pricier certified products from well-managed stocks over cheaper products from less well-managed stocks. So the effect of increasing affluence is not necessarily unidirectional, though intuitively it

[2] In output-oriented—usually quota-regulated—systems, unutilized vessel capacity 'created' by efficiency gains produces a pressure to increase quotas or allow the employment of this capacity in other fisheries.

might seem so. Similarly, technological advances have enabled increasing catches by, for example, providing access to resources that were previously inaccessible. On the other hand, much technological innovation in the fisheries sector is today directed towards minimizing the environmental impacts of fishing, e.g. by reducing unwanted by-catch or by minimizing destructive impacts on the seafloor.

In any case, 'management' (at any scale) remains society's answer to the challenges presented by the various activities that are driven by the factors of the IPAT equation. The remainder of this Handbook is dedicated to chapters on how management of different activities unfolds and what the main challenges are.

References

Chertow MR (2000) The IPAT equation and its variants. J Ind Ecol 4:13–29

Eigaard OR, Marchal P, Gislason H, Rijnsdorp AD (2014) Technological development and fisheries management. Rev Fish Sci Aquacult 22:156–174

FAO (2002) The state of world fisheries and aquaculture 2002. FAO, Rome. ftp://ftp.fao.org/docrep/fao/005/y7300e/y7300e00.pdf. Accessed 26 May 2016

FAO (2014) The state of world fisheries and aquaculture 2014. FAO, Rome. http://www.fao.org/3/a-i3720e.pdf. Accessed 26 May 2016

Goudie AS (2013) The human impact on the natural environment: past, present, and future. Wiley-Blackwell, London

Hadjimichael M, Hegland TJ (2016) Really sustainable? Inherent risks of eco-labeling in fisheries. Fish Res 174:129–135

Halpern BS, Walbridge S, Selkoe KA, Kappel CV, Micheli F, D'Agrosa C, Bruno JF, Casey KS, Ebert C, Fox HE, Fujita R, Heinemann D, Lenihan HS, Madin EMP, Perry MT, Selig ER, Spalding M, Steneck R, Watson R (2008) A Global Map of Human Impact on Marine Ecosystems. Science 319(5865):948–952

Halpern BS, Frazier M, Potapenko J, Casey KS, Koenig K, Longo C, Lowndes JS, Rockwood RC, Selig ER, Selkoe KA, Walbridge S (2015) Spatial and temporal changes in cumulative human impacts on the world's ocean. Nat Commun 6(7615):1–7. doi:10.1038/ncomms8615.

Madsen N, Tschernij V, Hansen K, Larsson P-O (2006) Development and testing of a species-selective flatfish ottertrawl to reduce cod bycatches. Fish Res 78:298–308

Norse EA, Brooke S, Cheung WWL, Clark MR, Ekeland I, Froese R, Gjerde KM, Haedrich RL, Heppell SS, Morato T, Morgan LE, Pauly D, Sumaila R, Watson R (2012) Sustainability of deep-sea fisheries. Mar Policy 36:307–320

Roberts CM (2002) Deep impact: the rising toll of fishing in the deep sea. Trends Ecol Evol 17:242–245

Selden R, Valencia S, Larsen A, Cornejo-Donoso J, Wassermann A (2016) Evaluating seafood eco-labeling as a mechanism to reduce collateral impacts of fisheries in an ecosystem-based fisheries management context. Mar Policy 64:102–115

Thrane M (2004) Environmental impacts from Danish fish products—hot spots and environmental policies. PhD thesis. Aalborg University, Department of Development and Planning, Denmark

United Nations (2015) World population prospects: the 2015 revision, key findings and advance tables. Department of Economic and Social Affairs, Population Division, Working Paper No. ESA/P/WP.241. United Nations, New York. http://esa.un.org/unpd/wpp/Publications/Files/Key_Findings_WPP_2015.pdf. Accessed 26 May 2016

Valdemarsen JW (2001) Technological trends in capture fisheries. Ocean Coastal Manage 44:635–651

York R, Gossard MH (2004) Cross-national meat and fish consumption: exploring the effects of modernization and ecological context. Ecol Econ 48:293–302

Part VI
General Aspects of Management and Governance of Human Activities

Chapter 28
Challenges and Foundations of Sustainable Ocean Governance

Till Markus

Abstract The article gives an overview of environmental conflicts in the marine realm. It also explains the central challenges and elements of sustainable international resource management and environmental conservation in this area. Overall, it is intended to provide an analytical frame for the many existing ideas, theories, and arguments from political and legal sciences as well as economics that embark on the quest for the elements of effective and sustainable ocean governance.

Keywords Ocean governance • Law of the sea • Marine environmental law • Effectiveness of international law • Effectiveness of marine environmental law • Making and implementing law of the sea • Making and implementing marine environmental law • Overcoming the prisoner's dilemma and the tragedy of the commons • Governing commons • Conflict structures in the marine realm

28.1 Introduction

Technological progress and the ever-increasing demand for raw materials of the growing world population propagate the economic utilization and exploitation of the seas. As a result, the associated burdens on marine ecosystems—including pollution, overfishing, eutrophication induced from the shores, acidification, warming, and the loss of biological diversity—also continue to grow and intensify to unsustainable levels. Furthermore, exploitation interests can clash not only with each other, but also with marine environmental protection interests. For these reasons, intervention by nation states and the international community is imperative. Recent developments in important areas of the commercial maritime sector as well as the present marine environmental status in many areas of the globe, however, indicate that the existing political and legal institutions are not yet capable of permanently

T. Markus
Research Centre for European Environmental Law, University of Bremen, Bremen, Germany
e-mail: tmarkus@uni-bremen.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_28

solving existing conflicts. This article, then, primarily serves as an orientation to the many ideas and arguments about the causes of marine environmental problems and possible approaches to solve them. First, an argument for the necessity of a sustainable arrangement for the use of the marine environment will be presented. Next, the fundamental structural obstacles to this will be discussed. The third step will be to discuss how these challenges can be overcome, and to identify some important elements necessary for the establishment of effective marine environmental protection regimes. The article will also bring together some of the relevant theories of environmental economics, international relations, and international law (especially international environmental law) to the problems of marine environmental conservation. Naturally, such an article can be neither comprehensive nor conclusive.

28.2 The Growing Need for Sustainable Utilization of the Seas

The protection of the marine environment from the negative effects of the advance of technology and the rise of marine exploitation was first considered shortly after World War II. Despite several conservation measures, however, up until the 1970s the relationship between humans and the seas was mainly based on exploitation (Beyerlin and Marauhn 2011: 121–143). Protection regimes only began to be created after rapidly increasing pollution became apparent, devastating accidents involving tankers took place, and the phenomenon of overfishing became understood. Since then, marine environmental policy and law have developed significantly, and now constitute independent and complex disciplines with their own extensive subcategories. The individual regimes deal with, among others, the protection of the marine environment from maritime navigation, inshore and open-sea fishing, mariculture, gravel and sand extraction, military activities, scientific research, and operations to produce oil, gas and wind energy, as well as the laying of oil and gas pipelines and energy and data cables (Sands and Peel 2012: 342–448; Rothwell and Stephens 2016: 308–346). The challenges to protect the marine environment from the effects of these diverse activities will become even more important in the future for two reasons. First, existing demand for maritime raw materials and marine space will continue to increase. Second, technology for maritime activities will continue to advance, yielding new ways to exploit the sea (WBGU 2013: 39 et. seq.; Chap. 27). Some of these trends are imaginable and identifiable: wave, current, and tidal power plants, carbon dioxide storage on the continental shelf, “intelligent” offshore energy grids, multi-use platforms, and the development of fish farming at ever increasing distances from the coast, to name a few. (WBGU 2013: 25–36; Future Ocean 2014; Chaps. 27 and 43). Moreover, the lasting development and transformation of land based activities—including agriculture, forestry, coastal tourism, the operation of harbors, and (not least!) industrial production and mining—have also been significant for conditions in the marine environment, as sewage and emissions from these activities often end up in the seas by way of rivers, ground water, or the atmosphere (European Environment Agency 2014; Chaps. 30 and 35). In particular, the rapid conversion of land use in transition states (e.g. Brazil, Russia, India, and China) will result in an even larger increase of stress on the seas in the very near future.

28.3 Central Challenges to Achieving Sustainable Ocean Governance

There are many challenges yet to be overcome before it will be possible to achieve effective and sustainable governance of human activities in the marine environment (see also Rothwell and Stephens 2016: 506–533; Young 1994; Young 1992: 160–194). The following sections are aimed at illuminating some of the social conflict challenges, some central informational and conceptual challenges, some legal and institutional challenges, and finally some of the individual and state self-interest challenges behind the continuing depletion of the marine environment and its resources.

28.3.1 Social Conflict Challenges

There are four main types of social conflict that emerge when dealing with marine and maritime interests. First and foremost are allocation conflicts among *users of a single resource*. For example, a fair distribution of fishing resources among fishers must be organized and structured. Second, conflicts exist among *users of different resources.* For example, a growing number of disputes emerge between fishers and offshore wind farm operators or mining companies about the use of particular (especially near-shore) areas. Third, the continuous technology and market driven expansion of maritime activities as well as their increasing environmental impacts require reconciliation between *user and conservation interests*. An example of this are the environmental regulations in areas of classic utilization, such as shipping, fishing, and offshore oil and gas extraction, which have progressively tightened over the last decades (Beyerlin and Marauhn 2011: 121–143; Sands and Peel 2012: 324–448). Finally, *inter-ecological conflicts* have been occurring ever more frequently. For example, offshore wind mills provide for energy production with low CO_2 emissions (and thus decreased ocean acidification), but they negatively impact the marine environment by creating noise, consuming energy, and striking birds. Another example is the use of ship scrubbers. While they do clean harmful ship emissions and thus help reduce atmospheric inputs into the atmosphere, their operation may also lead to pollutants entering waters (Markus and Helfst 2014).

The issues arising from these social conflicts can also be defined through their *cross-sectoral and cross-border problem structures* (Markus et al. 2011: 59–90; Erbguth and Schlacke 2014: 415 ff.; Chap. 49; Scott 2015: 463–489). Regarding the cross-sectoral aspect, it is key that impact-reducing measures in the areas of agriculture, fishing, transportation, industry, energy and defense policy actually contribute to marine environmental protection. Practically speaking, however, measures adopted under these specific policies are usually designed to fulfil sectoral interests by solving sectoral problems. As sectoral measures mostly are not made with the intent to primarily protect the seas, they are often not aligned with the needs of the marine ecosystem but instead the particular interests, goals and logic of individual sectors and fields of policy. The result of such an approach is almost always a failure to produce a systematic, coherent conservation concept which integrates all cumulative anthropogenic impacts (Salomon and Dross 2013; Markus et al. 2011: 1–32 ff.; Markus 2009: 15–24). Complicating things further, the various anthropogenic impacts, the ecosystem to be protected, and the ecosystem services often extend beyond national borders. This situation demands international, or at least, cross-border balancing of the clashing interests. Compared to environmental problems at the local or national level, cross-border issues often come with more actors and competing interests. This quite naturally increases the complexity of the conflicts and raises the transaction costs of their solutions.

28.3.2 Information and Conceptual Challenges

The protection of the marine environment requires a broad scientific understanding of its ecological state and its resources, as well as the specific and cumulative effects of various anthropogenic impacts. Furthermore, a fundamental understanding of the socio-economic and technical backgrounds of utilization and regulation is required for governing and controlling activities which impact the seas.

Currently, considerable knowledge gaps exist in many areas with respect to the marine environmental status and the dynamics of anthropogenic induced impacts (WBGU 2013: 39 ff.; Markus 2013: 1–21). In particular, the effects of future utilization are nearly impossible to predict. In many cases, sound and intercalibrated scientific evaluation methods are missing at the national and especially the international level. Where data does exist regarding specific impacts, it often is fragmented, both with regard to substance and standardization; available information from different sources is often difficult to integrate (Markus 2013: 1–21; Markus et al. 2015: 162–163; Chap. 52; regarding biodiversity, see Markus 2017a). Thus, national and international conservation efforts must be aware of all of the challenges and costs of collecting scientific information about the marine environment when designing their management regulations, strategies, programmes, measures, and actions.

Besides the immediate need for information, a fundamental, conceptual challenge exists in the field of marine environmental conservation. Against the background of the substantial differences between sea and land, the question arises as to what extent the legal instruments and measures originally designed for terrestrial problems can be applied to the sea, and to what extent they could contribute to solving conservation and utilization conflicts there (Wolf 2010: 365–371). The sea as a geographical space for human activities comprises the seabed and its subsoil, the water column, the sea surface, and the air space above. Utilization and inputs usually take place from the surface into the water column or at the seabed and its subsoil. In contrast to land, the sea surface itself has a relatively low utilization value. This poses a significant difference between the anthropogenic use and impact dynamics in the marine ecosystem and on land, which is why maritime environmental protection has to be conceived three dimensionally rather than two dimensionally as it is in terrestrial conservation (see also Wolf 2010: 366; Heselhaus 2011, para. 6–7). Furthermore, the acquisition of private property over space in the seas does not affect conservation efforts as it does on land (see also Heselhaus 2011, Rn. 7).

In order to successfully integrate the data and information into political or legal processes, it may be important that they are collected or generated in a certain manner. This is particularly true for the adoption of international environmental agreements as well as for their implementation. To allow for mutually candid bilateral or multilateral negotiations, the knowledge utilized in the process must be understood and accepted by all parties. For this, procedures and institutional mechanisms which convey and promote the clarification, neutrality, plurality, intercalibration, and quality of the relevant information may be required (Gillespie 2006: 211–226; Markus 2013: 1–21).

Furthermore, there is a considerable need to scrutinize the *implementation and observance* of regimes established. Knowledge about the implementation and observance is a fundamental requisite for a deeper understanding of the functioning and effectiveness of any regime and thus provides the basis for any necessary adjustments and developments. In addition, awareness about the effectiveness of the rules is an important incentive for the addressees of the rules to follow them (Ulfstein et al. 2007: 4–5; Markus 2016b).

28.3.3 Legal and Institutional Challenges

Marine conservation efforts are embedded in a complex network of global, regional and national regulatory systems. Existing regimes are usually substantively and geographically restricted. Often, they only address specific problems of marine environmental protection or alternatively are only effective locally or regionally. From a global perspective, this results in a complex, fragmented, overlapping, uncoordinated, and partially incoherent legal and institutional marine protection system.

The starting point of all law on marine environmental protection is the United Nations Convention on the Law of the Sea (UNCLOS) from 1982. Quoting Tommy T.B. Koh, of Singapore, President of the Third United Nations Conference on the Law of the Sea, UNCLOS is often referred to as the "constitution for the oceans". In its preamble, it declares that the contracting member states are "[p]rompted by the desire to settle, in a spirit of mutual understanding and cooperation, all issues relating to the law of the sea […]". UNCLOS divides the seas into different zones and allocates the coastal states sovereign powers, rights and duties (see, for example, Markus 2017b). UNCLOS distinguishes between so-called inland waters, territorial waters, archipelagic waters, exclusive economic zones (EEZ), the continental shelf, as well as the high seas and the so-called “Area”, the latter being defined in Art. 1(1) UNCLOS as the ‘seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction’. Whereas—in principle—the sovereignty of the coastal states extends to inland, territorial and archipelagic waters, they only have functionally limited sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources in the EEZs and on the continental shelf (Art. 56 and Art. 77 UNCLOS). The high seas stretch beyond the EEZ and the continental shelf. Here the “freedoms of the high seas” apply (freedoms of shipping, overflight, laying submarine cables and pipelines, installing systems, fishing, scientific research, etc.) Below the high seas water column lies the so called Area, which subjects to the ‘common heritage of mankind’ principle and is administered by the International Seabed Authority (Art. 136 ff. UNCLOS).

Besides zoning the seas and assigning certain sovereign powers, UNCLOS also prescribes duties to protect the marine environment (Art. 192–237 UNCLOS). Regulations relevant to the protection of the marine environment can also be found in other conventions, such as the Convention on Biological Diversity (CBD), the Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention), and the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention). Marine protection treaties also exist at the regional level as a product of the Regional Seas Programme of the United Nations Environmental Programme (UNEP) (Hafner 2006: 417 ff.). In northern Europe, this has resulted in the Convention for the Protection of the Marine Environment of the North-East Atlantic of 22 September 1992 (OSPAR Convention) and the Convention on the Protection of the Marine Environment of the Baltic Sea Area of 9 April 1992 (Helsinki Convention). In addition to agreements pursuing nature or species protection, sectoral international treaties are also essential for marine conservation (which constitutes one of the challenges for sustainable ocean governance, see above). Such treaties regulate specific activities and uses of the seas, e.g. the Agreement of 4 August 1995 for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stock (FSA). The success of marine environmental protection highly depends on the effectiveness of these conventions.

International marine environmental law is thus comprised of a patchwork quilt of regulations, competences and institutions, which should be coordinated and integrated to a certain degree. In practice, this integration is lacking all too often (for example, Markus and Singh 2016: 347–362; Zimmermann 2008; Rayfuse 1998: 579–605; Rayfuse 2004). For example, coastal states in Europe are increasingly developing spatial and sectoral planning instruments for marine areas under their jurisdiction (Chap. 54; Douvere and Ehler 2009: 77–88; Schubert 2015), but this is happening in a largely uncoordinated fashion. On the high seas, corresponding initiatives such as marine protected areas are highly restricted in scope, particularly in their geographical range as well as their level of protection (e.g. Matz-Lück and Fuchs 2012: 532–542). Even in the EU, for example, the various national marine policies are hardly coordinated and aligned (Markus et al. 2011: 59–90).

28.3.4 Individual and State Self-Interest Challenges

The following sections will discuss in further detail some actor dynamics which cause overburdening and overutilization of the marine environment and thus necessitate governmental intervention. Further, key negative incentives for states will be highlighted which make the adoption of international measures and conventions to protect the seas difficult.

28.3.4.1 Individual Interests and Social Dilemmas

As previously discussed, global population and economic growth, technological advance, changing consumption patterns, and the spatial concentration of economic activities constitute the basic drivers behind many marine environmental problems (Chaps. 26 and 27; WBGU 2013). While theoretically, the environmental problems created by these drivers could be mitigated or solved (for example, as long as they could be neutralized through energy and resource efficiency, or the use of environmentally friendly technology, or a shift towards consuming more environmentally friendly goods), these potential solutions are not typically implemented due to socio-economic dynamics.

The root cause for environmental problems is traditionally seen, especially by environmental economists as the destructive incentive structure in which the actors find themselves; it is this structure which fundamentally defines the relationships between the many users of environmental goods. From an economic point of view, the marine environment in its entirety, the individual ecosystem services it provides, and its resources constitute so called *common pool resources* (and thus a special case of what economists term as *public goods*) (Posner and Sykes 2010: 569–596; Cooper 1975: 357–377; for an early analysis, see Gordon 1954: 124–142). Common pool resources are defined by two central characteristics (for more details see Madison et al. 2010: 839–850). First, common goods in nature are subject to little control or authority (or sometimes none at all), which means that excluding individuals from using them is for the most part impossible. Secondly, their use is characterized by scarcity and rivalry, which means that the use of the environmental good by one actor reduces or makes more expensive the use by others (this burden imposed on third parties is usually termed *externality*). In sum, profits are usually privatized while costs and losses are usually socialized. For example, fishing activities by some reduce the opportunities and raise the costs for other fishers to catch fish. Also, the extraction of non-renewable resources such as oil, gas, minerals, sand, and gravel reduces the amount available to other parties and makes further extraction more complicated and expensive. In addition, the marine ecosystem's ecological carrying capacity and its potential to provide ecosystem services may be seen as common pool resources. Utilization and harm of every kind can affect ecosystem services, impairing, for example, marine waters' ability to promote biological diversity or provide clean coastal waters for recreational use. Finally, even marine resources which have yet to be discovered could be regarded as common pool resources. In principle, every newly discovered resource makes the search for other undiscovered resources more expensive (Posner and Sykes 2010: 569–596).

The public nature of marine environmental goods and the rivalry between users creates a social dilemma which is widely referred to as the '*tragedy of the commons'* (Gordon 1954: 124–142; Hardin 1968: 1243–1248; partially revising Hardin 1998: 682–683). From the point of view of a rationally-acting user of marine environmental resources, the situation is as follows: exploitation costs will decrease and profits will increase if competitors restrict their exploitation activities in order to preserve the environment or to promote the efficient distribution of the contested resource. An economic incentive thus arises to not contribute to conservation or the efficient use and to pocket higher profits (*free-riding*). If competitors, however, do not undertake any efforts for conservation or the efficient distribution of the resource at all, forgoing benefits of resource exploitation would be totally irrational from an economic perspective, because (a) the rational user would not be able to guarantee the preservation of the resource by himself alone, (b) as a single contender, only he or she alone would lose profits, and (c) the advantages of forgoing would solely benefit the competitors. This mostly ends in individual strategy decisions which lead to inefficient and destructive results for the community (Weimann 1995: 66 ff.). Not least, the competitive situation within the social dilemma is exacerbated by the fact that for single competitors, short-term, calculable profits have a higher value than long-term non-calculable benefits. That, again, results in exponential increase in pressure to utilize (also referred to as the *race to resource* or *race to fish*, etc.).

The solution to this dilemma can only come through cooperation among involved users which aims at an overall limited and efficient use and distribution of the resources. As seen above, though, such cooperation is difficult to obtain. Against this backdrop, traditional environmental economics has drawn two strategic conclusions: either utilization rights should be allocated under state control, or the common pool should be transferred to be private property (as already stated by Hardin 1968: 1243–1248). Both solutions would require external control and neither has proven to be consistently successful in practice. In particular, recent studies have shown that limiting oneself intellectually to these two solutions does not help to meet the challenges of the problem, and that, despite the social dilemma, cooperative solutions are possible by means of internalized norms and successful communication (Ostrom 1990; Ostrom 2010b: 641–671). Before all others, *Elinor Ostrom* identified eight 'design principles' in extensive studies that promote independent, largely autonomous cooperation solutions (Ostrom 2010b: 641–671). The principles include, for example: clear and accepted borders between legitimate users and non-users; sanctions which become increasingly severe when rules are broken repeatedly; precise monitoring of the resources and their users; local avenues for quick resolutions of conflicts; a minimum level of competences to create rules; and a non-hierarchical and polycentric system of decision making.

There is obviously a difference between solving local and global problems. The potential of local or regional cooperation to solve problems is, however, also of great importance for supra-regional and global marine environmental protection as international marine environmental policy is dependent on local and regional participation in its development and implementation. Additionally, solving global environmental problems usually takes much time, so the prior development of bottom-up initiatives is an essential factor for solving environmental problems.

28.3.4.2 States' Negative Interests

Despite the possible potential of autonomous governance approaches, state regulation seems indispensable in resolving local, regional and especially global environmental and resource problems. Considering the cross-border nature of such issues, this generally needs to be done cooperatively by groups of states. At this level, however, negative structural incentives can discourage states from cooperating with each other.

First and foremost, the social dilemma discussed above also occurs to some extent at the international level. If not all relevant states participate in the creation and implementation of a treaty concerning the conservation of a specific aspect or element of the marine environment, the position of states willing to participate is as follows: why should states participate in the cost intensive development and implementation of a treaty, when (a) through their unilateral action the preservation of the resource cannot be guaranteed, (b) they would lose their (short-term) benefits, (c) the advantages of their forbearing would only benefit other states? At the same time though, one should not overestimate the heuristic value of this social dilemma model to explain international relations (Rao 2002: 47–91); In the international framework, the complexity of interests and inner structures of the institutional players far exceeds the somewhat overly simplistic rationale of the *homo oeconomicus* (Wiener 1999: 749–794; Sprinz and Vaathoranta 1994: 77–105; Barrett 2003; Bodansky 2010: 108–190). Negotiation situations in particular are characterized by a complex set of international and national interests and values. To use *Putnam's* words, international negotiations are complex 'two level games' (Putnam 1988: 427–460).

With respect to environmental protection in general and marine protection in particular, the central challenge to cooperative problem-solving at the international level is that negotiating parties often have varying or even conflicting economic interests and differing values regarding nature. Beyond that, states usually have the tendency to shy away from the costs of designing and implementing new international treaties (especially creating new administrative structures). Not to mention, states are generally unwilling to suffer sovereignty costs (i.e. shifting power away to the international level), have diverging perceptions of the problems in question, and differ greatly regarding their administrative, technical and financial problem solving capacities (Bodansky 2010: 136–190; Markus 2016b).

Furthermore, the varying forms and complexities of problems and their causes, as well as the geographical and substantial fragmentation of competences and responsibilities, weigh heavily in international marine protection. Matters such as fishing, oil, gas and mineral extraction, as well as shipping are central areas of national sovereignty: the mining of resources deals with the energy and natural resource supply (energy sovereignty), fisheries touch on the planning and safeguarding of food supplies (food security/food sovereignty), and the regulation of shipping may encroach on national trade and geostrategic interests (Purohit and Markus 2013: 13–30; Markus 2016b). The final obstacle to mention here is that maybe, with the exception of the conservation of "very likeable species" (i.e. the polar bear or the orca), marine protection in its entirety tends to be rather abstract, complicated, and distant, and the problems are perceived in different ways in individual regions. A critical, trans-border general public community which effectively engages for the protection of the seas is thus slow to develop.

28.4 Foundations of a Sustainable International Ocean Law

As shown above, the need for a political, legal, and institutional framework for the sustainable use of the seas is growing. At present, the most crucial actors for the overcoming of the outlined problems are states. They develop, structure, and negotiate their solutions and strategies and then inscribe and fix them into international conventions (on the relevance of treaties in international law see generally Koch and Mielke 2009: 403–409; Simma 1994: 221–384). Considering the central role which states and their interstate agreements play in addressing marine environmental issues, the following shall discuss how the effectiveness of conventions can be maximized to solve the respective problems. The starting point of this discussion will be the fundamental question as to why states conclude international treaties and why they adhere to them (or why they do not) (e.g. Markus 2016b; Beyerlin and Marauhn 2011: 315–388; Bodansky 2010: 138–190; Barrett 2003; see also Brunnée 2003, 2012) fundamentals Bothe 2010, paras. 6–18; Guzman 2008; Koh 1997: 2599–2695; Neuhold 1999: 84–124; Henkin 1968; Joyner 1998: 271–309). As an overview and for simplicity reasons, factors that could encourage contractual solutions to cross-border environmental problems can be divided into three groups (Markus 2016b): Those which (1) encourage development and conclusion of international treaties, (2) are of substantive or material nature, and (3) promote an effective implementation. It should be kept in mind that the different aspects of the law making, the substance of the law and the implementation of law, are relatively dependent on each other (Koh 1997: 2649; Markus 2016b). In addition to these factors, other factors like the existence of reciprocal interests between states, their potential to use force or other sanctions to promote compliance, and possible reputational interests are deemed to play an important role in solving issues within the framework of international agreements (von Aaken 2013: 227–262).

It is usually not enough to ask in isolation either under which circumstances states conclude treaties, or whether a treaty's content is suitable or adequate to solve the problem, or why the treaty is eventually implemented. Instead, it is more reasonable to try to comprehensively clarify under which circumstances an international convention achieves the solution of a concrete problem, (i.e. problem effectiveness), as an isolated view of a single or random selection of measures and factors could lead to the neglect of other important measures or a misinterpretation of their relative importance.

For pragmatic reasons, various developments and actors which in reality play an increasingly important role in marine environmental protection have been disregarded here. One such case is the continuous transformation of the state and their national and international laws that govern cross-border or global societal developments and problems (Alston 1997: 435–448; Twining 2000; Berman 2014; Sousa de Santos 2002). This is also not the place to go into detail of cross-border private or subnational forms of cooperation, such as Stewardship Councils (Marine & Aquaculture), administrative networks, and NGOs acting quite independently of their nations in the influencing of law making (see for this, e.g. Boyle and Chinkin 2007: 41–209; Herberg 2008: 17–40; Winter 2012: 103–145; Winter 2006: 1–33; Dilling and Markus 2016; see also articles in Dilling et al. 2011).

28.4.1 Elements of Successful Negotiations of International Environmental Protection Conventions

The first category of elements contains those elements which can help the conclusion and development of international agreements (Franck 1990; Chayes and Chayes 1995; Palmer 1992: 259–283; Boyle and Chinkin 2007: 22–40; Bodansky 1999: 596–624). These can be further divided into domestic and international factors (note the description of the 'two-level game', above). Without domestic political consent, states cannot engage in much binding foreign policy. Thus, in general, it should be noted that foreign policy interests of states are not only determined by their external economic or geostrategic interests but to an important extent by their predominant internal economic conditions and values, the technological solutions available, as well as the level and distribution of costs of potential environmental protection measures.

Both at the domestic and interstate level, it is important that problem-framing takes center stage. This includes that the most credible information possible about the environmental problem is available, especially information on its effects and the possible costs of non-action. It also includes that the positive effects of the solution must be made clear. The more precise and illustrative the problem and possible courses of action are depicted, the better they can be communicated and negotiated through the political process.

Further, agreement on effective problem-solving approaches depends on whether a large group of strong private and state actors can successfully be brought on board. In that regard, it is not only important to gain the support of ecological interest groups, but also to provide for economic growth, jobs, the development of innovative industries, and the inclusion of other actors (e.g. offshore renewable energy sector; sustainable fishing; sustainable tourism, etc.)[1] These findings apply equally to the inter-state level. Also here, alliances of strong actors benefit the conclusion of effective international agreements.

Additionally, political windows of opportunity are often required for successful contractual framing or development. Events and situations such as catastrophes (e.g. algae outbreaks, tanker accidents, beached whales, collapse of commercially used fish stocks, etc.), domestic elections, the political responsibility and public interest of states in the context of international conferences (e.g. Conferences of Parties), and the redirection of interests (e.g. the exit from nuclear energy and the expansion of renewable energies in Germany) can potentially influence values, the perception of problems, the constellations of actors and so on in favor of marine protection.

From a procedural perspective, it seems reasonable to assume that a sensible amount of participation from regulates, experts, and the public improves both the technical and social regulatory context and the quality and effectiveness of legislation. Having said that, finding the right amount of participation of civil society in international negotiations is not only organizationally challenging but also problematic from a legitimacy point of view (Boyle and Chinkin 2007: 57 ff.). Essentially, the right amount of participation should be identified, determined and negotiated in each case. The basis of any form of participation is, however, that international negotiations have a high degree of transparency, which the public will be able to understand and assess, and then politically react to the process.

Another important factor is the choice of which national ministry or international organization has the mandate to prepare regulations or treaties (forum choice). It should be recognized that considerable differences exist between the individual ministries and international forums regarding their protection interests, technical competences and organizational and institutional facilities (see e.g. Markus and Ginzky 2011: 477–490; Ginzky 2014: 105–117).

Not least, the conclusion of an international treaty also depends on the personal leadership and negotiation skills of the respective negotiators as well as their official mandates (Boyle and Chinkin 2007: 103–108 and 144–151; Bodansky 2010: 136–190). This is true not only for Conferences of Parties themselves, but also for the preparatory conferences of the technical and legal working groups (Ginzky 2014: 105–117; Markus 2016b). So-called pioneer states play an important role here,

[1] Various scholars show the possibilities of economic growth based on energy and raw material efficiency, see among others and with further references E.-U. von Weizsäcker 2009.

because they take on technical, organizational, and political responsibility for the success of the development process (Lindenthal 2009). Regarding the negotiation mandate, it is especially important that it is formulated clearly and that the negotiating parties agree on the 'right' type of regulation (resolution, model law, binding framework agreement, etc.), choose a functionally adequate but also politically achievable regulatory frame for the future agreement's scope (content, geographic, as well as participating parties), and aim at the right intervention and control intensity (Bodansky 2010: 136–190).

28.4.2 Substantial and Material Elements of Successful Environmental Conventions

Regarding the substantial factors that help solve cross-border environmental problems in general and marine protection in particular, it is reasonable to differentiate between formal and material elements. For the former, the following elements are worth mentioning:

- The clearest structure and language possible (Chayes and Chayes 1995: 10–13);
- Procedures or institutions to control and promote implementation (scientific councils, secretariats, monitoring, reporting, and dispute settlement mechanisms, etc.);
- Flexible regulations that are open to development and enable quick adaption to new or worsening environmental problems;
- A balanced mixture of clear-cut binding regulatory duties on the one hand and market based mechanisms on the other.

With regard to material elements, rules within national laws or international treaties seem to be most effective when they are suitable to actually solve the social problems at hand. For example, concerning international protection of species and habitats, the last decades have clearly shown that *ad-hoc* moratoriums and comprehensive utilization bans are not very effective and may cause considerable problems in and of themselves. It has been shown more than once that the general possibility for utilization and participation of interested users in management decisions can be an incentive for conservation (Markus 2016b). Furthermore, conventions seem to be more effective when they also generate clearly visible benefits for the parties besides the associated costs. Win-win situations should thus be created and clearly communicated, with particular attention given to the creation of synergies with other policy fields (e.g. renewable energies as business sector of the future; certified fish production, etc.).

It is also assumed that the integration of justice considerations and respective discourses in international negotiations promote a will by those regulated to follow the law (Hurd 1999: 379–408; Albin 2001; Franck 1995; WBGU 2013: 335–337; Epiney 2007: 31–38). If integrated effectively, such considerations could have an effect on regime adherence with regard to, for example, the distribution of mineral resources in the deep seabed, or more generally on distribution equity in international environmental law (Czarnecki 2008).

28.4.3 Elements of Successful Implementation of Environmental Conventions

With regard to the implementation of international conventions, the question should also be asked as to which elements within these conventions promote the solution of environmental problems (for this, see among others the works and ideas in Ulfstein et al. 2007; in Treves et al. 2009; as well as in Beyerlin et al. 2006; Zimmermann 2007: 15–47; Markus 2016b). Some of the elements listed above should also be named here, but it should be highlighted that effectiveness and control in international and supranational law are dependent on the ability of nation states to legitimize, apply and enforce it. Groups of states bound by international law or international organizations often do not have the sovereign powers or means to apply and enforce the law agreed in the respective institutional frameworks, so international enforcement of multilateral environmental treaties thus still plays a secondary or subsidiary role in practice. As a result, it is important to see how solutions laid down in international conventions can be implemented at the national level in a way that is in line with the goals agreed on at the international level, as well as to see how they can be integrated into internal legal and institutional structures. The following are some characteristics of successfully implemented conventions:

- A culture of compliance in the national authorities and courts;
- Sufficient administrative expertise;
- The lowest possible implementation costs;
- Parallel domestic interests which will be positively affected by fulfilling international conservation duties;
- An existing public interest (i.e. the public interest may also be created by the duties from the international treaty);
- Specific and quantifiable requirements (as opposed to mere regulatory objectives, which are comparatively difficult to implement and control) (Bodansky 2010: 178 ff.);
- Cross-compliance mechanisms at the international level (i.e. the benefits guaranteed to addressees of rules in other policies and areas of law are made dependent on the fulfillment of their environmental duties);
- Joint implementation with other states through an international control system (scientific councils, secretariats, monitoring, reporting, and dispute settlement mechanisms, etc.);
- The inclusion of non-state actors in the control of implementation (complaint procedure; expert commissions, etc.) (Epiney 2006: 319 ff.).

In the area of international environmental law (including marine environmental law), it is especially important that in addition to sanction processes and dispute settlement procedures, treaties include mechanisms that promote their implementation (managerial approach) (Chayes and Chayes 1995; Raustiala and Slaughter 2002: 538–558). Apart from equipping a treaty regime with institutions such as secretariats, scientific committees, control committees, etc., the implementation can also be advanced through mechanisms such as technical and legal support (through technical and legal implementation guides), financial support (through funds and loans, etc.), as well as through procedures to include the public, the addressees of rules or independent experts.

28.5 Conclusion and Perspectives

This article gave an overview of the structures and causes of environmental conflicts in the marine realm. It also explained the central challenges and elements of sustainable international resource management in this area. The cursory character and style was necessary to introduce the many existing interpretations, theories and arguments. Individual aspects, such as the question of the possibility of just treaty terms, are the subject of extensive special literature, extracts of which were referred to here. For pragmatic reasons, various other developments which play an increasingly important role in the reality of marine environmental protection were disregarded: among others, the continual transformation of states and the increasing importance of cross-border private and subnational state cooperation. It should be highlighted that states and their law (in common) are only partial aspects to the solution of cross-border marine environmental problems. Inspired by Elinor Ostrom's terminology, the solution of marine environmental problems should be understood as being 'polycentric', i.e. to be achieved by many different actors (Ostrom 2010a: 550–557). In the future, all stakeholders will need to be effectively mobilized to achieve the goal of sustainable utilization of the seas.

References

von Aaken A (2013) Die vielen Wege zur Effektuierung des Völkerrecht. Rechtswissenschaft 3:227–262

Albin C (2001) Justice and fairness in international negotiations. Cambridge University Press, Cambridge

Alston P (1997) The Myopia of handmaidens: international lawyers and globalization. Euro J Int Law 8:435–448

Barrett S (2003) Environment & statecraft. Oxford University Press, Oxford

Berman PS (2014) Global legal pluralism: a jurisprudence of law beyond borders. Cambridge University Press, Cambridge

Beyerlin U, Marauhn T (2011) International environmental law. Hart Publishing, Oxford

Beyerlin U, Stoll PT, Wolfrum R (2006) Ensuring compliance with multilateral environmental agreements. Mirtinus Nijhoff Publishers, Leiden
Bodansky D (1999) The legitimacy of international governance. Am J Int Law 93:596–624
Bodansky D (2010) The Art and craft of international environmental law. Harvard University Press, Cambridge
Bothe M (2010) Compliance. In: Wolfrum R (ed) Max Planck encyclopedia of public international law. Oxford University, Oxford
Boyle A, Chinkin C (2007) The making of international law. Oxford University Press, Oxford
Brunnée J (2003) The Kyoto protocol: testing ground for compliance theories. ZaöRV 63:255–280
Brunnée J (2012) Promoting compliance in an evolving climate change regime. Cambridge University Press, Cambridge
Chayes A, Chayes AH (1995) The New Sovereignty: compliance with International Regulatory agreements. Harvard University Press, Cambridge
Cooper RN (1975) An economist's view of the oceans. J World Trade 9(4):357–377
Czarnecki R (2008) Verteilungsgerechtigkeit im Umweltvölkerrecht, Duncker & Humblot, Berlin
Dilling O, Markus T (2016) Transnationalisierung des Umweltrechts. ZUR 1:4–17
Dilling O, Herberg M, Winter G (2011) Transnational administrative rule-making: performance, legal effects and legitimacy. Hart Publishing, Oxford
Douvere F, Ehler CN (2009) New perspectives on sea use management: initial findings from European experience with marine spatial planning. J Environ Manage 1:77–88
Epiney A (2006) The role of NGOs in the process of ensuring compliance with MEAs. In: Beyerlin U, Stoll PT, Wolfrum R (eds) Ensuring compliance with multilateral environmental agreements. Martinus Nijhoff Publishers, Leiden, pp 319–352
Epiney A (2007) Gerechtigkeit im Umweltvölkerrecht. APuZ 24:31–38
Erbguth W, Schlacke S (2014) Umweltrecht. Nomos Verlag, Baden-Baden
European Environmental Agency (2014) Marine message. Publications Office of the European Union, Luxembourg
Franck T (1990) The power of legitimacy among nations. Oxford University Press, Oxford
Franck T (1995) Fairness in international law and institutions. Clarendon Press, Oxford
Future Ocean (2014) World ocean review 3: marine resources—opportunities and risks. Maribus, Hamburg
Gillespie A (2006) Establishing reliable foundations for the international scientific investigation of noise pollution in the oceans. RECIEL 15:211–226
Ginzky H (2014) Wofür Expertise?—Das Verhältnis von Recht zu außerrechtlichen Aspekten in der internationalen Rechtssetzung. In: Dilling O, Markus T (eds) Ex Rerum Natura Ius?—Sachzwang und Problemwahrnehmung im Umweltrecht. Nomos Verlag, Baden-Baden, pp 105–117
Gordon HS (1954) The economic theory of a common-property resource: the fishery. J Polit Econ 62:124–142
Guzman AT (2008) How international law works: a rational choice theory. Oxford University Press, Oxford
Hafner G (2006) Meeresumwelt, Meeresforschung und Technologietransfer. In: Graf Vitzthum W (ed) Handbuch des Seerechts. C.H.Beck Verlag, München, pp 347–460
Hardin G (1968) The tragedy of commons. Science 162:1243–1248
Henkin L (1968) How nations behave: law and foreign policy. Praeger, New York
Herberg M (2008) Global legal pluralism and interlegality: environmental self-regulation in multinational enterprises. In: Dilling O, Herberg M, Winter G (eds) Responsible business: self-governance and the law in transnational economic transactions. Hart Publishing, Portland, pp 17–40
Heselhaus S (2011) § 56 Bundesnaturschutzgesetz. In: Frenz W, Müggenborg H-J (eds) Bundesnaturschutzgesetz—Berliner Kommentar (1009 ff.). Erich Schmidt Verlag GmbH & Co. KG, Berlin
Hurd I (1999) Legitimacy and authority in international politics. Int Organ 53:379–408

Joyner C (1998) Compliance and enforcement in new international fisheries law. Int Comp Law J 12:271–309

Koch H-J, Mielke C (2009) Die Globalisierung des Uwmeltrechts. ZUR 9:403–409

Koh HH (1997) Why do nations obey international law? Yale Law J 106:2599–2695

Lindenthal A (2009) Leadership im Klimaschutz: Die Rolle der Europäischen Union in der internationalen Klimapolitik. Campus Verlag, Frankfurt

Madison M, Frischmann BM, Strandburg K (2010) The complexity of commons. Cornell Law REV 95:839–850

Markus T (2009) European fisheries law—from promotion to management. Europa Law Publishing, Groningen

Markus T (2013) Changing the base: legal implications of scientific criteria and methodological standards on what constitutes good marine environmental status. Trans Environ Law 1:1–21

Markus T (2017a) Die Erhaltung und nachhaltige Nutzung der Biodiversität. In: Proelß A (ed) Umweltvölkerrecht. Walter De Gruyter. Berlin, pp. 321–366

Markus Till, Singh P (2016) Promoting consistency in the deep seabed: addressing regulatory dimensions in designing the international seabed authority's exploitation code. Review of European and International Environmental Law, RECIEL 347–362

Markus T (2016b) Die Problemwirksamkeit des internationalen Klimaschutzrechts—Ein Beitrag zur Diskussion um die Effektivierung völkerrechtlicher Verträge. ZaöRV 3:716–752

Markus T (2017b) Art. 46 UNCLOS. In: Proelß A (ed) United Nations convention on the law of the sea: a commentary. C.H. Beck, München, pp. 334–352

Markus T, Ginzky H (2011) Regulating climate engineering: paradigmatic aspects of the regulation of ocean fertilization. Carbon Climate Law Rev 5:477–490

Markus T, Helfst P (2014) Regulierung der Einleitung von Abwässern aus Schiffsabgasreinigungsanlagen zum Schutze der Meere. Natur und Recht 36:760–768

Markus T, Schlacke S, Maier N (2011) Legal implementation of integrated ocean policies: the EU's marine strategy framework directive. Int J Mar Coastal Law 26:59–90

Markus T, Huhn K, Bischof K (2015) The quest for seafloor integrity. Nat Geosci 8:162–163

Matz-Lück N, Fuchs J (2012) Die Ausweisung mariner Schutzgebiete in hoheitsfreien Räumen am Beispiel des OSPAR-Abkommens. ZUR 10:532–543

Neuhold H (1999) The foreign policy "cost-benefit analysis" revisited. German YBIL 42:84–124

Ostrom E (1990) Governing the commons. Cambridge University Press, Cambridge

Ostrom E (2010a) Polycentric systems for coping with collective action and global environmental change. Glob Environ Chang 20:550–557

Ostrom E (2010b) Beyond markets and states: polycentric governance of complex economic systems. Am Econ Rev 100(3):641–672

Palmer G (1992) New ways to make international environmental law. Am J Int Law 86:259–283

Posner EA, Sykes AO (2010) Economic foundations of the law of the sea. Am J Int Law 104: 569–596

Purohit S, Markus T (2013) India's Coastal Regulation Zone Notification 2011—tipping the scales towards environmental sustainability? Law Environ Dev J 9(1):13–30

Putnam RD (1988) Diplomacy and domestic politics: the logic of two-level games. Int Organ 42:427–460

Rao PK (2002) International environmental law and economic. Blackwell Publishing, Oxford

Raustiala K, Slaughter A-M (2002) International law and compliance. In: Carlsnaes W, Risse T, Simmons BA (eds) Handbook of international relations. Sage, London, pp 538–558

Rayfuse R (1998) Enforcement of high seas fisheries agreements: observation and inspection under the convention on the conservation of antarctic marine living resources. Int J Mar Coastal Law 13:579–605

Rayfuse R (2004) Non-flag state enforcement in high seas fisheries. In: Lagoni R, Vignes D (eds) Publications on ocean developments. Brill Academic Publisher, Leiden

Rothwell DR, Stephens T (2010) The international law of the sea. Bloomsbury Publishing, London

Rothwell DR, Stephens T (2016) The international law of the sea. Bloomsbury Publishing, London
Salomon M, Dross M (2013) Challenges in cross-sectoral marine protection in Europe. Mar Policy 42:142–149
Sands P, Peel J (2012) Principles of international environmental law. Cambridge University Press, Cambridge
Schubert M (2015) Meeresraumordnung und Europarecht: Die Richtlinie 2014/89/EU zur Schaffung eines Rahmens für die maritime Raumplanung. In: Hebeler T, Hofmann E, Proeßl A, Reiff P (eds) Jahrbuch des Umwelt- und Technikrechts. Erich Schmidt Verlag, Berlin, pp 199–221
Scott KN (2015) Integrated ocean management: a new frontier in marine environmental protection. In: Rothwell DR, Elferink AO, Scott KN, Stephens T (eds) Oxford handbook on the law of the sea (Chapters in Books). OUP, Oxford
Simma B (1994) From bilaterlism to community interestin international law. Recueil des Cours VI:221–384
Sousa de Santos B (2002) Toward a new legal common sense, law, globalization and emancipation. Butterworths LexisNexis, London
Sprinz D, Vaathoranta T (1994) The interest based explanation of international environmental policy. Int Organ 48:77–105
Treves T, Tanzi A, Pitea C, Ragni C, Pineschi L (eds) (2009) Non-compliance procedures and mechanisms and the effectiveness of international environmental agreements. Asser Press, Den Haag
Twining W (2000) Globalisation and legal theory. Cambridge University Press, New York
Ulfstein G, Marauhn T, Zimmermann A (eds) (2007) Making treaties work. Cambridge University Press, Cambridge
Von Weizsäcker E-U (2009) Factor five: transforming the global economy through 80% improvements in resource productivity. Earthscan, London
WBGU (2013) The world in transitions: governing the marine Heritage. WBGU, Berlin
Weimann J (1995) Umweltökonomik. Springer-Verlag, Heidelberg
Wiener JB (1999) On the political economy of global environmental regulation. Georgetown Law J 87:749–794
Winter G (2006) Introduction. In: Winter G (ed) Multilevel governance of global environmental change. Cambridge University Press, New York, pp 1–33
Winter G (2012) Zur Architektur globaler Governance des Klimaschutzes. ZaöRV 72:103–145
Wolf R (2010) Eingriffsregelung in der AWZ. ZUR 7–8:365–371
Young OR (1992) The effectiveness of international institutions: hard cases and critical variables. In: Rosenau JN, Czempiel E-O (eds) Governance without government: order and change in world politics. Cambridge University Press, Cambridge, pp 160–194
Young OR (1994) International governance: protecting the environment in a stateless society. Cornell University Press, New York
Zimmermann A (2007) Dispute resolution, compliance control and enforcement in human rights law. In: Ulfstein G, Marauhn T, Zimmermann A (eds) Making treaties work. Cambridge University Press, Cambridge, pp 15–47
Zimmermann A (2008) Durchsetzung des Völkerrechts zwischen Fragmentierung, Multilateralisierung und Individualisierung. In: Fischer-Lescano A, Gasser H-P, Marauhn T, Ronzitti N (eds) FS M. Bothe zum 70, Geburtstag. Nomos Verlag, Baden-Baden

Chapter 29
Institutional Framework for Marine Environmental Governance

Pradeep Singh

Abstract This chapter provides an overview of the various actors and institutions that play a role in the protection of the marine environment. These actors and institutions can be classified into three categories, namely (1) those that are established and operate within the law of the sea regime, (2) those that operate under the auspices of the United Nations and effectuate marine environmental objectives, and (3) those that operate within other specific regimes that interrelate with the oceans and send impulses which guide the direction of marine environmental governance. This chapter aspires to identify the various roles played by these diverse actors and institutions and examine how they interact with each other in striving to protect the marine environment.

Keywords Institutional framework • Law of the sea • Protection of the marine environment • Actors and institutions in marine environmental governance

29.1 Introduction

The 1982 UN Convention on the Law of the Sea (UNCLOS) is the starting point for all discourse on the law of the sea, including the protection of the marine environment. The adoption of UNCLOS in 1982 marked a significant phase in the development of a foundational framework for managing and governing the oceans and placed substantial emphasis on the protection of the marine environment (Chap. 32; Rothwell and Stephens 2016: 517; Redgwell 2006: 180–182). In 'recognizing the

P. Singh
Research Centre for European Environmental Law, University of Bremen, Bremen, Germany

International Research Training Group INTERCOAST – 'Integrated Coastal Zone and Shelf-Sea Research, University of Bremen, Bremen, Germany and University of Waikato, Waikato, New Zealand
e-mail: pradeep@uni-bremen.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_29

desirability of establishing […] a legal order for the seas and oceans which will facilitate […] (*inter alia*) the study, protection and preservation of the marine environment' (Preamble, UNCLOS), the global community identified the protection of the marine environment as a key focus area which required international attention and cooperation. To this end, 46 articles of UNCLOS are dedicated towards the 'Protection and Preservation of the Marine Environment' (Part XII, UNCLOS).[1]

It is important to mention at the outset that while there are many institutions that are active in the law of the sea and maritime affairs, this chapter is focused on the institutional framework relating to the governance and protection of the marine environment. It particularly aims to provide an overview of these various actors and institutions, including their functions and mandate, and examine how they interact with each other in striving to protect the marine environment. The modern evolution of marine management has taken shape through the works of various international organizations, both within and outside UNCLOS, in accordance with their respective mandates or functions. Indeed. through the use of the phrase 'competent international organizations' in numerous provisions in Part XII, UNCLOS created a setting for multiple institutions 'to be involved in developing the legal framework for the protection of the marine environment' (Harrison 2015a: 58).

29.2 The Institutional Framework for Marine Environmental Protection

The various actors and institutions that play a role in marine environmental governance can be grouped into three categories. The first category comprises of organizations created through UNCLOS itself, the second category consists of institutions that form part of the United Nations 'family', while the third category includes actors that function and operate within other regimes that are either connected or related to the marine environment or concerned with it.

29.2.1 The UNCLOS Regime

The entry into force of UNCLOS in 1994 breathed life into three organizations: The International Seabed Authority, the International Tribunal for the Law of the Sea, and the Commission on the Limits of the Continental Shelf. In addition to the above, the annual meetings of the State Parties to UNCLOS is an important feature in facilitating the functional operation of UNCLOS and the permanent organizations. Each of these institutional arrangements and their relevance to marine environmental governance will be discussed in turn.

[1] In addition, numerous other provisions also make cross reference to the protection of the marine environment and conservation of living resources. See for instance: Articles 21(1)(f), 56(1)(b)(iii), 60(3) 61, 119, 123, 145, 236(2), and 290(1).

The International Seabed Authority (ISA), established pursuant to Article 156, is charged to administer Part XI of UNCLOS. Specifically, the ISA is responsible to regulate and govern the exploration and exploitation of minerals resources of the seabed and its subsoil in areas beyond national jurisdiction (otherwise known as the 'Area') which have been designated as part of the common heritage of mankind (Chap. 30). The ISA stands out compared to other international organizations because it has the mandate to adopt (and enforce) procedures, rules and regulations as well as to enter into legally binding contractual obligations with State sponsored operators conducting activities in the area (Markus and Singh 2016). With respect to the protection of the marine environment, the ISA is mandated under Article 145 of UNCLOS to take necessary measures 'to ensure effective protection for the marine environment from harmful affects which may arise from (activities in the Area)'. In the course of its development of mining regulations as well as recommendations and guidelines for contractors, the ISA has pays close attention to managing the environmental impacts from deep seabed mining activities as it progresses towards commencing large-scale commercial mining (Markus and Singh 2016; Rothwell and Stephens 2016: 20–21). Apart from that, the ISA in carrying out its task is guided by established and emerging norms of international environmental law such as environmental impact assessments, the precautionary approach and the ecosystems-based management (Jaeckel 2017; Makgill and Linhares 2016; Lodge 2015a: 252, 2015b: 168; Wedding et al. 2013). In this respect, the ISA has taken steps to protect deep seabed habitats such as the adoption of the Environmental Management Plan for the Clarion-Clipperton Zone in 2012 (Lodge et al. 2014).

The second institution established pursuant to Annex VI of UNCLOS is the International Tribunal for the Law of the Sea (ITLOS) and is one of the mechanisms for compulsory dispute resolution set up pursuant to Part XV of UNCLOS. In fact, ITLOS has been referred to as 'the centrepiece of Part XV mechanisms for the settlement of disputes' arising within UNCLOS (Rothwell and Stephens 2016: 21). To adjudicate over disputes arising in connection with Part XI of UNCLOS, the Seabed Disputes Chambers (SDC) was created within ITLOS (Article 14, Annex VI; Articles 186–191, UNCLOS). While the bulk of the early cases that formed the workload of ITLOS were on the prompt release of fishing vessels, ITLOS has on several occasions applied environmental principles to the law of the sea and stimulated the development of obligations to protect and preserve the marine environment (Tanaka 2015a: 54–55; Boyle 2007; Rothwell 2003; Mensah 1999). Recent examples of this can be seen in two Advisory Opinions: *Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area (Request for Advisory Opinion Submitted to SDC, Case No. 17, 2011)* and *Request for an Advisory Opinion Submitted by the Sub-Regional Fisheries Commission (Request for Advisory Opinion submitted to ITLOS, Case No. 21, 2015)*. Accordingly, it may be observed that ITLOS plays an important role in strengthening the environmental provisions of UNCLOS through interpretation (Churchill 2015: 30) as well as expanding it further to keep abreast with current developments in international environmental law.

The Commission on the Limits of the Continental Shelf (CLCS), the third institution created through Annex II of UNCLOS serves a specific function of making recommendations based on submissions by coastal states claiming a continental shelf beyond 200 nautical miles pursuant to Article 76 of UNCLOS. As this has a bearing on what ultimately belongs to the 'Area' and is therefore subjected to the mandate of the ISA and the common heritage of mankind principle, the function of the CLCS is indeed a pivotal one. Pertinently, although the CLCS does not have the authority to consider, influence or shape environmental themes, ascertaining (with finality) which areas fall within national jurisdiction and which do fall within the jurisdiction of the ISA is important as it determines who has the mandate to exercise jurisdiction over resources and take measures deemed necessary to protect the marine environment in the applicable areas (Mossop 2015: 177). Furthermore, preparing a submission to the CLCS entails the compiling of detailed hydrographical and geological information pertaining to the seabed which essentially requires significant marine scientific research and exploration endeavours on the part of the coastal state (Jenisch 2010: 377). This information could subsequently be relied on by the coastal state in taking measures to protect fragile ecosystems and designate marine protected areas.

Finally, the importance of the meeting of the State Parties to UNCLOS (SPLOS) as a forum providing member states the platform to deliberate on matters pertaining to UNCLOS must be highlighted (Tanaka 2015b: 34). While the nature and exact mandate of these meetings are ambiguous, a 'principal point of focus (of the agenda) is a review of the work of the ITLOS, the ISA, and the CLCS' (Rothwell and Stephens 2016: 21). In this sense, there are prospects for marine environmental concerns faced by those institutions to be raised and discussed among member states who should, as parties to a treaty, have a say in the direction in which UNCLOS is heading. Nevertheless, given that the purpose, functions, and powers of the SPLOS meetings have not been clearly defined under UNCLOS, coupled with the fact that matters involving the law of the sea are by and large political in nature, the reality is that the more pertinent and pressing issues have traditionally been dealt with by the UN General Assembly and the wider UN system (Harrison 2015b: 389–390).

29.2.2 The United Nations 'Family'

The UN 'family' here refers to the UN General Assembly and its organs and specialized UN institutions that contribute to marine environmental protection even though it may not necessarily be their primary function (Churchill and Lowe 1999: 22). It should be mentioned at the outset that as it would be a near impossible task to outline each organization and their role, this section will focus on key organizations involved in marine protection, namely the International Maritime Organization, the UN Food and Agriculture Organization, and the UN General Assembly. Some reference will be made to other UN related institutions, but this should not be treated as either a comprehensive or exhaustive analysis.

The International Maritime Organization (IMO) has been described as 'the organization that has probably had the most substantial direct effect upon the law of the sea' and has made significant progress in regulating navigational safety and marine pollution through its subsidiary committees such as the Maritime Safety Committee and the Marine Environment Protection Committee (Churchill and Lowe 1999: 23). Unlike the ISA, the IMO does not have broad powers to make legally binding regulations. However, it plays a significant role in marine environmental protection through the issuance of non-binding recommendations and by convening diplomatic conference for states to formally adopt instruments with legally binding effect. It is also pertinent to note that IMO rules and standards could have an impact on the interpretation of UNCLOS through 'rules of reference' (Karim 2015: 34; Tanaka 2015b: 35; Kachel 2008: 86–90), notably in cases where UNCLOS makes reference to 'applicable' or 'generally accepted' international rules and standards or recommendations established through or by the 'competent international organization' and thus referring, for example, to the IMO (Birnie et al. 2009: 76, 404; IMO 2014: 8).[2] Furthermore, even if a non binding recommendation is issued at the initial stage, this ordinarily will subsequently be followed by the formal stage of adoption at a diplomatic conference. For instance, the IMO Guidelines for Ship Recycling 2003 later transformed into the Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships 2009 (albeit not yet in force). Some important examples of binding treaties pertaining to the marine environment adopted through the IMO include the International Convention on the Prevention of Pollution from Ships 1973/1978 (MARPOL Convention), the International Convention on Oil Pollution Preparedness, Response and Cooperation, 1990, the International Convention on Harmful Anti-Fouling Substances 2001, and the recently entered into force International Convention for the Control and Management of Ships' Ballast Water and Sediments 2004. Once a treaty comes into force, there is the possibility for a subsidiary committee of the IMO (if so mandated) to introduce new standards that may bind member States through the use of annexes or schedules. This flexibility allows for standards to be updated constantly to reflect best contemporary practices. Another way in which the IMO contributes directly to marine environmental protection is through designating 'Particularly Sensitive Sea Areas' (PSSAs). PSSAs serve to protect marine areas which may be vulnerable to damage by international maritime activities by enabling the adoption of strict measures (such as mandatory pilotage schemes) pertaining to shipping routes in those areas. Lastly, it should also be mentioned that the IMO performs secretarial as well as technical functions for the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 (London Convention) and Protocol 1996 (London Protocol) which strives to prevent pollution at sea through dumping (VanderZwaag 2015: 143).

The UN Food and Agriculture Organization (FAO) and its Committee on Fisheries has made significant contribution to fishery science and the conservation of marine living resources (Churchill and Lowe 1999: 23) and serves as a platform for the negotiation of instruments in this area. In this respect, the Agreement to Promote Compliance with International Conservation and Management by Fishing

[2] With respect to prevention of pollution to the marine environment, see for instance, Articles 94(5), 210(4) and (6), 211, 216(1), 217(1), 218(1), 219, 220(1), (2) and (3), 226(1)(a) and (b), 228(1), and 230(1) and (2) of UNCLOS.

Vessels in the High Seas 1993 (FAO Compliance Agreement) and the recently entered into force Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing 2009 has been adopted under the auspices of the FAO. Additionally, the FAO also utilizes voluntary and non-binding instruments in tackling challenges faced in the conservation and sustainable use of fisheries (Boyle 2006: 50) such as the Code of Conduct on Responsible Fisheries 1995 and four International Plans of Action. It is pertinent to note that these FAO instruments do have a bearing on the interpretation and implementation of UN Agreement for the Implementation of the Provisions of UNCLOS relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks 1995 (UN Fish Stocks Agreement) and UNCLOS (Tanaka 2015b: 36).

The UN itself and in particular the UN General Assembly (UNGA), given its global geographical and political representation, is arguably one of the most crucial platform in furthering the law of the sea and marine environmental protection. This can be gleaned from several perspectives. First, the contribution of UNGA in the making of customary international law, enhancing legitimacy and democratisation in decision-making pertaining to law of the sea matters must be acknowledged, especially with respect to non State parties to UNCLOS (Boyle and Chinkin 2007: 108, 116; Tanaka 2015b: 37). As mentioned earlier, owing to its political nature, the more pertinent and pressing issues pertaining to the law of the sea have traditionally been resolved at the UN level as opposed to within the UNCLOS set up. Second, through the role it plays in promoting sustainable development, UNGA has pledged significant attention to the protection of the marine environment and the conservation of living resources. For instance, the Sustainable Development Goals of 2015, in particular Goal 14, emphasizes the need to 'conserve and sustainably use the oceans, seas and marine resources for sustainable development' (UNGA Resolution A/RES/70/1 of 25 September 2015). Stating aspirations and setting targets is an effective way to encourage policies and practices among member states as well as stimulate and galvanize global and national initiatives towards marine environmental protection.

Third, it should be emphasized that it was the UN which created the path for UNCLOS by facilitating the diplomatic conferences that lead up to its eventual drafting and adoption in 1982. Pertinently, it was also the UN which paved the way for the wide acceptance (and coming into force) of UNCLOS by resolving the deadlock pertaining to the deep seabed regime through the negotiating of the Agreement Relating to the Implementation of Part XI of UNCLOS in 1994, and subsequently also facilitated a second implementation agreement in the form of the UN Fish Stocks Agreement in 1995. Presently, following a UNGA Resolution in June 2015 (A/RES/69/292) to develop an international legally-binding instrument under UNCLOS for the 'conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction', a preparatory committee (the BBNJ PrepCom) comprising of UN member states, UNCLOS member states and institutions, and international organizations was created to discuss the scope and necessary content to a draft legal text. The BBNJ PrepCom has since reported back to UNGA and recommended for multilateral negotiations to be held in due course. This negotiation process is could lead to the adoption of a third implementation agreement to UNCLOS in the near future (Barnes 2016).

Fourth, apart from developing instruments for the advancement of UNCLOS and its objectives, another valuable contribution of UNGA is the annual review and implementation of UNCLOS and other matters pertaining to the oceans and maritime affairs. This practice, in the form of a report prepared by the UN Secretary General and presented to UNGA, followed by a resolution passed by the latter, has been the convention ever since UNCLOS entered into force in 1994 (Tanaka 2015b: 36). The UN Open-ended Informal Consultative Process on Oceans and the Law of the Sea (ICP), a resourceful forum created through a UNGA Resolution (A/RES/54/33, adopted 24 November 1999) that meets annually since 2002, creates an avenue for independent experts and observers to participate in discussing a wide range of marine affairs. The outcome of the ICP meetings is subsequently relied upon in the annual UNGA review process (Tanaka 2015b). Lastly, special mention ought to be given to the Division of Ocean Affairs and the Law of the Sea (DOALOS), one of the units belonging to the Office of Legal Affairs to the UN Secretariat, which performs the critical function of facilitating and administering all UN operations and responsibilities pertaining to ocean affairs and the law of the sea such as the UN Secretary General's annual report, the ICP meetings, the SPLOS meetings and the BBNJ PrepCom meetings, providing UN member states and intergovernmental organizations a wide range of technical services such as information and advice on UNCLOS and related instruments, and supporting the other institutions within the UN system in matters within this domain (de La Fayette 2006).

Beyond the above, several other UN specialized agencies that contribute to marine environmental governance in various capacities are noteworthy of reference. The UN Educational, Scientific and Cultural Organization (UNESCO) is responsible for the administration of the Convention Concerning the Protection of World Cultural and Natural Heritage 1972. As of 2013, about 46 marine areas have been inscribed on the UNESCO World Heritage List for their exceptional natural features (UNESCO 2013; Abdulla et al. 2013: 8). The Intergovernmental Oceanographic Organization of UNESCO (IOC) and its Advisory Body of Experts on the Law of the Sea also play an important role with respect to marine scientific research and the management, conservation and protection of the marine environment (Harden-Davies 2016: 261; Stephens and Rothwell 2015: 573–574). Apart from that, the World Meteorological Organization and its Marine Meteorology and Oceanography Programme (MMOP) also contributes to marine environmental governance through a fully integrated marine observing, data management and services system. The UN Environment Programme (UNEP) and its Regional Seas Programme (RSP) perform a vital role in the sustainable management and use of the marine and coastal environment. Through this endeavour, a total of 13 action plans have been launched, also giving rise to birth of several regional treaties. Furthermore, UNEP also operates to tackle marine pollution from land-based sources and in this respect initiated the Global Programme of Action for the Protection of Marine Environment from Land-based Activities in 1995. Other UN organizations, such as the World Health Organization which has taken steps to regulate sanitary matters affecting international shipping and the International Atomic Energy Agency which has worked on issues pertaining to damage caused by nuclear powered vessels, also contribute to marine environmental protection (Churchill and Lowe 1999: 23).

Finally, the UN set up also comprises of a versatile scientific advisory body known as the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP). This independent body consists of numerous experts acting in their personal capacity to advise the UN system on the scientific aspects of marine environmental protection. GESAMP undertakes an interdisciplinary and science-based approach to marine environmental affairs and seeks to coordinate and streamline the individual efforts taken by the various UN agencies through a joint advisory mechanism. It is also responsible for the publication of the GESAMP Reports and Studies Series in which the results of its major reviews, analyses and assessments are published (IMO 2005). This includes the publication of numerous reports on the volume of pollutants in the marine environment (Rothwell and Stephens 2016: 366).

29.2.3 Beyond UNCLOS and the UN System

Numerous other regimes and actors exist and operate outside of UNCLOS and the UN family which have an enormous influence in the growth and direction of marine environmental governance. In this section, the relationship between UNCLOS and other international and regional treaty regimes, including the role of various other actors and institutions such as scientific and technical advisory bodies as well as non- governmental organizations in the protection and preservation of the marine environment, will be discussed. The similar caveat from the earlier section that this should not be treated as either a comprehensive or exhaustive analysis applies.

The Convention on Biological Diversity 1992 (CBD) has a long-standing relationship with UNCLOS. With respect to the marine environment, Article 22 of the CBD instructs member States to carry out their obligations under the CBD in a manner consistent with the 'rights and obligations of States under the law of the sea'. The commonly accepted position is that as a specialized treaty, the CBD regime (in so far as it pertains to the conservation of marine biodiversity and is consistent with the general principles and objectives of UNCLOS) generally prevails over Part XII of UNCLOS (Boyle 2006: 56–57).[3] In this respect, the CBD regime through its Conference of Parties (COP) has made numerous key decisions providing guidance to parties on the conservation and sustainable use of marine living resources and the identification of marine protected areas (Harrison 2015a: 64–65). Nevertheless, the CBD has some shortcomings and this is especially glaring in the protection of

[3] Conversely, where the application of the CBD directly infringes upon the rights or obligations of States under UNCLOS, such as the establishment of protected areas in territorial or archipelagic which exclude the right of innocent passage (and therefore undermines the spirit of UNCLOS), the provisions of UNCLOS would take precedence (Wolfrum and Matz 2000: 475–478).

marine biodiversity in areas beyond national jurisdiction (de La Fayette 2006: 74). It should also be remembered that a significant number of provisions under UNCLOS are customary international law and commands the adherence of parties through state practice. The CBD, however, operates more as a framework convention in guiding parties on conservation and preservation measures to be adopted at the national level. Thus, it comes as no surprise that UNCLOS is given priority (as a matter of UN policy) when it comes to the law of the sea and marine management. Accordingly, instruments such as the UN Fish Stocks Agreement and the current negotiations at the BBNJ PrepCom are brought under the UNCLOS umbrella and not the CBD.

The World Trade Organization (WTO) also has a stake in the law of the sea matters (Rothwell and Stephens 2016: 22), in particular living resources. As pointed out by Harrison, 'the nature of international economic law means that the rules prescribed by these institutions have the potential to constrain the discretion of states when adopting environmental measures' (2015a: 65). While trade barriers are generally prohibited under the WTO regime, specifically the General Agreement on Trade and Tariff 1994 (GATT), it is clear that trade bans or sanctions and related measures imposed through regional or global agreements with the objective of promoting marine conservation efforts would be valid if certain conditions are met (Boyle 2006: 60). Examples of other multinational environmental agreements that play a role in conservation of marine living resources and marine environmental protection in general are the International Convention on the Regulation of Whaling 1948 (ICRW), the Convention on Wetlands of International Importance especially as Waterfowl Habitat 1971 (Ramsar Convention), the Convention on International Trade in Endangered Species 1973 (CITES), and the Convention on Migratory Species 1976 (CMS).

The Intergovernmental Panel on Climate Change (IPCC), the UN Framework Convention on Climate Change 1992 (UNFCCC), the Kyoto Protocol 1995, and the recent Paris Agreement of 2015 (collectively part of the climate regime) deserve unique treatment despite the fact that its focus is on atmospheric conditions and greenhouse gas emissions and not the marine environment *per se*.[4] In this regard, the climate regime is closely connected to the oceans as the oceans serve as a carbon sink (it is in fact the world's largest carbon sink) in removing carbon dioxide from the atmosphere (Craig 2012: 50; Chap. 47). It also suffers from the adverse impacts of climate change such as ocean acidification which causes the destruction of ecosystems and depletion of living resources (Stephens 2015: 432–434; Fennel and

[4] At the outset, it should be mentioned that UNCLOS through Articles 207 and 212 provides for the regulation of pollution of the marine environment from land-based sources and from or through the atmosphere respectively. Nevertheless, based on the context in which they were negotiated, Articles 207 and 212 did not intend to regulate the emissions of greenhouse gases, but rather the release of toxic, harmful or noxious substances into the marine environment from any source (Article 194(1), (3)(a)). Be that as it may, there is room to argue that greenhouse gases fall within the definition of 'pollution to the marine environment' as defined under Article 1(1)(4) of UNCLOS, which, when read together with the above provisions, could potentially categorize them as a source of marine pollution and thus falling within the scope of UNCLOS (Boyle 2012a, 832).

VanderZwaag 2016: 367–349). These threats are pertinent to the marine environment and concerns UNCLOS (Doelle 2006: 319). Furthermore, the oceans provide some potential solutions to mitigate climate change such as through the generation of renewable energy and possibly through geoengineering (i.e. ocean fertilization and carbon capture and storage) techniques in future. This falls within the domain of the law of the sea regime as well (O'Hagan 2016; Leary and Esteban 2009; Dixon et al. 2014; Scott 2015; Markus and Ginsky 2011).

Despite there being limited room under UNCLOS to argue that state parties are obligated to take positive measures to combat climate change (Stephens 2015: 797), it is clear that the climate regime alone would not be able to successfully address climate change 'without support from other international regimes and institutions' (Boyle 2012b: 333–334). Furthermore, even if the causes of climate change cannot be tackled through UNCLOS, there is an important role for UNCLOS in 'addressing "conventional" threats such as pollution, overexploitation, and habitat degradation and loss' to enhance the resilience of marine ecosystems (Redgwell 2012: 409). In this respect, the IPCC plays an important role as it provides periodical scientific assessment reports on the state of the climate (which includes a section specifically on the oceans). Hence, even though it does not have a controlling influence in the legal governance of the oceans, the works of the IPCC in reality releases certain impulses which shape the direction of marine governance.

Along these lines, other multilateral environmental agreements that predominantly regulate air and atmospheric pollution, such as the Convention on Long-Range Transboundary Air Pollution 1979 (LRTAP) and its Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone 1999, and the Stockholm Convention on Persistent Organic Pollutants 2001, will similarly have an impact on the development of marine environmental protection under the law of the sea. Although UNCLOS 'do(es) not prejudge the question of whether any part of the atmosphere is itself part of the marine environment', there are some indications within its provisions which suggest 'that the atmosphere itself can be regarded as a component of the marine environment' (Nordquist et al. 1990: 67). Furthermore, Article 237 of UNCLOS (which facilitates the operation of other specific conventions and agreements that relate to the protection of the marine environment) arguably provides an opening to link marine environmental protection 'with other aspects of environmental control of the atmosphere' (Nordquist et al. 1990: 212–213). Hence, it is expected that ocean-atmospheric interactions and institutions which function in that sphere will receive greater attention in future (Chap. 32).

Apart from the IPCC, two other scientific bodies that actively contribute to marine environmental governance are the International Hydrographic Organization (IHO) and the International Council for the Exploration of Seas (ICES). The IHO is an intergovernmental organization that aims to survey the oceans and compile hydrographic data. These scientific data are essential for all maritime activities, including but not limited to navigation, construction of onshore and offshore structures such as ports and renewable energy infrastructure, resource exploration, and more pertinently the protection of the marine environment (Pfeiffer 2006: 197). The ICES is an intergovernmental organization that provides scientific advice to regional regimes in the North Atlantic and the Baltic Sea to promote sustainable use of the marine environment and protect marine ecosystems. This function is carried out through its two sub-committees, the Advisory Committee on Fisheries Management and the Advisory Committee on the Marine Environment (Braethan 1998: 29). A third and rather new body created in 2012, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), is starting to function and is expected to play a significant role in assessing marine ecosystems and marine conservation efforts.

The significance of regional-focused regimes must also be highlighted, in particular the Regional Seas Programmes (RSPs) which exist through UNEP or independently from it, and the numerous Regional Fisheries Management Organizations (RFMOs) that have been created by or through the FAO or independently from it. In this respect, UNCLOS mandates member States whose maritime zones neighbour with each other, as well as on the high seas, to cooperate through regional initiatives in taking measures to protect and preserve the marine environment including the conservation of living resources. This is reflected in numerous provisions of UNCLOS.[5]

Through the initiatives of UNEP, notably the creation of the RSP, numerous regional arrangements have come into existence. To date, there are 13 RSPs in existence with the participation of some 143 countries, located in the following marine areas: Mediterranean, ROPME Sea Area (the Gulf of Arabia and Oman leading out into to Arabian Sea), Western Africa, South-East Pacific, Red Sea and Gulf of Aden, Wider Caribbean, Eastern Africa, Pacific, Black Sea, North-East Pacific, East Asian Seas, South Asian Seas, Northwest Pacific. While most have evolved into the conclusion of a regional treaty (namely: the Convention for the Protection of the Mediterranean Sea against Pollution 1976 (Barcelona Convention), the Regional Convention for Cooperation on the Protection of the Marine Environment from Pollution 1978 (Kuwait Convention), the Convention for Cooperation in the Protection, Management and Development of the Marine and Coastal Environment of the Atlantic Coast of the West, Central and Southern Africa Region 1981 (Abidjan Convention), the Convention for the Protection of the Marine Environment and Coastal Zones of the South-East Pacific 1981 (Lima Convention), the Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment 1982 (Jeddah Convention), the Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region 1983 (Cartagena Convention), the Convention of the Protection, Management and Development of the Marine and Coastal Environment of the Eastern African Region 1985, (Nairobi Convention), the Convention for the Protection of the Natural Resources and Environment of the South Pacific Region 1986 (Noumea Convention), the Convention on the Protection of the Black Sea Against Pollution 1992 (Bucharest Convention), and the Convention for Cooperation in the Protection and Sustainable Development of the Marine and Coastal Environment of the North-East Pacific 2002 (Antigua Convention)) with their respective associated protocols dealing with

[5] For instance, Articles 61, 63, 64, 118, 119, 123, 197, and 200 of UNCLOS.

specific matters, others remain in the form of soft law instruments such as 'Action Plans' or memoranda of understanding (such as the East Asian Seas Action Plan (EASAP), Northwest Pacific Action Plan 1994 (NOWPAP), and the South Asian Seas Action Plan 1995 (SASAP)) and their associated outline strategies.

It is to be stressed here that most of these regional arrangements have a central body comprising of representatives and experts from member states which serves to administer the respective instruments in accordance with the objectives and purposes therein. While UNEP administers some of these regimes, more than half of them are administered autonomously (Freestone and Salman 2007: 349). The operational tasks include implementing and executing various marine protection and conservation measures, publishing periodical reports, organizing regular meetings attended by member states, and facilitating communication and cooperation between member states and UNEP. Independent from (but operating in partnership with) UNEP are several independent regimes in the Baltic Sea, North-East Atlantic, Caspian Sea, Antarctic and Arctic. All except the latter have a framework treaty regime to govern the respective marine areas, notably, the Convention for the Protection of the Marine Environment of the Baltic Sea 1992 (Helsinki Convention), the Convention for the Protection of the Marine Environment of the North-East Atlantic 1992 (OSPAR Convention), the Framework Convention for the Protection of the Marine Environment of the Caspian Sea 2003 (Tehran Convention), and the Antarctic Treaty System (comprising of the Antarctic Treaty 1959, the Convention for the Conservation of Antarctic Seals 1972, the Convention for the Conservation of the Antarctic Marine Living Resources 1980, and the Protocol on Environmental Protection to the Antarctic Treaty 1991). As for the Arctic, the eight Arctic countries adopted the Arctic Environmental Protection Strategy 1991 (AEPS). Similarly, a commission, conference of parties, or council is established as the institutional body to implement and govern regime operations, namely, the Baltic Marine Environment Protection Commission (HELCOM), the OSPAR Commission, the Conference of Parties to the Tehran Convention, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) and its Scientific Committee (SC-CCAMLR), and the Arctic Council respectively.

The FAO has to some extent played a role in the establishment of Regional Fisheries Management Organizations (RFMOs), although there exist numerous examples which have been set up independently. It is through the RFMOs that the cooperative mechanism for the management of living resources envisaged by UNCLOS is effected (Rayfuse 2015: 440). Through UNCLOS and the UN Fish Stocks Agreement 1995, member States interested in fisheries within a shared area are obliged to cooperate through bilateral or regional efforts. For highly migratory species (mostly tuna), some existing regimes include the International Commission for the Conservation of Atlantic Tunas (ICCAT), the Indian Ocean Tuna Commission (IOTC) and the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) (Unterweger 2015). As for non-tuna stocks, examples of some RFMOs are the North-East Atlantic Fisheries Commission (NEAFC), the Northwest Atlantic Fisheries Organization (NAFO), the North Atlantic Salmon Conservation Organization (NASCO), the South-East Atlantic Fisheries Organization (SEAFO), the South Pacific Regional Fisheries Management Organization (SPRFMO), the General Fisheries Commission for the Mediterranean (GFCM), and the CCAMLR in the Antarctic (Rayfuse 2015: 442–443). According to Rayfuse, there are five broad categories of measures that are taken by RFMOs, to wit, 'measures relating to stock assessment, management of fishing effort, allocation of fishing opportunities, compliance and enforcement, and protection of the wider marine environment' (Rayfuse 2015: 450). Even though the FAO exercises minimal authority over most of the RFMOs, it nevertheless still plays a 'catalytic and coordinating role by bringing together these institutions to discuss common challenges and what can be done to address them' (Harrison 2011: 233).

While region-based mechanisms have their inherent drawbacks (such as outliers and free riders as well as ineffective enforcement), such initiatives have proven to be a useful approach towards the conservation of living resources and the protection of the marine environment. The RSP arrangements allow for a proven environmental protection framework to be applied from one region to another and modified accordingly to specifically tailor the needs and priorities of the different geographical location. It also provides a platform for the exchange of information and collaborative interface between scientists, researchers and government officials from the respective States to solve common concerns and threats to the marine environment (Harrison 2015a: 69; Hulm 1983: 4; Haas 1989). Despite some shortcomings (especially in addressing pollution to the marine environment from land-based sources as well as lack of enforcement bite), RSPs have, in the 40-some years of its existence, brought a positive influence on the protection of the marine environment (Oral 2015: 361–362). Likewise, the RFMOs have made a positive and major contribution in the field of fisheries (Churchill and Lowe 1999: 23–24) despite the many challenges faced with respect to regime participation, allocation of the total allowable catch and unregulated fishing (Molenaar 2003). While such institutional measures are largely effective in the region in which it operates among parties, the greatest challenge faced by RFMOs is the enforcement of conservation measures adopted in the high seas against non-parties (Gillespie 2011: 446). In response to this challenge, the growing attention towards port state enforcement measures provides a possible solution to this debacle and can help supplement the efforts by RFMOs to promote the conservation of living resources (Palma-Robles 2016: 151–152).

The role of civil societies and industry should also be acknowledged as they form part of the general institutional framework and help shape the direction of marine environmental protection. Non-governmental organizations (NGOs) such as the International Union for Conservation of Nature and Natural Resources (IUCN),[6] the

[6] It is pertinent to note that the IUCN is a 'hybrid organization' with representation from governments, governmental agencies, non-governmental organizations, and groups of experts and scientists (Willetts 2011: 72–73). Recently, the IUCN was treated by ITLOS as an 'intergovernmental organization' and invited to participate in the proceedings of the *Request for an Advisory Opinion Submitted by the Sub-Regional Fisheries Commission* through the submission of a written statement (see Order 2013/2 dated 24 May 2013, Case No. 21 of ITLOS), to which the IUCN obliged.

World Wildlife Fund for Nature (WWF), the Pew Charitable Trusts, and Greenpeace often feature at international fora to promote environmental protection and sustainability (Spiro 2007: 782–783). They are often granted observer status at various levels and invited to participate in workshops or consultative processes. Industry also plays a controlling role in the direction of marine environmental protection. With respect to representation from the industry, establishments such as the International Chamber of Shipping (ICS), the International Cable Protection Committee (ICPC), the Deep Seabed Mining Alliance (DSMA), the International Marine Minerals Society (IMMS) and the World Oceans Commission (WOC) serve as a platform to gather the interested business community together and represent them in dealing with the relevant organizations and other stakeholders. It should also be mentioned that groups of scientists and experts which collaborate and form networks, coalitions or initiatives such as Future Earth, the Deep Sea Conservation Coalition (DSCC) and the Deep Ocean Stewardship Initiative (DOSI) also play a vital role in furthering environmental causes through promoting marine environmental research and disseminating scientific findings and reports. The participation of a diverse-range of actors undoubtedly increases transparency, improves output quality and enhances overall legitimacy of the institutional decision-making process.

29.3 Institutional Interactions, Coordination and Cooperation

Due to the numerous institutional frameworks involved in the protection of the marine environment, the concern of fragmentation in the form of multiplicity of actors and efforts arises. Essentially, the concern is that there are overlaps in the functions of institutions as well as the measures and initiatives they adopt. While the concern of fragmentation is valid, neither is it the case that the current conditions of multiplicity in marine environmental protection are wholly dysfunctional, nor does it necessarily operate as an obstacle to effective marine environmental protection. In fact, this could mean that the matter at hand is regulated more extensively, such as designating an ecologically important marine area (taking the example of the Great Barrier Reef in Australia) as a marine protected area under national law, a ‘special area’ under MARPOL and a PSSA through the IMO, as well as a World Heritage site under UNESCO (Van Dyke and Broder 2015: 69–71). Even though numerous regimes operate in isolation (yet simultaneously) in the furtherance of their own cause, this in reality permits for various measures to be adopted pursuant to different mandates under several legal instruments with the aim of achieving a mutual objective. In other words, having more tools in the toolbox while on the one hand could give a cluttered, chaotic and inefficient impression, could also on the other hand be seen as providing more solutions or alternative options. In some cases of coinciding jurisdiction, enforcement could be more effective under one regime as opposed to another. Thus, intersecting regimes could in fact function in harmony and integrate to close gaps in between individual regimes which impedes the success of the overall objective of governance.

Thus, the notion that fragmentation in international law-making is inherently bad or undesirable and needs to be surmounted is rejected. Rather, the problem of fragmentation with respect to marine environmental protection only becomes an issue where there are competing activities where overlapping measures are adopted that are either inconsistent or in conflict with each other. Thus, what is most necessary in addressing the concern of fragmentation is enhancing coordination and promoting coordination between the various actors and institutions involved in marine environmental protection (Chap. 32). In this section, the institutional interaction between the various regimes, organizations and actors will be explored through examples of existing initiatives.

Within the UNCLOS set-up, the interactions between the three organizations are minimal. ITLOS remains as one of the avenues for dispute resolution between parties to UNCLOS and may serve to provide guidance in the form of advisory opinions when called upon. The ISA and the CLCS have a common denominator in the form of Articles 76 and 82 of UNCLOS. In this respect, it is important to fix the outer limits of the continental shelf beyond 200 nautical miles of coastal states in order to determine (with finality) what falls within the scope of the Area and is subjected to the common heritage of mankind principle. Further, coastal states are also required to make payments or contributions in kind for the exploitation of mineral resources of the continental shelf beyond 200 nautical miles. While there is interest in the outcome of the determination made by the CLCS, the ISA does not play an active role in that process.

With respect to the UN system, it can already be observed from the various actors involved as described above that the interactions between them are numerous. Each specialized agency operates within the scope of their own mandate which often overlaps with one another. One example is the IMO and the International Labor Organization (ILO) which have both adopted instruments on the training of seafarers. This potential conflict has been addressed through an agreement between both organizations, known as a Relationship Agreement between the IMO and the ILO, where both sides are invited to attend meetings of each other and initiated the avenue of joint committees to address common issues (Harrison 2011: 241, 259–260). The IOC of UNESCO, WHO and UNEP also work together on several endeavours, most notably the Global Ocean Observing System (GOOS) Programme, a global system for observations and analysis of the oceans to provide descriptions of the present state of the marine conditions and future predictions. Within the UN system, the tasks performed by the UN Secretariat and UNGA help circumvent any potential conflict as well as to coordinate initiatives that are proposed or carried out. In this respect, the role of DOALOS and the advisory function of GESAMP deserve special mention as these are the mechanisms that ensure that activities within the UN family are coordinated and optimized. Thus, while there is numerous functional overlap and multiplicity in efforts, potential conflicts are minimized and dealt expeditiously.

Turning to the interaction between UNCLOS and the UN system, it can be gleaned from the above that the latter plays a vital role in shaping the former. In fact, it is DOALOS that serves to coordinate the SPLOS meetings and performs other secretarial functions for UNCLOS. More importantly, there is particular interaction between the ISA and the UN. In this respect, reference is made to the UN-Oceans mechanism which came into existence through an ICP recommendation. In the 2003 Resolution on the oceans and the law of the sea (A/RES/58/240), UNGA called for the establishment of 'an effective, transparent and regular inter-agency coordinating mechanism for issues relating to oceans and seas within the United Nations system'. As a result, the Oceans and Coastal Areas Network (UN-Oceans), a new inter-agency mechanism for coordination and cooperation on issues relating to oceans and coastal issues was created (A/RES/59/24) and has met annually since 2005. In the 2013 Resolution on the oceans and the law of the sea (A/RES/68/70), the revised scope of UN-Oceans was approved and reads as follows: 'UN-Oceans is an inter-agency mechanism that seeks to enhance the coordination, coherence and effectiveness of competent organizations of the United Nations system and the International Seabed Authority, within existing resources, in conformity with the United Nations Convention on the Law of the Sea, the respective competences of each of its participating organizations and the mandates and priorities approved by their respective governing bodies'. Conversely, the interaction between the UN and the CLCS is limited to secretarial functions. Thus, conflict between UNCLOS and the UN system is kept at a minimal level. Further, certain non-parties to UNCLOS such as regional or international organizations may approach ITLOS in accordance with Annex VI or Annex IX of UNCLOS under specific circumstances (Roach 2016: 90). The *Request for an Advisory Opinion Submitted by the Sub-Regional Fisheries Commission (Request for Advisory Opinion submitted to ITLOS, Case No. 21, 2015)* is a good illustration of this.

The greatest challenge for marine environmental protection lies within the initiatives taken beyond UNCLOS and the UN system. This involves conflicts arising from interaction between actors and institutions within that category itself, and between actors and institutions from that category with those within the UNCLOS and UN system. The arduous task of identifying each and every conflict is near impossible and is not the purpose of this contribution. Due to space constraints, only several illustrations can be given to highlight the convoluted interactions. One good example is the cross-sectoral relationship between the RSPs and the RFMOs (Tetzlaff 2016: 116). In this respect, the OSPAR Commission and the NEAFC concluded a Memorandum of Understanding in 2008 in which both organizations agreed to, inter alia, 'discuss jointly their respective concerns over the management of human activities that impact on the marine environment and the living marine resources in the North-East Atlantic including in areas beyond national jurisdiction and possible actions and measures to address them', 'develop a common understanding of the application of the precautionary approach/principle' and 'cooperate regarding marine spatial planning and area management'. Similarly, the CCAMLR entered into cooperative 'Arrangements' with the CCSBT in 2015 and SPRFMO in 2016 respectively to facilitate exchange of scientific information as well as to cooperate to harmonize approaches in areas of mutual concern.

There are also numerous examples in which cooperative arrangements have been made between UNCLOS organizations with actors and institutions beyond UNCLOS and the UN. For instance, the Memorandum of Understanding in 2010 between the ISA and ICPC and the recent Memorandum of Understanding in 2016 between the ISA and the IHO which effectively paves the path to inter-agency cooperation. Similarly, there are numerous instruments between UN specialized agencies and other international organizations such as the early Agreement of Cooperation between the IMO and OSPAR in 1998 to consult each other on matters of common interest, as well as the Memorandum of Understanding between the IOC of UNESCO, UNEP and IAEA to facilitate capacity-building in member States to improve their ability to access, manage and protect marine environments. The interactions between UNEP and the RSPs as well as between FAO and the RFMOs are also prime examples of cooperation and coordination efforts in marine environmental protection. The various other treaties which influence marine environmental protection also work together with each other on a recurrent basis. One example is the numerous joint work programmes with other biodiversity related treaty bodies such as CITES, Ramsar and CMS (Harrison 2015a: 75). Indeed, the various 'MEAs [Multilateral Environmental Agreements] with their conferences of parties, subsidiary bodies and secretariats have generally been successful in providing a non-bureaucratic and dynamic framework for environmental cooperation' (Ulfstein 2007: 889).

Finally, the interactions between institutions and civil society need to be demonstrated. The importance of NGOs and their participation in international law-making through consultation and cooperation is gaining increasing traction. While the extent of their involvement is usually restricted in scope and limited to specific subject areas, they play an important role in advocating for progressive norm-setting in marine environmental protection (Beckman 2013: 425–426; Peet 1994; Barnes 1984; Levy et al. 1993: 409–410). The influence of industry and scientific communities in shaping law-making should also be recognized. In this respect, it should be noted that the ISA has granted observer status to these stakeholders: WWF, Pew Charitable Trusts and Greenpeace (NGOs), ICPC and the International Association of Drilling Contractors (industry), and DSCC and DOSI (scientific communities).

The institutionalization of information exchange between treaty bodies, the execution of memoranda of understanding, the carrying out of joint action plans, and the creation of collaborative expert working groups play an important role in coordinating efforts and promoting cooperation among regimes and actors in environmental law-making (Wolfrum and Matz 2003: 159–175). While fragmentation remains a valid concern due to the high number of organizations and actors involved in various areas, the adverse consequences arising from it (i.e. overlapping and directly conflicting measures taken by the wide range of actors and inefficiencies in terms of resources) may be averted through enhanced cooperation at all levels through the mechanism explained earlier. From the above examples, there is ample evidence that these mechanisms can work. Furthermore, the positive impacts on the environment arising through multiplicity of actions (i.e. comprehensive and meticulous measures adopted by numerous regimes and thoroughness in coverage) can be appreciated. Accordingly, the future of ocean governance and protection of the marine environment will to a large extent depend on managing the adverse effects of fragmentation through enhanced cooperation and improving transparency in decision-making (Chap. 32).

29.4 Conclusion and Perspectives

The institutional dynamics of environmental governance is multilayered and intricate (Hey 2007: 753). This chapter has demonstrated the complexity surrounding marine environmental protection. In this respect, several conclusions may be observed. First, while UNCLOS is the 'constitution of the oceans' and remains the starting point for all aspects pertaining to ocean affairs, not much development with respect to the law of the sea and marine environmental protection (with the exception of the deep seabed mining regime and the contribution of ITLOS) takes place within its institutional framework. Second, the UN system, in particular the UNGA, performs the most crucial role with respect to the development of ocean governance and marine environmental protection. Through its various organs, institutions and related agencies, the UN system comprehensively covers all current and emerging concerns relating to the marine environment. Hence, UNGA remains the 'solid core and serves as the coordinator of activities and the originator of developments in the law of the sea' (de La Fayette 2006: 74). Third, even though the UN carries the weight of developing the law of the sea, it often does so in a deferred capacity in the place of the UNCLOS regime because of the political interest involved in key matters pertaining to the oceans and the fact that the UNGA commands wider global participation. Thus, while decisions pertaining to the law of the sea are negotiated through the UNGA, the output instruments are often linked and placed under the UNCLOS regime which has ample room for evolution depending on the needs and interests of the international community (Boyle 2006: 61–62). Fourth, a substantial amount of support in furthering the cause of marine environmental protection comes from outside the UN family where the UN or its related agencies have little influence over its shape and direction. Nevertheless, the UN still maintains inroads in creating the framework through setting up or encouraging regional initiatives. Fifth, the initiatives taken outside UNCLOS and the UN system, although largely autonomous and not subservient to the latter, always remain guided by (and to some extent restricted to) the objectives and purposes defined by the latter. Sixth, the concern of fragmentation and the resulting multiplicity and overlap arising as a result of the wide range of institutions is a valid one, but questions of inefficiency and ineffectiveness can be reduced through cooperation and coordination efforts. Lastly, while numerous measures can be taken at the global level by international institutions, it is the regional initiatives such as efforts taken by RSPs and RFMOs as well as directives issued at the European Union level (Ringbom 2015: 125–126; Boyes and Elliot 2014), and national institutional arrangements (i.e. particularly coastal states as well as port states) that play the most important role in marine environmental protection and the conservation of marine resources since they are the ones who implement, apply and enforce the measures adopted at the international level (Franckx 1998: 322; Redgwell 2007: 923).

Nevertheless, the role of these international organizations in this respect should not be underestimated. As observed by Churchill and Lowe, the 'recommendations and conventions which they make or initiate, the constant and detailed surveillance which they exercise over maritime matters, and the reports which they prepare, all exert a great influence on States' perceptions of what is happening in the seas. They mould the formulation of national maritime policies, and hence State practice and the development of international law' (1999: 24). Further, international organizations also function as an important 'mechanism for securing international cooperation in conservation of marine living resources and regulation of marine pollution' (Tanaka 2015a: 53). In the age of ocean governance where greater emphasis is being placed on integrated management, as well as the increasing interest in deep sea exploration and exploitation in areas beyond national jurisdiction, the instances where international environmental law will mix with traditional law of the sea obligations will only increase (Rothwell 2007: 1023). It is expected that the institutional framework within the law of the sea would stand to benefit as a result of this increased interaction, especially with respect to the protection and conservation of the marine environment as well as ocean governance in general.

References

Abdulla A, Obura D, Bertzky B, Shi Y (2013) Marine natural heritage and the World Heritage list: Interpretation of World Heritage criteria in marine systems, analysis of biogeographic representation of sites, and a roadmap for addressing gaps. IUCN, Gland

Barnes J (1984) Non-governmental organizations: Increasing the global perspective. Mar Policy 8:171–183

Barnes R (2016) The proposed LOSC implementation agreement on areas beyond national jurisdiction and its impact on international fisheries law. Int J Mar Coastal Law 31:1–37

Beckman D (2013) Marine environmental biology and conservation. Jones and Bartlett Learning, Burlington

Birnie P, Boyle A, Redgwell C (2009) International law and the environment, 3rd edn. Oxford University Press, Oxford

Boyes S, Elliot M (2014) Marine legislation: The ultimate 'horrendogram'—International law, European directives and national implementation. Mar Pollut Bull 86:39–47

Boyle A (2006) Further development of the 1982 Convention on the law of the sea: mechanisms for change. In: Freestone D, Barnes R, Ong DM (eds) The law of the sea: progress and prospects. Oxford University Press, Oxford

Boyle A (2007) The environmental jurisprudence of the International Tribunal for the Law of the Sea. Int J Mar Coastal Law 22:369–381

Boyle A (2012a) Law of the sea perspectives on climate change. Int J Mar Coastal Law 27:831–838

Boyle A (2012b) Climate change and international law: a post-Kyoto perspective. Environ Policy Law 42:333–343

Boyle A, Chinkin C (2007) The law making of international law. Oxford University Press, Oxford

Braethan J (1998) International co-operation on fisheries and environment. TemaNord, Copenhagen

Churchill R (2015) The LOSC regime for protection of the marine environment: fit for the twenty-first century? In: Rayfuse R (ed) Research handbook on international marine environmental law. Edward Elgar Publishing, Cheltenham

Churchill R, Lowe V (1999) The law of the sea, 3rd edn. Manchester University Press, Manchester

Craig RK (2012) Comparative ocean governance: Place-based protection in an era of climate change. Edward Elgar Publishing, Cheltenham

Dixon T, Garrett J, Kleverlaan E (2014) Update on the London Protocol: developments on trans-boundary CCS and on geoengineering. Energy Procedia 63:6623–6628

Doelle M (2006) Climate change and the use of the dispute settlement regime of the Law of the Sea Convention. Ocean Dev Int Law 37:319–337

Fennel K, VanderZwaag DL (2016) Ocean acidification: Scientific surges, lagging law and policy responses. In: Warner R, Kaye S (eds) Routledge handbook of maritime regulation and enforcement. Routledge, New York

Franckx E (1998) Regional marine environment protection regimes in the context of UNCLOS. Int J Mar Coastal Law 13:307–324

Freestone D, Salman SMA (2007) Ocean and freshwater resources. In: Bodansky D, Brunee J, Hey E (eds) The Oxford handbook of international environmental law. Oxford University Press, Oxford

Gillespie A (2011) Conservation, biodiversity and international law. Edward Elgar Publishing, Cheltenham

Haas P (1989) Do regimes matter? Epistemic communities and Mediterranean pollution control. Int Organ 43:377–403

Harden-Davies H (2016) Marine science and technology transfer: Can the International Oceanographic Commission advance governance of biodiversity beyond national jurisdiction. Mar Policy 74:260–267

Harrison J (2011) Making the law of the sea: a study in the development of international law. Cambridge University Press, Cambridge

Harrison J (2015a) Actors and institutions for the protection of the marine environment. In: Rayfuse R (ed) Research handbook on international marine environmental law. Edward Elgar Publishing, Cheltenham

Harrison J (2015b) The law of the sea convention institutions. In: Rothwell D, Elferink A, Scott K, Stephens T (eds) The Oxford handbook on the law of the sea. Oxford University Press, Oxford

Hey E (2007) International institutions. In: Bodansky D, Brunee J, Hey E (eds) The Oxford handbook of international environmental law. Oxford University Press, Oxford

Hulm P (1983) The regional seas program: what fate for UNEP's crown jewels. Ambio 12:2–13

IMO (2005) The new GESAMP: Science for sustainable oceans—a strategic vision for the IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Groups of Experts on Scientific Aspects of Marine Environmental Protection. IMO, London

IMO (2014) Implications of the United Nations Convention on the Law of the Sea for the International Maritime Organization: study by the Secretariat of the IMO (LEG/MISC8, 30 January 2014)

Jaeckel A (2017) The International Seabed Authority and the precautionary principle. Brill, Leiden

Jenisch U (2010) Renaissance des Meeresbodens—Mineralische Rohstoffe und Seerecht—Teil 1. NordÖR 10:373–382

Kachel M (2008) Particularly sensitive sea areas: the IMO's role in protecting vulnerable marine areas. Springer, Berlin

Karim MS (2015) Prevention of pollution of the marine environment from vessels: the potential and limits of the International Maritime Organization. Springer, Heidelberg

de La Fayette L (2006) The role of the United Nations in international ocean governance. In: Freestone D, Barnes R, Ong DM (eds) The law of the sea: progress and prospects. Oxford University Press, Oxford

Leary D, Esteban M (2009) Climate change and renewable energy from the ocean and tides: calming the sea of regulatory uncertainty. Int J Mar Coastal Law 24:617–651

Levy MA, Keohane RO, Haas PM (1993) Improving the effectiveness of international environmental institutions. In: Haas PM, Keohane RO, Levy MA (eds) Institutions for the Earth: sources of effective international environmental protection. MIT Press, Cambridge
Lodge M (2015a) The deep seabed. In: Rothwell D, Elferink A, Scott K, Stephens T (eds) The Oxford handbook on the law of the sea. Oxford University Press, Oxford
Lodge M (2015b) Protecting the marine environment of the deep seabed. In: Rayfuse R (ed) Research handbook on international marine environmental law. Edward Elgar Publishing, Cheltenham
Lodge M, Johnson D, Le Gurun G, Wengler M, Weaver P, Gunn V (2014) Seabed mining: International Seabed Authority environmental management plan for the Clarion-Clipperton Zone—a partnership approach. Mar Policy 49:66–72
Makgill R, Linhares AP (2016) Deep seabed mining: key obligations in the emerging regulation of exploration and development in the Pacific. In: Warner R, Kaye S (eds) Routledge handbook of maritime regulation and enforcement. Routledge, New York
Markus T, Ginzky H (2011) Regulating climate engineering: paradigmatic aspects of the regulation of ocean fertilization. Carbon Climate Law Rev 4:477–490
Markus T, Singh P (2016) Promoting consistency in the deep seabed: addressing regulatory dimensions in designing the International Seabed Authority's Exploitation Code. Rev Euro Comp Int Environ Law 25: 347–362
Mensah TA (1999) The International Tribunal for the Law of the Sea and the protection and preservation of the marine environment. Rev Euro Comp Int Environ Law 8:1–5
Molenaar EJ (2003) Participation, allocation and unregulated fishing: the practice of Regional Fisheries Management Organizations. Int J Mar Coastal Law 18:457–480
Mossop J (2015) Reconciling activities on the extended continental shelf with protection of the marine environment. In: Rayfuse R (ed) Research handbook on international marine environmental law. Edward Elgar Publishing, Cheltenham
Nordquist MH, Rosenne S, Yankov A (eds) (1990) United Nations convention on the law of the sea 1982: a commentary, vol IV. Martinus Nijhoff Publishes, Dordrecht
O'Hagan AM (2016) Regulation of marine renewable energy. In: Warner R, Kaye S (eds) Routledge handbook of maritime regulation and enforcement. Routledge, New York
Oral N (2015) Forty years of the UNEP regional seas programme: from past to future. In: Rayfuse R (ed) Research handbook on international marine environmental law. Edward Elgar Publishing, Cheltenham
Palma-Robles MA (2016) Fisheries enforcement and the concept of compliance and monitoring, control and surveillance. In: Warner R, Kaye S (eds) Routledge handbook of maritime regulation and enforcement. Routledge, New York
Peet G (1994) The role of (environmental) non-governmental organizations at the Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO), and the London Dumping Convention (LDC). Ocean Coast Manag 22:3–18
Pfeiffer S (2006) The International Hydrographic Organization (IHO): how to successfully modernize an international organisation. In: Ehlers P, Lagoni R (eds) International maritime organisations and their contribution towards a sustainable marine development. Lit Verlag, Hamburg
Rayfuse R (2015) Regional fisheries management organizations. In: Rothwell D, Elferink A, Scott K, Stephens T (eds) The Oxford handbook on the law of the sea. Oxford University Press, Oxford
Redgwell C (2006) From permission to prohibition: the 1982 Convention on the Law of the Sea and protection of the marine environment. In: Freestone D, Barnes R, Ong DM (eds) The law of the sea: Progress and prospects. Oxford University Press, Oxford
Redgwell C (2007) National implementation. In: Bodansky D, Brunee J, Hey E (eds) The Oxford handbook of international environmental law. Oxford University Press, Oxford
Redgwell C (2012) UNCLOS and climate change. Am Soc Int Law Proc 106:406–409
Ringbom H (2015) Vessel-source pollution. In: Rayfuse R (ed) Research handbook on international marine environmental law. Edward Elgar Publishing, Cheltenham

Roach JA (2016) The role of global organizations. In: Warner R, Kaye S (eds) Routledge handbook of maritime regulation and enforcement. Routledge, New York
Rothwell D (2003) The International Tribunal for the Law of the Sea and marine environmental protection: expanding the horizons of international oceans governance. Ocean Yearbook 17:26–55
Rothwell D (2007) The contribution of ITLOS to ocean governance through marine environmental dispute resolution. In: Ndiaye TM, Wolfrum R (eds) Law of the sea, environmental law and settlement of disputes: Liber Amicorum Judge Thomas A. Mensah. Martinus Nijhoff Publishers, Leiden
Rothwell D, Stephens T (2016) The international law of the sea, 2nd edn. Hart Publishing, Oxford
Scott KN (2015) Geoengineering and the marine environment. In: Rayfuse R (ed) Research handbook on international marine environmental law. Edward Elgar Publishing, Cheltenham
Spiro P (2007) Non-governmental organizations and civil society. In: Bodansky D, Brunee J, Hey E (eds) The Oxford handbook of international environmental law. Oxford University Press, Oxford
Stephens T (2015) Ocean acidification. In: Rayfuse R (ed) Research handbook on international marine environmental law. Edward Elgar Publishing, Cheltenham
Stephens T, Rothwell D (2015) Marine scientific research. In: Rothwell D, Elferink A, Scott K, Stephens T (eds) The Oxford handbook on the law of the sea. Oxford University Press, Oxford
Tanaka Y (2015a) Principles of international marine environmental law. In: Rayfuse R (ed) Research handbook on international marine environmental law. Edward Elgar Publishing, Cheltenham
Tanaka Y (2015b) The international law of the sea, 2nd edn. Cambridge University Press, Cambridge
Tetzlaff K (2016) The role of regional organizations. In: Warner R, Kaye S (eds) Routledge handbook of maritime regulation and enforcement. Routledge, New York
Ulfstein G (2007) Treaty bodies. In: Bodansky D, Brunee J, Hey E (eds) The Oxford handbook of international environmental law. Oxford University Press, Oxford
UNESCO (2013) Marine world heritage: safeguarding the crown jewels of the ocean. UNESCO, Paris
Unterweger I (2015) International law on tuna fisheries management: is the Western and Central Pacific Fisheries Commission ready for the challenge? Nomos, Baden-Baden
Van Dyke JM, Broder SP (2015) International agreements and customary international principles providing guidance for national and regional ocean policies. In: Cicin-Sain B, VanderZwaag DL, Balgos MC (eds) Routledge handbook of national and regional ocean policies. Routledge, Oxon
VanderZwaag DL (2015) The international control of ocean dumping: navigating from permissive to precautionary shores. In: Rayfuse R (ed) Research handbook on international marine environmental law. Edward Elgar Publishing, Cheltenham
Wedding LM, Friedlander AM, Kittinger JN, Watling L, Gaines SD, Bennett M, Hardy SM, Smith CR (2013) From principles to practice: a spatial approach to systematic conservation planning in the deep sea. Proc R Soc B 280:1–10
Willetts P (2011) Non-governmental organizations in world politics: the construction of global governance. Routledge, Oxon
Wolfrum R, Matz N (2000) The interplay of the United Nations convention on the law of the sea and the convention on biological diversity. In: Frowein JA, Wolfrum R (eds) Max Planck yearbook of United Nations law. Kluwer Law International, The Hague
Wolfrum R, Matz N (2003) Conflicts in international environmental law. Springer, Heidelberg

Chapter 30
International Principles of Marine Environmental Protection

Gerd Winter

Abstract This contribution starts with clarifying the role principles play as a form into which propositions of environmental protection are brought. It is submitted that the role principles play in political-legal practice, in legal reasoning and in positivist texts should be distinguished. On this basis various contents of international principles of marine environmental protection are discussed, including cooperation, "neminem laedere", precaution, environmental impact assessment, marine scientific research, transparency/participation, sustainability, and common heritage of mankind.

Keywords General principles of international law • Principles of policy • Principles of law • Marine environmental protection • Environmental impact assessment • No harm rule • Precaution

30.1 Introduction

It is easy to posit that such and such proposition is a principle. For instance, few would object that cooperation, liability for damage, common heritage of mankind, sustainability, precaution, participation, transparency are principles that should guide the uses of natural resources. The question however is what that means in legal terms, in other words if and to what extent a proposition has a binding character. Before elaborating on the content of principles (Sect. 30.3) it is therefore advisable to clarify their legal status (Sect. 30.2). This is no simple task because there is hardly a term which has been given so many different meanings as "principle".

G. Winter
University of Bremen, Bremen, Germany
e-mail: gwinter@uni-bremen.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_30

30.2 The Legal Status of Principles

It is submitted that clarity can be reached if the term principle is construed in three different contexts, a pragmatic, a doctrinal, and a positivist. In the pragmatic context the role principles play in political and legal practice is addressed. In the doctrinal context their role in the interpretation of the law is determined. And in the positivist context the term principle may signify anything the law-maker prescribes.

30.2.1 Principles in a Pragmatic Context: From Policy to Law

Political discourses often refer to "principles" when new ideas are recommended for law reform. Such propositions are policy principles without legally binding effect. By contrast, legal principles have binding effect if they are based in legal acts or court judgments and meant to be binding.

Principles of policy often emerge from political debate. A major example in the environmental area is the principles of environmental protection which were debated in the run-up to the UN Conference on Environment and Development at Rio of 1992 and agreed as policy principles in an "Agenda 21". An example for the legalization of a policy principle is that of precaution. It was introduced into German law in 1974 as a result of a clear political priority of a new—the social and the free democrats'—coalition. In the alternative legal principles may emerge from social practice, common sense and good reason of the legal profession. This is their very source in common law systems. An example is the introduction of strict liability by the House of Lords for those uses of land that go beyond the "ordinary" or "natural", a rule that to the judges "seems but reasonable and just" and is claimed to correspond to earlier rulings.[1] Such judge-made law is also well known in the civil law systems as a corollary to statutory law.[2] Usually practice and common sense will first be framed and propagated as principles of policy before a court takes the step to accept it as a principle of law (Esser 1964: 137).

Against the Neo-Kantian view of strict differentiation between rules of law and social norms the world of rules is not simply bifurcated. In between policy and legal principles an area of discourse and propositions exists that ressembles a chameleon because it changes its colours of being policy or law depending on circumstances. Propositions within that area are not binding but nevertheless a remote source of law, remote meaning that they are by courts "referred to", "kept in mind", "invoked", "reminded" or else, thus not taken as binding but neither taken as purely uncommittal.

---

[1] Rylands v. Fletcher (1868) 3 LR HL 330 where Lord Cairns suggests the terms natural/ non-natural citing Justice Blackburn for the reference to reason and justice.

[2] For an in-depth analysis of the relationship between principles and codified law see Esser 1996, p. 141 et seq. See also his observation (p. 223) that there has emerged a convergence of continental axiomatic and Anglo-American topical thought.

They could be called principles of emerging law,[3] or proto-legal principles as I will call them.

Sometimes such principles are framed in programmatic documents signed by state representatives without being meant to be binding. They then figure as what is called soft law. As already mentioned, a wealth of "soft law" principles is contained in the outstanding product of the 1992 Rio Conference, the Agenda for the twenty-first century (Agenda 21 1992).

Even if a principle is contained in a law or treaty it is not necessarily a principle of law. The lawmakers must have intended to give the principle binding effect. They may instead wish to give guidance rather than orders in what direction the law shall develop. They will indicate this by calling a proposition a task, a value, an objective, or else, or express it in particularly vague language. For instance, sustainable development is called an objective of the European Union in Art. 3 Treaty on the Functioning of the European Union (TFEU). With its broad sense of balancing ecological, social and economic concerns it lacks determinable content. It is therefore not a legal principle but can nevertheless be conceived as a proto-legal principle of EU law.

In the reasonings of international courts proto-legal principles play a particularly important role because binding contract or customary law that is ready to decide cases is often scarce. International courts are therefore more than national courts inclined to apply or even establish proto-legal principles. An example is the often cited elaboration of the sustainability "concept" in *Gabčíkovo* where the ICJ opines as follows:

> Throughout the ages, mankind has, for economic and other reasons, constantly interfered with nature. In the past, this was often done without consideration of the effects upon the environment. Owing to new scientific insights and to a growing awareness of the risks for mankind—for present and future generations—of pursuit of such interventions at an unconsidered and unabated pace, new norms and standards have been developed, set forth in a great number of instruments during the last two decades. Such new norms have to be taken into consideration, and such new standards given proper weight, not only when States contemplate new activities but also when continuing with activities begun in the past. This need to reconcile economic development with protection of the environment is aptly expressed in the concept of sustainable development.[4]

That a "need" shall be "aptly expressed" in a "concept" escapes any logic of separating factual and normative propositions. In spite of—or just because of its elusiveness this reasoning does have some legal bearing—the one (I believe) here characterized as proto-legal.

The transformation of principles of policy via proto-legal principles into principles of law displays a "constructivist" potential of the international legal discourse (Koskenniemi 2000: 397). It is submitted that this potential deserves to be better reaped given the present state of the environment.

---

[3] See Lang 1999, p. 171 who suggests that "three different categories of principles of a decreasing legally binding nature" should be distinguished, i.e. principles of existing law, principles of emerging law, and potential principles of law.

[4] Gabčíkovo Nagymaros Case 1997, p. 75.

30.2.2 Principles in Legal Doctrine: From Basics to Specifics

Doctrinal literature is sometimes entitled "Principles of…", such as of international law (Brownlie 2008) or of international environmental law (Sands et al. 2012). In that respect "principles" only means fundamentals, essentials, etc. for didactic purposes, with a view to concentrate on the most important matter and leave details for further study.

Within the realm of binding law principles and rules are often opposed as different compositions of the law. While principles are formulated in abstract terms and are open for more precise elaboration rules are concrete and determined. Principles are basic propositions "behind" a diversity of rules and influence their interpretation and application. They enhance the normative power of rules, advise how to interpret them, help to fill regulatory gaps, guide discretionary powers, and inform about necessary exceptions to a rule.[5]

Some legal philosophers consider as a major characteristic of principles that they are subject to balancing against other principles while rules are conclusive (Dworkin 1977/1978: 24; Alexy 1994). It is however doubtful if this is a helpful distinction. Principles can be both open or conclusive. There can be principles committed to one objective or value and thus subject to compromise if conflicting with opposing principles in a concrete case (Dworkin 1977/1978: 25–28). But some principles may nevertheless be uncompromising, especially if they are of extremely high value, such as the prohibition of slavery and of torture. A principle may also embrace and even command the balancing of interests, such as the principle of proportionality insofar as it requires to weigh up purposes and means.

If opposing principles are balanced there is no general norm establishing absolute cardinal or even ordinal ranks between conflicting principles. If the law does not establish priorities all principles are equal in an abstract sense. The relative weight of principles will then change with the given individual circumstances and can therefore only be determined in the concrete case. One guidance (or meta-principle) recognized in such circumstances is that the more one principle will be impaired by a measure the weightier must the counter principle be if it shall prevail (Alexy 1994: 146).

Often rules are used to take a decision about a conflict of principles in a specific area of the law. For instance, the rule of strict environmental liability implies a decision in favour of environmental protection and against freedom of investment. A rule may also provide for a balancing of concerns that represent diverging principles. As a major example, human rights are construed so that a measure encroaching on the basic right (which represents eg the principle of property protection) can be justified by an overriding public interest (which represents e.g. the principle of environmental protection), proportionality serving as a means to accommodate the opposing interests.

[5] For more functions of principles, e.g. in relation to extra-legal negotiation and self-regulation, see Verschuuren 2003, pp. 38 et seq.

Rules may also provide that exceptions are possible thus opening a door for concerns which represent a counter principle to the principle which primarily stands behind the rule.

Further, the rule may characterize one of the competing concerns to be of preponderant importance. Then, the principle has, in the concrete case, a *prima facie* priority over conflicting principles. This has among others effects on the distribution of the burden of proof between parties. In international trade law, for instance, free international trade in products is (disputably) considered as a principle of fundamental value. Trade restrictions may be based on environmental protection as the counter principle. A state taking such measures is regarded to bear the burden of proof which reflects the lesser importance conceded to environmental protection. It must be noted though that recent practice has somewhat alleviated the defendant's burden of proof by requiring the plaintiff to presenting *prima facie* evidence against the environmental protection measure (Beef Hormones Case 1998, WTO AB no. 104).

30.2.3 Principles in a Positivist Context

30.2.3.1 Overview

As said, principles in the pragmatic context are either policy, proto-legal or legally binding. Principles in the doctrinal context characterize the role they play in legal methodology. Principles in the positivist sense are those who have been termed as such by a state based authority, be it by a constitution, legal act, court ruling or international treaty. The positivist qualification of a principle does not exclude to reason that a proposition termed a principle by legal command is not a principle in the pragmatic or doctrinal sense, and vice versa, that a proposition not termed as such by law is nevertheless a principle in the pragmatic or doctrinal sense.

An example shall be given considering the sources of international law. International law stems from one or more of the four sources of international law:

1. an international treaty, in other words the consensual agreement between parties (Art. 38 (1) (a) ICJ Statute)
2. international customary law, which rests on two conditions, i.e. a general practice which is accepted as law (Art. 38 (1) (b) ICJ Statute)
3. the "general principles of law recognized by civilized nations" (Art. 38 (1) (c) ICJ Statute)
4. the decisions of international organizations (IOs) that are endowed with law-making powers[6]

[6] Binding decisions of international organizations are often categorized as emanating from treaties and thus being (indirect) treaty law. However, such categorization would ignore that many international organizations have established themselves as (de facto) powerful public authorities. Cf. v. Bogdandy/ Dann/ Goldmann 2010, pp. 30 et seq.; Bodansky 1999.

Table 30.1 Principles in international law

Codified context	Doctrinal context	Pragmatic context
1. Treaty	Principle ↓ Rule	Policy principle
2. Custom		Proto-legal principle
3. General principle of law recognized by civilized nations		Legal principle
4. Decision of International Organisation		

Thus a treaty, customary provision or IO-decision may, for instance, lay down—in the doctrinal sense—the principle of cooperation between neighboring states and specify it through a set of concrete rules. The same can occur with "general principles of law recognized by civilized nations" although the codified term "principle" seems to indicate that no—concrete—rules can be derived from the third source. However, taking into account the difference in terminology of codified texts and of legal doctrine a principle as defined in Art. 38 (1) (c) ICJ Statute can well be either a principle or a rule in the doctrinal sense. The following table is meant to clarify the relationship between codified and doctrinal contexts, taking also the pragmatic context into consideration (Table 30.1).

The third and fourth of the sources have the potential of working more proactively than the other ones. Concerning the law of international organizations the acceleration of law-making, as for instance through voting by "consensus", majority, and possible opt out (Hey 2007: 755 et seq.), is often the very reason why such organization was established. "General principles of law recognized by civilized nations" may emerge more rapidly than customary law because they are based on widely shared *opinio iuris* and do not presuppose a general practice (*consuetudo*) of states.

30.2.3.2 General Principles of Law

General principles of law must in our context be looked at more closely because of their use of the term principle. As mentioned the source is called "general principles of law recognized by civilized nations". Such recognition may be expressed in national laws or in international treaties. While reference to national laws have prevailed in the past, international treaties have recently played a more important role as material for abstracting common principles (Verdross and Simma 1984: 386–387; Bassiouni 1989/1990: 772; Daillier et al. 2009: 384–386). The ICJ when ascertaining such principles has exercised a sometimes only cursory comparison of legal systems combined with references to legal logic and general jurisprudence (Cassese 2005: 190, 192). This oscillation between existing law and law making reflects the history of Art. 38 (c) ICJ Statute which is that the provision laid out a compromise between two groups of drafters, those who wanted to bind courts to the positive law of states, and those who advocated powers of courts to create new law from good reason (Cassese 2005; Jacoby 1997: 175–178).

The reference in Art. 38 (1) (c) ICJ Statute to “civilized nations” has been suspected to allow misuse for placing capitalist principles (such as property protection) above socialist and Third World principles which caused the socialist doctrine to deny altogether that principles of law can be a source of its own (Tunkin 1974: 198–203; Paech and Stuby 2013: 469–472). This concern has today become unfounded (Paech and Stuby 2013: 468). It could also be that the reference has covertly served to exclude reference to legal orders that do not adhere to a minimum standard of friendly relations and human rights. The question in our context would be if the clause could serve to exclude from reference those legal orders which do not adhere to a minimum standard of preserving the natural resources of human life.

One trajectory of principles development often to be found in international court reasoning can be called generalization from particular treaties. A principle laid down in sectoral or regional treaties may be transferred to similar others thus being generalized and gaining a status independent of its origin (Wolfrum 2010, paras. 41–53). For instance, the principle (which may more precisely be called a rule in the doctrinal sense) that major projects must be subjected to prior environmental impact assessment stems from the Europe centered Espoo Convention and further developed into a global “general principle of law recognized by civilized nations” and even international customary law (see below II. 4). In future, the three columns of the—likewise regional—Aarhus Convention, transparency, participation and access to justice, may take the same route (see below II. 6).

Content-wise, “general principles of law recognized by civilized nations” have traditionally been modeled on interactions between equal individuals promoting their individual rights, such as principles of reparation of wrongful acts, undue enrichment, estoppel/good faith, burden of proof, res iudicata, etc. (Verdross and Simma 1984: 390–394; Müller and Wildhaber 2000: 39–59; Cheng 2006; Lauterpacht 1927). They were found to be appropriate also in relation to interactions between states when defending or promoting their subjective rights to equal sovereignty.

Apart from such civil law-like constellations, in our context of environmental law it is highly momentous whether “general principles of law” can also be drawn from domestic law or international treaties of an interventionist character. For many national legal systems and international treaties stipulate certain principles of environmental protection that restrict rights of individuals and sovereign rights of states, respectively. In a world of withering natural resources it would be apposite to upgrade such interventionist propositions to “general principles of law of civilized nations”.

30.2.3.3 General Principles of International Law

A further category of international law is called general principles of international law. There is a multitude of opinions about their legal character. Some authors understand them to be identical with general principles of law recognized by civilized states under Art. 38 (1) (c) ICJ Statute (Bassiouni 1989/1999) or a subcategory

(Mosler 1976: 44) or separated from the latter (Cassese 2005: 188). In any case it seems to be common ground that general principles of international law do not constitute an additional (fifth) source of international law but add quality to norms emerging from one or all of the traditional four sources. They are thus principles in the doctrinal sense.

The *differentia specifica* of general principles of international law is their fundamental importance. This was clearly expressed in the *Nicaragua* case, where the ICJ held that fundamental principles (*in casu*: the prohibition of using force) can be common to both treaty and customary law and guide their further development:

> […] the Charter gave expression in this field to principles already present in customary international law, and that law has in the subsequent four decades developed under the influence of the Charter, to such extent that a number of rules contained in the Charter have acquired a status independent of it. The essential consideration is that both the Charter and the customary international law flow from a common fundamental principle outlawing the use of force in international relations (Nicaragua case 1986, ICJ no. 181).

The court here construes the "common fundamental principle" as being independent of the Charter. But this does not necessarily imply that that principle of international law constitutes a self-standing source of international law. It should rather be construed as a case of the third source category.

This means that general principles of international law can be a qualification not only of treaty and customary law but also of "general principles of law recognized by civilized nations", especially where such principles are derived from international treaty law rather than from domestic laws. But not all of the "principles of law of civilized nations" are of fundamental importance. Some rather reflect legal logic, legal methodology, or more technical issues. Vice versa, the very fundamentality of a general principle of international law may allow it that less scrutiny is applied in comparing and generalizing laws as would be required for abstracting "general principles of law of civilized nations".

As the term "general" has many different meanings (such as overarching, abstract, common, etc.) the "general principles of international law" might be better characterized as being the "fundamental (or essential) principles of international law", while the "general principles of law" in the sense of Art. 38 (1) (c) ICJ Statute may rather be labeled "common principles of law". The system of principles and rules can thus be completed as in Table 30.2.

The fundamental importance of the general principles of international law justifies it to conceive them as an emerging world constitution. In that vein many of those principles belong to the category of peremptory norms, or *ius cogens* (Cassese 2005: 64–67). In addition they act like any other principle in the legal doctrinal sense, having the function of stressing the importance of principles and rules laid down in treaty, customary, IO and "common" law, interpret them and fill possible gaps of the same.

There are two deeper reasons which justify the fundamental character of such general principles. One is sovereignty, the other morality. Sovereignty is the core structure of the international system since the Westfalian peace. It is the basis of fundamental principles like the equality of states, non-intervention into internal

Table 30.2 Principles in international law completed

Codified context	Doctrinal context	Pragmatic context
Treaty	Policy principle	General (or fundamental) principle of international law
Custom		
General principle of law recognized by civilized nations (suggested: common principle)	Proto-legal principle	Principle
Decision of International Organisations	Legal principle	Rule

affairs, and the prohibition of aggression. Morality is the basis of fundamental human rights such as the prohibition of slavery, torture, rape and crimes against humanity (Cassese 2005: 46–67).

Referring to international environmental law the fundamentality of the living conditions of humanity should be a sufficient justification for developing general principles also of international environmental law. Unfortunately international courts and scholars have hardly ventured into this area.

30.3 The Content and Status of Legal Principles in Marine Environmental Law

We now turn to applying the categories of "principles" to a sectoral policy, marine environmental protection, with the double purpose to determine the content and the legal status of the related propositions. The following propositions shall be discussed: Cooperation, *neminem laedere*, precaution, environmental impact assessment, freedom of marine scientific research, transparency and participation, economic uses of the sea, and common heritage of mankind. As a general observation it should be noted that the stricter the content of a principle is the more difficult it becomes to acknowledge it to be binding, and vice versa, the less binding the principle is the stricter its content can become.

30.3.1 Cooperation

One common principle of international law in general as well as of marine environmental law in particular is the obligation of states to cooperate. It has often been stated by international courts such as by the International Tribunal for the Law of the Sea (ITLOS) which held "that the duty to cooperate is a fundamental principle in the prevention of pollution of the marine environment under Part XII of the Convention and general international law" (MOX Plant Case, ITLOS 2001, para.

82). As exemplified in the same case such cooperation consists of the coordinated investigation and monitoring of causes and adverse effects, the exchange of information and the elaboration of preventive and remedial measures (MOX Plant case, ITLOS 2001, Prescription 1). In another case ITLOS stressed the duty to cooperate and make efforts to reach an agreement (Southern Bluefin Tuna case, ITLOS 1999, para. 90 Prescriptions 1. (e) and (f)). The duty originated in litigation on bilateral conflicts between states but has been extended to common goods that require the cooperation between many states, and between states and with and within international organizations.

There are many instances of such cooperation duties in UNCLOS. One authoritative statement is contained in Art. 197 which reads:

> States shall cooperate on a global basis and, as appropriate, on a regional basis, directly or through competent international organizations, in formulating and elaborating international rules, standards and recommended practices and procedures consistent with this Convention, for the protection and preservation of the marine environment, taking into account characteristic regional features.[7]

While these duties are well established and can be regarded as forming rules of international customary law, they fall short of being armoured with tailored means of enforcement. If the duty is disrespected this can be stated by a court, but remedies are only available according to general international customary law, including compensation for damage (which hardly arises out of procedural failure such as non-cooperation) and the right to take countermeasures, which however are not easy to define.

30.3.2 Neminem Laedere

Another important principle is the no-harm imperative. Its elaborate preconditions and effects allow to call it a rule. As such it is recognized as binding, having the status of international customary law (Epiney and Scheyli 2000: 104 et seq.). Its scope is however narrow, because it only covers transboundary (i.e. not internal) causation chains, and damage that is serious and established by clear and convincing evidence. The effectiveness of this rule is weak, because according to ruling opinion it contains only a duty of conduct, not of effect, which means that states bear a due diligence obligation to take preventive measures but no absolute obligation to prohibit damage. In consequence, if a damage has been caused and compensation is at stake, states are not strictly liable, but only if they failed to practice due diligence (Birnie et al. 2009: 143 et seq., 216 et seq.).

UNCLOS has somewhat specified and extended the scope of the no-harm rule. While focusing on marine pollution it identifies certain types of causation

[7] For further duties see Arts. 117 (living resources in the High Seas), 199 (contingency plans for pollution incidents), 208 (4) (sea-bed activities), Art. 210 (4) (dumping), 211 (1) (pollution from vessels), 212 (3) (pollution from and through atmosphere), 226 (2) (inspection of foreign vessels), 235 (3) (liability for environmental damage). See further Tanaka 2015, p. 278.

processes, including from land-based sources, the air, dumping, vessels, and installations (Art. 194 UNCLOS; Rothwell and Stephens 2016, ch. 15). Addressing the marine environment in general, UNCLOS includes not only transboundary pollution but also causation chains within one national jurisdiction as well as from one jurisdiction to areas beyond national jurisdiction. Art. 194 lays down due diligence obligations preventing damage but is tacit about remedies in cases of breach of duties. In such cases the general rules of customary law on liability apply.

UNCLOS is underdeveloped in relation to the protection of biodiversity (Tanaka 2015: 338). Art. 194 para. 5 generally asks for measures protecting “rare or fragile ecosystems as well as the habitat of depleted, threatened or endangered species and other forms of marine life”. More specific obligations are mostly only concerned with fish resources (see further below Sect. 30.3.3.3).[8] Beyond the area of fish resources UNCLOS lacks specific provisions on the protection of marine biodiversity. To fill it recourse must be taken to the many principles and rules of the Convention on Biodiversity of 1992 (CBD). Art. 237 (1) UNCLOS encourages such recourse by asserting that chapter XII UNCLOS is without prejudice to agreements concluded in furtherance of the general principles set forth in UNCLOS, including the mentioned Art. 194 para. 5. The CBD constitutes precisely such agreement.

In substantive terms, while Art. 194 para. 5 UNCLOS is confined to rare or fragile ecosystems and habitats of depleted, threatened or endangered species the CBD goes further by demanding protection of any ecosystem, habitat and population of species (Art. 8 lit. (d), Art. 9 lit. (d) CBD).

30.3.3 Precaution

30.3.3.1 Origin

The no harm rule has its origin in the early years of environmental law when it grew out of police law which was based on rather restrictive preconditions of state intervention. Police action was only allowed if the damage that should be prevented was significant and highly probable. Since then concern about uncertainty of adverse effects and how to deal with it has entered national and international debates.

The first step was to acknowledge that if the potential effect is disastrous (such as from the melting down of the core of a nuclear power plant) preventive measures must be taken even if the event is uncertain or unlikely. This category of duties has been recognized to be part of the no-harm rule (International Law Commission 1996, Art. 2 and Commentary). Further on new products and technologies with uncertain effects and likelihood such as chemical substances and genetically modified organisms have also been subjected to scrutiny. In addition, new risks with diffuse causes like climate change have emerged.

[8] See however Art. 196 concerning the introduction of alien species.

As a principle coping with such situations precaution has been proposed. Precaution advises that measures should be taken preventing adverse effects even if the likelihood and/or dimension of the effects is not yet scientifically proven.

30.3.3.2 Legal Status

The principle of precaution does not explicitly appear in UNCLOS, nor in the CBD, but, for instance, in the Framework Convention on Climate Change. It also figures in sectoral and regional marine conventions such as the Fish Stock Agreement and the Helsinki and OSPAR Conventions.

Beyond its sectoral and regional realm, could the principle be conceived as general and global customary law? The international legal discourse is hesitant to accept this. What can be regarded as consented is to speak of a "precautionary approach", meaning that precaution does not constitute a self-standing norm but should be employed to guide the interpretation of existing international law (cf. Southern Blue Fin Tuna case, ITLOS 1999, para. 77; Birnie et al. 2009: 163; Sands et al. 2012: 222; Tanaka 2015: 255). This is very timid given the widespread overexploitation of natural resources. The example of climate change demonstrates that the now imminent catastrophical damage could have been prevented by timely measures had precaution been accepted as a legal principle back in the 1980s and 1990s.

Considering the status as customary law, it must be conceded that precaution has not become common practice of states thus lacking the first of the two components of customary law, *consuetudo* and *opinio iuris*. However, in view of the frequent appearance of precaution in programmatic documents and soft law (such as, notably, Agenda 21) it is at least to be recognized as a proto-legal principle. Beyond that, considering that it has been enshrined in many national laws and international treaties, and building on the trajectory "generalization from partial treaties" (see above Sect.30.2.3.2) time has come to accept precaution as a "general principle of law recognized by civilized nations" in the sense of Art. 38 (1) (c) ICJ Statute.

30.3.3.3 Content

Precaution has been given many different contents. An ambitious definition with regard to the protection of the marine environment can be found in Art. 3 (2) Helsinki Convention which reads:

> The Contracting Parties shall apply the precautionary principle, i.e., to take preventive measures when there is reason to assume that substances or energy introduced, directly or indirectly, into the marine environment may create hazards to human health, harm living resources and marine ecosystems, damage amenities or interfere with other legitimate uses of the sea even when there is no conclusive evidence of a causal relationship between inputs and their alleged effects.

This definition does not narrowly refer to serious damage but includes any harm to living resources and marine ecosystems into its scope. It thus transcends the narrower scope of the no harm rule. On the side of the likelihood of damage it supposes "no conclusive evidence". This can mean two things which should be distinguished: the lack of available knowledge on the one side, and the low level of probability on the other. If the knowledge basis on causal links is largely missing it is scientifically not grounded to posit a probability of effects. In contrast, if the knowledge base is sufficient, a statement of probability (if possible accompanied by a statement on the probability of error) can be made. It must then be decided whether a low level of probability suffices or a higher level is required. Precaution could mean in this situation, that a low level suffices.

An ambitious formulation of precaution like in Art. 3 (2) Helsinki Convention rests on sectoral or regional law. If we envisage a principle and even rule of precaution as a norm of universal law the content will have to be more modest. The scope of effects will need to be narrowed and the required level of certainty and probability be raised. In addition, the measures to be taken will be shaped considering available technology and cost-effectiveness. If we were to formulate such rule in a broadly acceptable way, precaution might be framed as follows:

> States shall not rely on scientific uncertainty to justify inaction when there is enough evidence to establish the possibility of a risk of serious harm, even if there is as yet no proof of this. In determining whether and how far to apply precautionary measures, states may take account of their technological capabilities and the cost-effectiveness of the measures.

This rather narrow framing—serious harm, sufficient evidence, state of technology, cost-effectiveness—might make it easier for the persistent objector of precaution, the USA, to accept it.

The example of fisheries may demonstrate how the no harm rule and the precautionary reading of laws are related. UNCLOS establishes, both for the EEZ and the High Seas, a rule that stocks of fish populations shall be maintained at levels which can produce the maximum sustainable yield (MSY). Environmental factors such as the interdependence of stocks as well as economic factors such as the needs of coastal communities and developing states shall be taken into account (Art. 61 and 119 UNCLOS). The principle at the basis of these provisions is sustainability of fisheries. The preservation of stocks at levels providing MSY can be regarded as a no harm rule. Economic concerns may be factored in but should not be allowed to cause a decline of stocks below MSY size or even their collapse. Precaution comes in if there is uncertainty of assessment of stocks or fishing pressure, and notably if environmental factors such as ecosystemic conditions of stocks (which often escape precise scientific determination) shall be considered. This means that a precautionary reading of Arts. 61 and 119 UNCLOS would require states to raise stock sizes well above MSY levels (Markus and Salomon 2012: 266–267).

30.3.3.4 Context of Application

Precaution tends to be differently interpreted depending on whether it shall empower or prescribe state action (Winter 2006: 598–603; Scott and Vos 2002). Court practice shows that if a state has actually made use of precaution enabling it to act, the courts will tend to accept even a rather broad reading of the pertinent principle or rule. This reflects judicial self-restraint in view of the fact that the decision whether to act or not is widely a political matter and that this should be mirrored in the interpretation of the relevant law.

For instance, in the *BSE* case the European Community (EC) had taken legal measures directed against the export of British beef to other member states. The European Court of Justice (ECJ) was asked by Britain to check if the competence basis, namely that for agricultural policy, had duly been applied. Referring to the environmental policy principles and the principle of integration of these principles into other policies the court supported the Commission's rather broad concept of precaution:

> "Where there is uncertainty as to the existence or extent of risks to human health, the institutions may take protective measures without having to wait until the reality and seriousness of those risks become fully apparent." (BSE case, ECJ 1998, para. 99)[9]

The rhetoric is somewhat different whenever the ECJ expresses itself on commanding functions. This was for instance done in the somewhat ironical case where the addressee of a Community product regulation complained that the Community did not first of all address a competitor whose product was even more dangerous as his own, arguing that the regulation was not strict enough as required by the standard of high level of protection under Art. 130r ECT (now Art. 191 TFEU). In *Safety High Tech* the ECJ rejected the claim holding that

> "whilst it is undisputed that Article 130r(2) of the Treaty requires Community policy in environmental matters to aim for a high level of protection, such a level of protection, to be compatible with that provision, does not necessarily have to be the highest that is technically possible." Safety High Tech, ECJ 1998, para 49.[10]

As the case is one of a commanding context (the plaintiff aimed at nullification claiming that the EC breached the duty to act), it is understandable that the court preferred a modest reading of the level of protection. In contrast, in an enabling situation it probably would have accommodated itself with measures aiming at the highest level of protection.

The difference of approaches if applied to our example of fisheries management would suggest that the precautionary reading of the MSY rule commands states to maintain and restore a precautionary of level of fish stocks, and enables states to go even further and prohibit any fishing, or non-artisanal fishing in certain areas, such as in nature protection zones where fish species are considered as part of an ecosystem rather than as object of exploitation (Winter 2009: 324–325).

---

[9] In Pfizer the Court of First Instance (CFI) qualified the precautionary principle somewhat more restrictively (Pfizer, CFI 2002 para. 144): "Rather, it follows from the Community Courts' interpretation of the precautionary principle that a preventive measure may be taken only if the risk, although the reality and extent thereof have not been 'fully' demonstrated by conclusive scientific evidence, appears nevertheless to be adequately backed up by the scientific data available at the time when the measure was taken."

[10] ECJ C-284/95 *Safety High-Tech* [1998] E.C.R. I-2603 (para. 49).

30.3.4 Environmental Impact Assessment

States must undertake an environmental impact statement (EIA) prior to the realization of a project that may cause transboundary environmental harm. This requirement has the legal status of international customary law. It is part of the no-harm rule but its importance is better emphasized if it is stated as a self-standing proposition. In the words of the ICJ an EIA is

> a practice, which in recent years has gained so much acceptance among States that it may now be considered a requirement under general international law to undertake an environmental impact assessment where there is a risk that the proposed industrial activity may have a significant adverse impact in a transboundary context, in particular, on a shared resource. Moreover, due diligence, and the duty of vigilance and prevention which it implies, would not be considered to have been exercised, if a party planning works liable to affect the régime of the river or the quality of its waters did not undertake an environmental impact assessment on the potential effects of such works (Pulp Mills case, ICJ 2010, para. 204).

Although the (regional) Espoo Convention does specify the content and procedure of an EIA (Annex II and Art. 5 Convention on Environmental Impact Assessment in a Transboundary Context) and could therefore have been referred to as a source for the trajectory "generalization of partial treaties" (see above Sect. 30.2.3.2) the court refuses to transfer the Espoo requirements to the pending case which was located in South America. In consequence, the court leaves it to the states to identify the precise content of the EIA (although setting a frame in requiring that regard must be had to "the nature and magnitude of the proposed development and its likely adverse impact on the environment"), and rejects the allegations that an EIA must consider alternatives and be open for public participation (Pulp Mills case, ICJ 2010, paras. 205, 210, 216).

Anyway, while an EIA does not appear as an explicit requirement, UNCLOS is to be read in the light of the said customary principle, rudimentary as it may be. This means that any industrial activity that may have a transboundary significant adverse effect must be subjected to a prior EIA. As the principle is embedded in the no-harm rule and this rule is applicable also in the domestic realm of coastal states as well as to pollution of the high seas the EIA requirement also extends to activities having domestic effect or effect on the high seas. This means, for instance, that the construction of artificial islands, industrial installations and structures, the laying of cables etc. require the prior conduct of an EIA (Art. 60 together with Art. 194 (3) (c) UNCLOS).

30.3.5 Freedom of Marine Scientific Research

Marine scientific research (MSR) is of high importance both for the protection and utilization of the seas. For that reason Art. 238 UNCLOS enshrines the freedom of MSR of all states. The principle stands in tension with the interest of coastal states in exclusivity of their research if the research aims at exploring commercial uses of the sea. There is also a potential conflict with environmental concerns if the research activities have adverse effects through e.g. introducing dangerous substances or disturbing living organisms (Hubert 2015).

Various provisions of UNCLOS and other international conventions provide for solutions to these conflicts. For instance, in the EEZ the principles of free research (Art. 238, 239 UNCLOS) and sovereign rights (Art. 55, 56 UNCLOS) are brought into a sequence of rules starting with free (albeit regulated) research and allowing coastal states to defend their exclusive rights if the MSR is not basic research but touches upon the exploitation of resources (Art. 246 UNCLOS). Concerning environmental effects, Art. 240 UNCLOS binds MSR to respect national and international law protecting the marine environment (Hubert 2015).

30.3.6 Transparency and Participation

Access of the public to environmental information and participation of the general or at least the affected public in environmental decision-making are policy principles widely shared in the global policy discourse on international governance. The (regional) Aarhus Convention established rules elaborating the principles. The Helsinki and OSPAR Conventions do have rules on access to information about the state of the marine environment, activities adversely affecting it, and measures taken to protect it (Art. 17 Helsinki Convention, Art. 9 OSPAR Convention). They however lack provisions on public participation. UNCLOS, contrastingly, does not acknowledge neither a principle of access to information nor one on participation (Chang 2012, pp. 38–44). The sharing of information only appears in the context of results of marine scientific research and technology transfer and only as a loose duty of states to publish or disseminate information, not as a right of individuals (Arts. 244, 277 UNCLOS). Likewise, participation is only randomly mentioned in relation to research (Art. 249 (1) (a) UNCLOS) and technology transfer (Art. 266 (1) UNCLOS).

Once again, the trajectory "generalization from partial treaties" (above Sect. 30.2.3.2) may be suggested as a possible path towards introducing the principles of access to information and participation also into the UNCLOS regime. If so, it should be kept in mind that the two principles can apply either to activities of states or of international bodies. In the Aarhus, Helsinki and OSPAR conventions access to information and participation is related to state activities. Generalization from them would lead to principles addressing governance at the level of states. In addition, access to information and participation should also be developed in relation to documents and decision-making of international organs like conferences of parties, ministerial committees, secretariats and working groups. But such postulates have as yet rather the status of policy principles.

30.3.7 Sustainability and Economic Uses of the Sea

The environmental principles expounded under Chaps. 4–9 must be seen in the context of principles guaranteeing the utilization of the seas for economic purposes. Outstanding in UNCLOS is the freedom of all states of navigation. It is a legal principle that extends to almost all geographical zones of the sea, comprising the territorial sea (Art. 17 (1) UNCLOS), the exclusive economic zone (Art. 58 UNCLOS) and the high seas (Art. 87 (1) (a) UNCLOS). In contrast, the right to over-flight, to lay submarine cables, to construct artifical islands and other installations is differently allocated depending on the pertinent zone. More principles of economic uses concern the exploitation of natural resources of the seas which are also differently allocated zone-wise. For instance, the exploitation of fish resources belong to the sovereign rights of the coastal state, exclusively within its territorial sea, on a shared concept within the EEZ (Art. 62 (2) UNCLOS), and on a concept of competition within the high seas (Arts. 2, 56, 87 (1) (e) UNCLOS).

These utilization rights trigger conflicts with duties of environmental and resource protection. Is there any legal guidance as to which side shall prevail? Some guidance can be found in Art. 237 (2) UNCLOS which says that environmental protection obligations from other treaties shall be carried out in a manner consistent with the general principles and objectives of UNCLOS. Does this mean that for instance navigation prevails if nature protection areas shall be established following CBD requirements? I believe, not, for utilization rights are only one part of the said principles and objectives, environmental protection belonging to them too. As far as environmental protection obligations from other treaties are embraced by the environmental general principles and objectives under Art. 237 (2) UNCLOS, the conflict with utilization rights becomes one on equal footing of environmental obligations and utilization rights.

One might take recourse to the principle of sustainable development to solve such conflicts. This principle is a kind of master (or meta-) concept of weighing opposing concerns. It has above (Sect. 30.2.1) been characterized as a policy principle, not (yet) a principle of law, or more appropriately as a proto-legal principle. In its common reading it asks for the equal weighing of social, economic and environmental concerns. In a long-term perspective, however, environmental concerns must have preponderance because without natural resources humanity cannot survive (Winter 2008: 28; Bosselmann 2017: 52). For instance, if a fish stock is about to collaps a state that takes radical measures such as prohibiting any fishing must be allowed to disregard that fishermen may loose their jobs and consumers may miss their usual fish supply until fish-stocks have recovered.

30.3.8 Common Heritage of Mankind

The Area, i.e. the seabed and ocean floor and subsoil thereof beyond the limits of national jurisdiction, and its resource are common heritage of mankind (Arts. 1 (1), 136 UNCLOS). This principle is the basis of a sophisticated set of rules on common uses, distribution of gains, environmental protection and related institutions (see further Chap. 44 in this book). The principle had been discussed for application on more resources, such as the living resources of the seabed, the high seas, and the EEZ, but was not adopted to that effect. It is therefore a principle of treaty law with limited scope (Wolfrum 2009). It has however survived as a policy principle in the gradual formation of the meanwhile 20 regional fisheries organizations that cover regional areas both of EEZ's and parts of the high seas (Unterweger 2014: 103 et seq.). Together with the global Fish Stock Convention they can be understood to conceive the related fish stocks—or at least the straddling and highly migratory stocks—as common heritage of mankind, i.e. as a common good that must be managed by common institutions.

In addition, the principle has been revived as a basis for the ongoing negotiations on a multilateral agreement on marine biodiversity including access to genetic resources and benefit sharing concerning the area beyond national jurisdiction (ABNJ), including resources found on and in the seabed as well as in the high seas. The process was triggered by the UN General Assembly (UNGA) and is guided by UNGA Resolution 2011a. As the term common heritage is not liked by industrialized states it is largely avoided in the drafting process and will hardly enter into the more pragmatic language of the envisaged agreement (Greiber 2013: 402–403, 407–411). The principle is nevertheless present as a basic idea (or proto-principle) of the emerging regime waiting for being revealed as a legal principle of the enacted regime at a later stage of doctrinal analysis. After all, law-makers have never been able to prevent doctrinal reconstructions which they did not want to lay open in the pragmatic negotiation of compromises.

30.4 Conclusions

This contribution has, as a first step, ventured to clarify the meaning of principles and rules. It is advisable to distinguish between three contexts of use of this term: the pragmatic context of law-making where policy, legal and proto-legal principles should be distinguished, the context of doctrinal systematization where principles and rules are distinguished and given meaning, and the positivist context of legal source where customary law, treaty law, secondary law of international organizations and general principles of law must be distinguished. In the context of law-making it can be observed that legal principles often emerge from policy principles. The context of doctrinal systematization allows to see that general principles of law in the wording of Art. 38 (1) (c) ICJ Statute can formulate principles as well as rules in the doctrinal sense. It also allows to categorize general principles of international law as principles in the doctrinal sense which qualify norms resulting from either of the four sources of international law.

As a second step the principles and rules of marine environmental protection were reconstructed both in terms of content and legal status.

The obligation between states to cooperate is an old and well established rule of international customary law, although the content is not precisely determined and sanctions in the case of breach are not specified.

The no-harm rule is also an uncontested norm of international customary law. It is also an important facet of UNCLOS, although with a focus on marine pollution and fisheries.

In contrast, precaution has ambitious contours and binding character only according to sectoral and regional treaties. It is nevertheless a general principle of law in the sense of Art. 38 (1) (c) ICJ Statute if taken as an approach (or rather: principle in the doctrinal sense) that redirects the interpretation of existing law. The principle could however also be formulated as a conclusive rule, albeit with a less ambitious content than that of the said sectoral and regional norms.

The obligation to elaborate an environmental impact assessment prior to the authorization of a dangerous installation was by the ICJ recognized as a rule of customary law. Content-wise the EIA must cover all environmental effects, but there is no obligation to also study alternatives to the proposed project. Nor is public participation part of the customary rule. Such more ambitious requirements are added by regional treaties.

The freedom of marine scientific research is a legal principle of UNCLOS, hence of treaty law. Taking its conflicting principle—exclusive rights over resources in the EEZ of coastal states—into consideration UNCLOS has established a system of rules that ensure free basic research but acknowledges the coastal state's power to restrict research if aimed at exploration of resources rather than only basic research.

Transparency and public participation widely lack as a concern of UNCLOS. They can be regarded as proto-legal principles which may after some time develop into a general principle of law based on a generalization from the regional Aarhus-Convention.

Environmental principles and rules of treaty or customary law stand in potential conflict with principles and rules enabling economic uses of the seas, such as the freedom of navigation and sovereign rights over natural resources situated in the territorial sea and EEZ. UNCLOS puts economic uses and environmental protection on equal footing. The principle of sustainable development may be invoked to help finding bridges, especially if designed to ask for prioritization of nature protection. With such content it is however rather a policy principle waiting for legalization.

Finally, common heritage of mankind is a legal principle of UNCLOS with a narrow scope, covering the Area and its mineral resources. An extension to genetic resources of the high seas is under discussion.

References

Agenda 21 (1992) http://habitat.igc.org/agenda21/. Accessed 20 April 2016

Alexy R (1994) Theorie der Grundrechte. Suhrkamp, Frankfurt

Bassiouni MC (1989–1990) A functional approach to "general principles of international law". Michigan J Int Law 11:768–818

Beef Hormones Case (1998) (US, Canada, Australia vs. EC), WT/DS26/AB/R, WT/DS48/AB/R
Birnie P, Boyle A, Redgwell C (2009) International law and the environment. Oxford University Press, Oxford
Bodansky D (1999) The legitimacy of international governance: a coming challenge for international environmental law? Am J Int Law 93:596–624
Bogdandy AV, Dann P, Goldmann M (2010) Völkerrecht als öffentliches Recht: Konturen eines rechtlichen Rahmens für Global Governance. Der Staat 49:23–50
Brownlie I (2008) Principles of public international law, 7th edn. Clarendon Press, Oxford
BSE case, United Kingdom/Commission, ECJ C-180/96 (1998) ECR I 2265
Cassese A (2005) International law, 2nd edn. Oxford University Press, Oxford
Chang Y-C (2012) Ocean governance: a way forward. Springer Verlag, Heidelberg
Cheng B (2006) General principles of law as applied by international courts and tribunals. Cambridge University Press, Cambridge
Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention). http://www.ospar.org/site/assets/files/1290/ospar_convention_e_updated_text_in_2007_no_revs.pdf
Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention). http://www.helcom.fi/Documents/About%20us/Convention%20and%20commitments/Helsinki%20Convention/Helsinki%20Convention_July%202014.pdf
Daillier P, Forteau M, Pellet A (2009) Droit international public. Lextenso éditions, Paris
Dworkin R (1977/1978) Taking rights seriously. Harvard University Press, Cambridge, MA
Epiney A, Scheyli M (2000) Umweltvölkerrecht. Stämpfli Verlag, Bern
Esser J (1964) Grundsatz und Norm in der richterlichen Fortbildung des Privatrechts. Mohr, Tübingen
Gabčíkovo-Nagymaros Case, Hungary/Slovakia, ICJ judgment of 25 September 1997. http://www.icj-cij.org/docket/files/92/7375
Greiber T (2013) Common pools for marine genetic resources. A possible instrument for a future multilateral agreement addressing marine biodiversity in areas beyond national jurisdiction. In: Chege Kamau E, Winter G (eds) Common pools of genetic resources. Routledge, Oxon, pp 399–413
Hey E (2007) International institutions. In: Bodansky D, Brunnée J, Hey E (eds) The Oxford handbook of international environmental law. Oxford University Press, Oxford, pp 749–769
Hubert A-M (2015) Marine scientific research and the protection of the seas and oceans. In: Rayfuse R (ed) Research handbook on international marine environmental law. Edward Elgar, Cheltenham, pp 313–336
Jacoby S (1997) Allgemeine Rechtsgrundsätze: Begriff und Funktion in der Europäischen Rechtsgeschichte. Duncker & Humblot, Berlin
Koskenniemi M (2000) General principles: reflexions on constructivist thinking in international law. In: Idem (ed) Sources of international law. Ashgate, Aldershot, p 359 et seq
Lang W (1999) UN-principles and international environmental law. Max Planck UNYB 3:157 et seq
Lauterpacht H (1927) Private law sources and analogies of international law. Longmans, Green and Co., London
Markus T, Salomon M (2012) The law and policy behind the upcoming reform of the common fisheries policy. JEEPL 9:257–284
Mosler H (1976) Völkerrecht als Rechtsordnung. ZaöRV 36:6–49
MOX Plant case, Ireland/United Kingdom (2001) (Provisional Measures) ITLOS Case No. 10. www.itlos.org/fileadmin/itlos/documents/cases/case_no_10/Order.03.12.01.E.pdf
Müller JP, Wildhaber L (2000) Praxis des Völkerrechts. Stämpfli Verlag, Bern
Nicaragua case, Nicaragua/United States of America (1986) ICJ judgment of June 27, 1986. http://www.icj-cij.org/docket/files/70/6503.pdf
Paech N, Stuby G (2013) Völkerrecht und Machtpolitik in den internationalen Beziehungen. VSA Verlag, Hamburg

Pfizer case, Pfizer/Commission (2002) CFI T-13/99 [2002] ECR II 3305
Pulp Mills case, Argentina/Uruguay (2010) ICJ judgment of 20 April 2010
Rothwell DR, Stephens T (2016) The international law of the sea, 2nd edn. Hart Publishing, London
Rylands v. Fletcher (1868) 3 LR HL 330. http://www.bailii.org/uk/cases/UKHL/1868/1.html. Accessed 5 March 2017
Safety High Tech, ECJ C-284/95 (1998) E.C.R. I-2603.
Sands P, Peel J, Fabra A, MacKenzie R (2012) Principles of environmental law. Cambridge University Press, Cambridge
Scott J, Vos E (2002) The ambivalence of the precautionary principle. In: Joerges C, Dehousse R (eds) Good governance in Europe's integrated market. Oxford University Press, Oxford, p 260 et seq
Southern Bluefin Tuna case, New Zealand/Japan; Australia/Japan (1999) (Provisional Measures) ITLOS Case No. 3 and 4 (27.08.1999)
Tanaka Y (2015) The international law of the sea, 2nd edn. Cambridge University Press, Cambridge
Tunkin GI (1974) Theory of international law. Allen & Unwin, London
Unterweger I (2014) International law on tuna fisheries management. Nomos Verlag, Baden-Baden
Verdross A, Simma B (1984) Universelles Völkerrecht: Theorie und Praxis. Duncker & Humblot, Berlin
Verschuuren J (2003) Principles of environmental law. Nomos Verlag, Baden-Baden
Winter G (2006) The legal nature of environmental principles in international, EU, and exemplary national law. In: Idem (ed) Multilevel governance of global environmental change. Cambridge University Press, Cambridge, pp 587–605
Winter G (2008) A fundament and two pillars. The concept of sustainable development 20 years after the brundtland report. In: Bugge H-C, Voigt C (eds) Sustainable development in international and national law. Europa Law Publishing, Groningen, pp 25–45
Winter G (2009) Towards a legal clinic of fisheries management. In: Ders (ed) Towards sustainable fisheries management: a comparative analysis. IUCN Environmental Policy and Law Paper No. 74. IUCN, Bonn, pp 299–321
Wolfrum R (2009) Common heritage of mankind. Max Planck Encyclopedia Public Int Law. www.opil.ouplaw.com. Accessed 27 Apr 2016
Wolfrum R (2010) General international law (Principles, Rules, Standards). Max Planck Encyclopedia Public Int Law. www.opil.ouplaw.com. Accessed 24 Apr 2016

Chapter 31
Overview of Management Strategies and Instruments

Carolin Kieß

Abstract The rapidly increasing demand for marine space for different purposes, such as offshore wind farms, oil and gas exploitation, fishing, aquaculture, shipping and tourism and the cumulative impact of the various activities on the marine and coastal environment have led to a growing recognition of the need for sustainable management strategies and legal governance. There is a broad variety of regulatory tools and the choice of instruments depends on the nature of the activity concerned and its potential effects on the marine environment. Direct regulation of marine uses may encompass the setting of restrictions and prohibitions as well as the establishment of licensing and permitting requirements. Integrated policies and cross-sectoral planning and management approaches like marine spatial planning are required to deal with conflicting uses and cumulative effects. Monitoring, surveillance and reporting obligations are important tools to acquire information on the state of the marine environment and the effects of various activities upon it. Besides the more traditional forms of direct regulation, market-based instruments like environmental taxes, charges or eco-labelling may provide incentives to consumers and businesses for environmentally friendly behaviour. This chapter gives an overview of various management strategies and instruments and their application to human activities in the marine environment.

Keywords Command-and-control • Cross-sectoral planning instruments • Area-based management • Consumer information incentives

C. Kieß
Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, Bonn, Germany
e-mail: Carolin.Kiess@bmub.bund.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_31

31.1 Introduction

Many international conventions call upon States to adopt laws and regulations which regulate the exploitation of marine resources and other marine activities. The power to legislate in respect of a person, property or event (legislative or prescriptive jurisdiction, see Malanczuk 1997: 109) differs as regards the maritime zones under the United Nations Convention on the Law of the Sea (UNCLOS). While the sovereignty of a coastal State extends beyond its land territory and internal waters to the territorial sea, its regulatory competence in the EEZ and over the continental shelf is limited (see Chap. 29). It is confined to the matters expressly indicated in UNCLOS in respect of which sovereign rights or jurisdictional powers are granted to a coastal State (Hodgson et al. 2014: 14). The high seas and the deep seabed located beyond the limits of States' continental shelves are areas beyond national jurisdiction (ABNJ). There are a number of organisations at the international and regional level which are competent to regulate activities such as shipping, fishing, dumping and mining within ABNJ.[1]

Environmental principles like the precautionary principle or the polluter pays principle may guide the choice of regulatory instruments as well as their application. The precautionary principle for instance requires preventive measures to be taken when there are reasonable grounds for concern that human activities may bring about hazards e.g. to human health or harm living resources and marine ecosystems even when there is a lack of scientific certainty (see Chap. 30).

This chapter first outlines the importance of environmental standards and their implementation through direct regulation, followed by a description of more complex multi- and cross-sectoral steering approaches as well as other planning tools and their application to marine issues. Then, instruments providing for the gathering of environmental information and public participation are addressed. The last section of the chapter gives examples for the application of economic and voluntary instruments in relation to marine environment protection.

31.2 Direct Regulation

International conventions may require States to adopt regulations which directly regulate certain marine activities. Frequently, the use of regulatory techniques like permitting requirements (see, e.g., Art. 210 UNCLOS as regards the prevention, reduction, and control of pollution by dumping), the setting of quotas (see, e.g., Art. 62 UNCLOS on the regulation of fishing in the EEZ) or the use of procedural instruments like environmental impact assessment is suggested or mandated. In

[1] The enforcement of international legal regimes on the high seas is primarily the responsibility of the flag State whereas a special regime applies to deep-sea mining activities in the Area (see Kimball 2005: 6).

some cases, States directly work together in international organisations, such as the regional fisheries management organisations (RFMOs) or the International Seabed Authority, to regulate certain activities. Due to its prescriptive nature, direct regulation is often referred to as 'command and control regulation'. Commands may be issued through a combination of licenses, prohibitions and standards, which are then controlled by monitoring, reporting and inspection regimes, as well as by negative sanctions such as threats of criminal and other forms of liability (Lee 2009: 83).

31.2.1 Standard-Setting

Regulation in the field of environmental law normally aims at the implementation of certain environmental standards. Source-related standards are set by reference to the source of pollution and may be further divided into emission standards, process standards and product standards.

Process standards may determine the requirements to be met by the design and construction of an installation or relate to requirements on the operation of an installation (see e.g. Art. 194 (3) (c) and (d) UNCLOS as regards the prevention of pollution from installations; see also Sands and Peel 2012: 157). They also may relate to the course of activities like e.g. the so-called 'technical measures' under the EU Common Fisheries Policy establishing conditions for the use and structure of fishing gear and restrictions on access to fishing areas (see Regulation (EU) No 1380/2013, Arts. 4 (1) (20) and 7 (2)). Many multilateral environmental agreements require the application of 'best available techniques' (1992 OSPAR Convention, Art. 2 (3) (b) and Appendix 1) or 'best available technology' (1992 Helsinki Convention, Art. 3 (3) and Annex II) and 'best environmental practice' (1992 OSPAR Convention, Art. 2 (3) (b) and Appendix 1; 1992 Helsinki Convention, Art. 3 (3) and Annex II).

Emission standards, sometimes referred to as 'emission limit values', specify the levels, concentration or mass of substance of pollutants. An example is MARPOL 73/78 which, in order to prevent and minimize pollution from ships, limits, the discharge of oil (Annex I) and noxious substances (Annex II) and sets limits on sulphur oxide and nitrogen oxide emissions from ship exhausts (Annex VI). Product standards relate to the qualities of a certain product, e.g. its physical or chemical composition, the technical performance or the handling and packaging.

In contrast to the aforementioned source-related standards, environmental quality standards focus on the quality of the protected target. They may prescribe the maximum allowable level of a certain pollutant in a particular medium (such as soil, air or water) which must not be exceeded but may also relate to the quality of the environment as such. Under the Marine Strategy Framework Directive 'good environmental status' (GES) is to be determined according to certain qualitative descriptors (see Annex I MSFD), nonetheless GES is an imprecise standard which needs further elaboration.[2]

Standards may be implemented through direct regulation but as well may be established by voluntary agreements (like e.g. the FAO Code of Conduct for Responsible Fisheries) or be set by private institutions (see Sect. 31.5). Depending on the nature and design of the underlying instrument, standards may be binding or non-binding, they may serve as an objective or guideline or provide binding threshold values. Different types of standards are not exclusive to each other, e.g. an emission standard will often be set in order to achieve an environmental quality standard (Bell et al. 2013: 243).

31.2.2 Restrictions and Prohibitions

A prohibition may be imposed if an impairment of the environment by a certain activity must be strictly avoided and its permissibility shall therefore not depend upon an individual decision of the administration (see Kloepfer et al. 2004: 271). For instance, as the dumping of wastes and the discharge of oil and other harmful substances by ships have been recognized as being among the main sources of marine pollution, several international and regional agreements ban or severely restrict those activities. The Protocol on Environmental Protection to the Antarctic Treaty designates Antarctica as a natural reserve devoted to peace and science and prohibits any activity relating to mineral resources other than scientific research (Arts. 2 and 7 Environment Protocol). Environmental instruments restricting hazardous products, processes or activities often use easily-amendable lists appended to the regulation to name the controlled substances or activities (Kiss and Shelton 2004: 232), see e.g. the Annexes to the London Convention and its 1996 Protocol.[3]

Taking or trade restrictions are regulatory techniques which are frequently used in order to prevent over-exploitation of natural resources. Taking, e.g., may be restricted by fixing fishing quotas. The regular setting of total allowable catches (TACs), i.e. catch limits expressed in tonnes or numbers, still is a core management instrument of the EU Common Fisheries Policy (Salomon et al. 2014: 77).[4] Taking restrictions also may apply to non-living marine resources in international commons areas such as the deep sea-bed (see Art. 133 et seq. UNCLOS). The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)

---

[2] Commission Decision 2010/477/EU on criteria and methodological standards on good environmental status of marine waters contains a number of criteria and associated indicators for assessing GES, in relation to the descriptors laid down in Annex I MSFD.

[3] Annex I of the London Convention contains a 'black list' of hazardous substances which may not be dumped whereas its Annex II sets out a 'grey list' of other identified materials for which dumping requires a special permit. The 1996 London Protocol takes the opposite approach and prohibits all dumping, except for possibly acceptable wastes on the so-called 'reverse list'.

[4] With the new Basic Regulation, TACs have to be fixed in line with the management target of maximum sustainable yield (MSY), see Art. 2 (2) Basic Regulation.

provides an example for trade restrictions: Depending upon their conservation status, different trade restrictions apply to specimens of species listed[5] ranging from trade with permits or certificates to almost complete trade prohibition.

31.2.3 Licensing and Permitting

Licensing or permitting requirements[6] allow applying environmental standards and policies to individual situations. Requiring prior government authorization is one of the most widely used techniques to prevent environmental harm, not only to control industrial emissions but also various other kinds of activities.[7] This serves to exercise anticipatory control, making sure that an activity is only carried out if certain requirements or conditions are met (Bell et al. 2013: 237). Permission or consent may be granted with a permanent or temporary character, the latter being adapted more easily to changing circumstances or new scientific knowledge. If an activity starts without permission or if the permission is contravened the relevant laws normally impose administrative or criminal sanctions.

31.3 Strategies, Plans and Programmes

Conflicts between environmental objectives and user interests as well as conflicting uses and the cumulative effects of various activities on the marine environment cannot be solved by sector-by-sector approaches alone (see Chap. 49). Marine spatial planning as well as other cross-sectoral planning instruments provide comprehensive management tools. A marine protected area is a (multi-sectoral) planning tool specifically focusing on the conservation of biodiversity. Area-based management instruments are also applied in sector-specific regulations for activities like shipping or fishing, e.g. no-take areas, no-go areas.

---

[5] Among the species listed in the appendices of the convention are marine species or groups of species like cetaceans (whales, dolphins and porpoises), sea turtles and corals.

[6] Bell, McGillivray and Pedersen (2013, p. 236) hint at the fact that different pieces of legislation use different words (permission, authorization, consent or license) but essentially mean the same thing.

[7] See e.g. Art. 210 (5) UNCLOS requiring express prior approval of the coastal State as regards dumping within the territorial sea, the EEZ or onto the continental shelf; Arts. III-VI CITES requiring different kinds of export permits for species listed; Arts. 2 and 6 Seeanlagenverordnung [SeeAnlV] (Marine Facilities Ordinance) making the construction of installations in the German EEZ for commercial purposes subject to approval by the Maritime and Hydrographic Agency (BSH).

31.3.1 Integrated Maritime Policies: The Marine Strategy Framework Directive

Like the USA, Canada, Japan or Norway the EU has come to recognize the need to apply an inter-sector and crosscutting approach to governance of maritime affairs since the intensive development of sea-based activities poses a challenge to sustainable development and use of the sea resources (European Commission 2008: 4 with further references). The Marine Strategy Framework Directive (Directive 2008/56/EC, MSFD) constitutes the environmental pillar of the European integrated maritime policy. It aims to establish a framework within which the necessary measures shall be taken to achieve or maintain good environmental status (GES) in the marine environment (Art. 1 (1) MSFD). Member States are required, in respect of each marine region or subregion concerned, to develop and implement marine strategies for their marine waters which must apply an ecosystem-based approach to the management of human activities (Arts. 1 (2), (3) and 5 MSFD).

To deal with existing knowledge gaps the MSFD obliges Member States to carry out an initial assessment of the current environmental status of the waters concerned (Arts. 5 (2) (a) (i) and 8 MSFD). They are required to determine a set of characteristics for GES on the basis of the qualitative descriptors set out in Annex I MSFD (Arts. 5 (2) a (ii) and 9 MSFD). They also have to establish a comprehensive set of environmental targets and associated indicators for their marine waters to guide towards achieving GES in the marine environment (Arts. 5 (2) (a) (iii) and 10 MSFD). The MSFD indicates characteristics, pressures and impacts to be taken into account but the specification of targets as well as the development of assessment criteria is left to the implementation process (see Annex III and IV MSFD, see also Markus et al. 2011: 88). The same applies to the measures to be taken in order to achieve or maintain GES, which are to be identified by Member States and to be integrated into a programme of measures (Art. 13 MSFD).[8] The MSFD provides that the programme of measures shall include spatial protection measures, contributing to coherent and representative networks of marine protected areas (Art. 13 (4) MSFD), and thus stresses the importance of MPAs for the protection of marine biodiversity. Implementing measures have to be reported to and assessed by the European Commission (Arts. 9(2), 10(2), 11(3), 12, 13 (9), 16, 20 and 21 MSFD).

31.3.2 Marine Spatial Planning

Spatial planning is an important tool for managing the development and use of land which aims to create a more rational organization of land uses and the linkages between them, to balance demands for development with the need to protect the environment, and to achieve social and economic objectives (UNECE 2008: 1). Despite the long tradition of spatial planning on land, its application to the marine

[8] Annex VI MSFD indicates types of measures, e.g. input and output controls, control of spatial and temporal distribution of activities, economic incentives, communication and stakeholder involvement, that shall be taken into consideration.

environment still is a recent development (see Chap. 54). Marine spatial planning facilitates the implementation of the ecosystem-based approach and should take into account the various pressures on marine ecosystems and resources by human activities as well as land-sea interactions and climate change effects. An example is provided by directive 2014/89/EU which establishes a common framework for marine spatial planning in the EU. It aims to identify the utilisation of maritime space for different sea uses as well as to manage spatial uses and conflicts in marine areas.

Spatial plans can only address the spatial and temporal distribution of activities, thus they cannot replace other measures regulating the intensity of human activities (e.g. the setting of quotas in relation to fishing effort). The process of marine spatial planning is similar to land use planning in the terrestrial environment, the principal output being a comprehensive, mulit-sectoral marine spatial plan or comprehensive development plan (Douvere and Ehler 2009: 78). For example, the German Raumordnungsplan Nordsee' (Spatial Plan North Sea) contains provisions aimed at the coordination of uses and functions like shipping, the exploitation of resources, the laying of pipelines and submarine cables, scientific marine research, wind power production, fisheries and mariculture as well as the protection of the marine environment (regarding differences between territorial and marine spatial plans see Chap. 28).

31.3.3 Marine Protected Areas

Protected areas are a key instrument as regards the conservation and sustainable use of biodiversity (see Art. 8 CBD; see Chap. 46). The Aichi Biodiversity Targets, adopted by the international community in 2010, call for at least 10% of coastal and marine areas, especially those of particular ecological importance, to be conserved through effective systems of marine protected areas and other effective area-based conservation measures. There currently is no universally accepted definition for the term ‘marine protected area’ but a definition proposed by the International Union for Conservation of Nature (IUCN) is widely used (Hodgson et al. 2014: 42): “Any area of intertidal or sub-tidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment.”[9] Most Multilateral Environmental Agreements designed to protect biodiversity, habitats or threatened species and all Regional Seas Conventions applying to European seas have developed mechanisms for the designation and management of MPAs as a means to achieve their objectives (Frank 2007: 331).[10]

---

[9] Resolution 17.38 of the IUCN General Assembly, 1988.

[10] See e.g. Art. 3(1)(b)(ii) of Annex V OSPAR Convention, OSPAR Recommendation 2003/3 on a Network of Marine Protected Areas; Art. 15 Helsinki Convention, HELCOM Recommendation 35/1 ‘System of Coastal and Marine Baltic Sea Protected Areas (HELCOM MPAs)’; as regards the high seas see paragraph 2 of General Assembly Resolution 69/292 of 6 July 2015 ‘Development of an international legally binding instrument under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction’.

In relation to other management instruments, MPAs may be qualified as planning tools (see Kloepfer et al. 2004: 232): Protected areas should be integrated into the wider land- and seascape; ecological connectivity and the concept of ecological networks, including connectivity for migratory species, have to be taken into account (CBD 2011: 15). The latter is exemplified by the Habitats directive (Directive 92/43/EEC), establishing the EU-wide Natura 2000 ecological network of protected areas. A central element of MPAs is the management of human activities taking place in the area. Thus within an MPA certain activities, e.g. fisheries or mineral extraction, may be limited or entirely prohibited in order to meet specific conservation, habitat protection or ecosystem monitoring objectives.[11]

Sector-specific management instruments providing for area-based restrictions, which are applied for activities like shipping or fishing, may directly or indirectly contribute to the protection of marine biodiversity. MARPOL e.g. provides for the designation of 'Special Areas' in which the adoption of special mandatory methods for the prevention of pollution is required.[12] Particularly Sensitive Sea Areas (PSSAs) are defined as areas that need special protection through action by IMO because of their significance for recognized ecological, socio-economic or scientific reasons and which may be vulnerable to damage by international shipping activities (IMO 2005). As regards fisheries management, time and area restrictions may serve to protect commercially used fish stocks by preventing overfishing and to ensure that fishing effort is commensurate with the productive capacity of the fishery resources and their sustainable utilization (Hall 2002: 51).

31.4 Environmental Information and Public Participation

Information on the state of the environment and on activities which have adverse or damaging effects is considered to be a prerequisite to effective national and international environmental management, protection and co-operation (Sands 2003: 826; Chap. 28). In order to collect reliable information, many legislative acts establish monitoring, surveillance and reporting obligations.[13] According to the OSPAR Convention (Annex IV, Art. 1), monitoring may encompass the repeated measurement of the quality of the marine environment and each of its compartments, activities or natural and anthropogenic inputs which may affect the quality of the marine environment and the effects of such activities and inputs. Monitoring serves to

[11] See e.g. Council Regulation (EC) No 602/2004 as regards the protection of deepwater coral reefs from the effects of trawling in an area northwest of Scotland.

[12] See IMO Assembly Resolution A.927(22), Guidelines for the Designation of Special Areas under MARPOL 73/78 and Guidelines for the Identification and Designation of Particularly Sensitive Sea Areas (Nov. 29, 2001).

[13] See e.g. Art. 204 UNCLOS; Art. 5 (l) Straddling Fish Stocks Agreement; Art. 7 CBD; Annex IV Art. 1 OSPAR Convention; Arts. 11, 17 Habitats Directive (Directive 92/43/EEC); as regards national laws see e.g. Art. 6 of the German Bundesnaturschutzgesetz [BNatSchG] (Federal Nature Conservation Act).

identify patterns and trends as regards the state of the environment. It also may be undertaken for the purposes of ensuring compliance with the relevant legal regime or for research purposes.

The availability of and access to environmental information[14] ensures the participation of citizens in national decision-making processes. Requirements for public participation in various categories of environmental decision-making are set out by the UNECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters (Aarhus Convention).[15] Public participation can improve the quality of decisions by promoting the disclosure of relevant information to participants in the environmental decision-making process; it also can increase the acceptance of decisions (Kloepfer et al. 2004: 252). Access to justice can improve implementation through allowing judicial enforcement by actors which otherwise often would not have standing according to national law.

Environmental assessment is a procedure that ensures that the environmental implications of decisions are taken into account before the decisions are made. It contributes to the integration of environmental considerations into decision-making processes at an early stage. Environmental assessment may be undertaken for individual projects, such as a pipeline, offshore wind farm or the extraction of crude oil or natural gas (then called 'environmental impact assessment' (EIA)), or for plans and programmes, e.g. marine spatial plans (then called 'strategic environmental assessment' (SEA)). A large number of binding and non-binding instruments now provide for EIA[16] or SEA.[17] Environmental assessment describes a process, the assessment being concluded by a written statement which is supposed to guide the decision-making by providing information on environmental impacts of the activity (Sands 2003: 799 et seq.). Instruments like the Espoo Convention and Protocol or the EU directives also provide for public participation in government decision-making.

---

[14] According to Art. 2 (3) Aarhus Convention, the term 'environmental information' encompasses information on the state of elements of the environment, such as air and atmosphere, water, soil, land, landscape and natural sites, biological diversity and its components, including genetically modified organisms, and the interaction among these elements and a broad range of activities or measures (such as administrative measures, environmental agreements, policies, legislation, plans and programmes).

[15] The first international instrument to create a right of access to environmental information was Council Directive 90/313/EEC (see Sands 2003, p. 854); the 1992 OSPAR Convention in Art. 9 provides for access to information.

[16] See e.g. Principle 17 of the Rio Declaration, Art. 206 UNCLOS, the Espoo Convention and Directive 2011/92/EU.

[17] See e.g. the 2003 Protocol on Strategic Environmental Assessment to the Espoo Convention or Directive 2001/42/EC of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment.

31.5 Economic and Voluntary Instruments

Economic instruments like taxes, subsidies, tradeable permits, consumer information incentives or civil liability primarily aim to influence the motivation of the addressee[18]; they are considered indirect behavioural steering approaches (Kloepfer and Winter 1996: 47). Taxes and charges are classic economic instruments, the rationale behind them being that they may create an economic disincentive to environmentally damaging behaviour. In the context of marine environment protection, product taxes or charges can serve to discourage the consumption of products that frequently end up as marine litter, such as disposable plastic bags. The same applies to deposit refund systems, e.g. for bottles (Newmann et al. 2015: 377, 381). Whereas tax revenues are added to the general public budget, charge revenues are used to specifically finance environmental measures (Sands 2003: 161).

Another marked-based instrument are tradeable permits, e.g. individual transferable fishing concessions and quotas. Individual transferable (or 'tradeable') quotas (ITQs) are set in relation to a total allowable catch and may serve to eliminate overcapacity of fishing fleets and to improve economic results of the fishing industry. Countries like Australia or New Zealand apply the instrument of ITQs.[19] As regards the EU, Art. 21 of Regulation (EU) No 1380/2013 provides that Member States may establish a system of transferable fishing concessions, but other than originally proposed by the Commission the establishment of such a system is not made mandatory (see Salomon et al. 2014: 81).

Consumer information incentives such as the labels awarded by the Marine Stewardship Council (MSC) and Friend of the Sea (FOS), may promote sustainable fishing practices. Eco-labelling and certification provide competitive advantages for companies in terms of more secure supply relationships based on certification, consolidation of position in existing markets, and of new niche markets for environmentally friendly products. (FAO 2010: 134). The Code of Conduct for Responsible Fisheries of the FAO is a voluntary agreement which was adopted by more than 17O members of the FAO. Together with related instruments it forms the basis for private standard setting like the eco-labelling initiative of the MSC (see Friedrich 2013: 359).[20]

In order to deter harmful activities and to remedy environmental damage, civil liability for hazardous activities and compensation for damage together with related insurance obligations may be established. Several conventions provide for liability

[18] See Annex VI (6) MSFD, according to which economic incentives make it the economic interest of those using the marine ecosystems to act in ways which help to achieve the good environmental status objective.

[19] See the OECD database on instruments used for environmental policy and natural resources management, http://www2.oecd.org/ecoinst/queries/Default.aspx.

[20] Another example for a voluntary agreement is the 'Freiwillige Vereinbarung zum Schutz von Schweinswalen und tauchenden Meeresenten' (voluntary agreement for the conservation of harbour porpoises and sea ducks) between German fishery associations and the Ministry of Energy transition, Agriculture, Environment and Rural Areas Schleswig-Holstein (MELUR) of 17.12.2013.

and compensation for damage by oil pollution or the carriage of hazardous and noxious substances (see Kiss and Shelton 2004: 286 et seq.) The system is based on the 1969 Convention on Civil Liability for Oil Pollution Damage, which was replaced by its 1992 Protocol and which establishes ship owner's liability and requires ships to maintain insurance in respect of oil pollution damage.[21] As regards the Antarctic, Annex VI to the Environment Protocol on 'Liability Arising from Environmental Emergencies' covers environmental emergencies which relate to scientific research programmes, tourism and other governmental and non-governmental activities in the Antarctic Treaty area (see Art. 1; Annex VI did not enter into force yet).[22]

Economic incentives, market-based instruments as well as information requirements and voluntary tools allow to engage stakeholders at different levels and can be important complements to direct regulation. Voluntary approaches can be used to establish norms which go further than existing law, but they cannot replace international and domestic law and its enforcement (Friedrich 2013: 366).

31.6 Conclusion

At international, European and national level a broad variety of management strategies and instruments exists which can be used to protect the marine environment. The regulatory techniques to be applied basically are the same as in terrestrial environment protection, though sometimes their application to marine issues still is under development. Standards are essential for the functioning of environmental legislation, being used as a guideline or providing binding threshold values or environmental quality objectives. The application of economic and voluntary instruments contributes to marine environment protection. Nonetheless, setting enforceable legal rules, be it substantive environmental standards or procedural requirements, is fundamental to environmental law. Efficient environmental management as well requires sufficient information which also should be made available to the public and non-governmental organizations to allow for their participation in decision-making processes. As coastal States only enjoy sovereignty or sovereign rights over the maritime zones in the waters adjacent to their coasts, international regulation and possibly administration need to be further developed in order to be able to apply adequate instruments in relation to areas beyond national jurisdiction.

[21] It is complemented by the International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage (FUND) of 1971, also amended in 1992.

[22] In contrast to civil liability systems, the European Directive 2004/35/EC on environmental liability with regard to the prevention and remedying of environmental damage takes an administrative approach, i.e. it is based on the powers and duties of public authorities, and also covers damage to 'the environment in itself' (i.e. damage is not limited to clean-up costs and loss of profit).

References

1959 The Antarctic Treaty, 402 UNTS 71; 19 ILM 860 (1980)
Bell S, McGillivray D, Pedersen O (2013) Environmental law. Oxford University Press, Oxford
Bundesnaturschutzgesetz (BNatSchG, Federal Nature Conservation Act) of 29. July 2009 (Federal Law Gazette Part I (BGBl) p 2542), as last amended by act of 31 August 2015 (Federal Law Gazette I p 1474)
Commission Decision 2010/477/EU of 1 September 2010 on criteria and methodological standards on good environmental status of marine waters, OJ L 232, 2.9.2010, p 14
1992 Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention), 2354 UNTS 67; 32 ILM 1069 (1993)
1998 Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters (Aarhus Convention), 2161 UNTS 447; 38 ILM 517 (1999)
1992 Convention on Biological Diversity (CBD), 1760 UNTS 79; 31 ILM 818 (1992)
CBD (2003) Eighth Meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA), Montreal, Canada 10–14 March 2003. Recommendation VIII/3. Marine and coastal biodiversity: review, further elaboration and refinement of the programme of work
CBD (2004) Seventh Meeting of the Conference of the Parties to the CBD, Kuala Lumpur, 9–20 and 27 February 2004. Decision VII/5. Marine and coastal biological diversity
CBD (2011) Strategic plan for biodiversity 2011–2020. Further information related to the technical rationale for the Aichi Biodiversity targets, including potential indicators and milestones. UNEP/CBD/COP/10/INF/12/Rev.1
1969 Convention on Civil Liability for Oil Pollution Damage (CLC), 973 UNTS 3; 9 ILM 45
1991 Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention), 1989 UNTS *3*09
1973 Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), 993 UNTS 243
1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention), 1046 UNTS 120; 11 ILM 1294 (1972)
1992 Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention), 1507 UNTS 167; 1994 OJ (L 73) 20; 13 ILM 546 (1974)
Council Regulation (EC) No 602/2004 of 22 March 2004 amending Regulation (EC) No 850/98 as regards the protection of deepwater coral reefs from the effects of trawling in an area north west of Scotland, OJ L 97, 1.4.2004, p 30
Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (Habitats Directive), OJ L 206, 22.7.1992, p 7
Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment, OJ L 197, 21.7.2001, p 30
Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive, MSFD), OJ L 164, 25.6.2008, p 19
Directive 2011/92/EU of the European Parliament and the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment, OJ L 26, 28.01.2012, p 1
Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning, OJ L 257, 28.8.2014, p 135
Douvere F, Ehler CN (2009) New perspectives on sea use management: initial findings from European experience with marine spatial planning. J Environ Manag 90:77–88
European Commission (2008) Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions: guidelines for an integrated approach to maritime policy—towards best practice in integrated maritime governance and stakeholder consultation. Brussels, 26.6.2008. COM(2008) 395 final

FAO (2010) The state of world fisheries and aquaculture 2010. FAO, Rome. http://www.fao.org/docrep/013/i1820e/i1820e.pdf. Accessed 4 April 2016
Frank V (2007) The European community and marine environmental protection in the international law of the sea. Martinus Nijhoff, Leiden
Friedrich J (2013) International environmental "soft law". Springer, Heidelberg
Hall S (2002) The use of technical measures in responsible fisheries: area and time restrictions. In: Cochrane KL (ed) A fishery managers guidebook. Management measures and their application. FAO Fisheries Technical Paper. No. 424. FAO, Rome, pp 49–74
Hodgson S, Serdy A, Payne I, Gille J (2014) Towards a possible international agreement on marine biodiversity in areas beyond national jurisdiction. Study for the ENVI Committee. IP/A/ENVI/2014-04
IMO (2005) Assembly resolution A.982(24): revised guidelines for the identification and designation of particularly sensitive sea areas. http://www.imo.org/en/OurWork/Environment/PSSAs/Documents/A24-Res.982.pdf. Accessed 14 June 2016
73/78 International Convention for the Prevention of Pollution from Ships (MARPOL 73/78), 12 ILM 1319 (1973); 1340 UNTS 184
Kimball LA (2005) The international legal regime of the high seas and the seabed beyond the limits of national jurisdiction and options for cooperation for the establishment of marine protected areas (MPAs) in marine areas beyond the limits of national jurisdiction. Secretariat of the Convention on Biological Diversity, Montreal
Kiss A, Shelton D (2004) International environmental law. Transnational Publishing, Ardsley
Kloepfer M, Winter G (1996) Instruments of direct behavioural regulation. In: Winter G (ed) European environmental law. Dartmouth Publishing Company, Aldershot, pp 47–62
Kloepfer M, Kohls M, Ochsenfahrt V (2004) Umweltrecht. Verlag C. H. Beck, München
Lee M (2009) Law and governance of water protection policy. In: Scott J (ed), EU environmental governance (pp 1–35). Oxford: Oxford University Press
Malanczuk P (1997) Akehurst's modern introduction to international law. Routledge, London
Markus T, Schlacke S, Maier N (2011) Legal implementations of integrated ocean policies: the EU's marine strategy framework directive. Int J Mar Coastal Law 26:59–90
Newman S, Watkins E, Farmer A, ten Brink P, Schweitzer J-P (2015) The economics of marine litter. In: Bergmann M, Gutow L, Klages M (eds) Marine Anthropogenic Litter, pp 367–394. doi: 10.1007/978-3-319-16510-3_14
1991 Protocol on Environmental Protection to the Antarctic Treaty (Environment Protocol), 30 ILM 1455 (1991)
1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Protocol), 36 ILM 1 (1997)
Raumordnungsplan für die deutsche ausschließliche Wirtschaftszone in der Nordsee (Spatial Plan for the German Exclusive Economic Zone in the North Sea), Appendix volume to Federal Law Gazette I Nr. 61 of 25 September 2009; for an unofficial English translation see. http://www.bsh.de/en/Marine_uses/Spatial_Planning_in_the_German_EEZ/documents2/Spatial_Plan_North_Sea.pdf. Accessed 20 Mar 2016
Regulation (EU) No 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EC (Basic Regulation), OJ L 354, 28.12.2013, p 22.
1992 Rio Declaration on the Environment and Development (Rio Declaration), UN Doc. A/CONF.151/26 (vol. I); 31 ILM 87 (1992).
Sands P (2003) Principles of International Environmental Law. Cambridge University Press, Cambridge
Sands P, Peel J (2012) Principles of International Environmental law. Cambridge University Press, Cambridge
Salomon M, Markus T, Dross M (2014) Masterstroke or paper tiger—the reform of the EU's Common Fisheries Policy. Mar Policy 47:76–84

Seeanlagenverordnung (SeeAnlV) (Marine Facilities Ordinance), 23 January 1997, Federal Law Gazette I p 57, as last amended by Act of 31 August 2015 (Federal Law Gazette I p 1474)

1995 United Nations Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (Straddling Fish Stocks Agreement), 34 ILM 1542 (1995); 2167 UNTS 88

UNECE (2008). Spatial Planning—Key Instrument for Development and Effective Governance with Special Reference to Countries in Transition, ECE/HBP/146. http://www.unece.org/hlm/prgm/urbanenvperf/Publications/spatial_planning.pdf. Accessed 25 Mar 2016

1982 United Nations Convention on the Law of the Sea (UNCLOS), 1833 UNTS 3; 21 ILM 1261 (1982)

Chapter 32
Future Prospects of Marine Environmental Governance

Pradeep Singh and Aline Jaeckel

Abstract This chapter provides an outlook on the future of sustainable ocean governance with a particular focus on environmental protection. It identifies fragmentation, knowledge gaps, lack of international cooperation and coordination, as well as ineffective enforcement as some of the pressing challenges. These will likely increase both quantitatively and qualitatively in the future, as new and emerging ocean uses will be added to the list of stressors. This chapter discusses a number of options for the improvement of marine environmental governance into the future.

Keywords Ocean governance • Law of the sea • Marine environmental protection • Conservation principles, development, challenges of ocean governance • Future outlook on marine governance

32.1 Introduction

Currently at 7.3 billion people, the global population is expected to rise to 9.7 billion people in 2050 (UN Population Division 2015). A growing population will add to humanity's carbon footprint which had already increased 11-fold between 1961 and 2011 (Global Footprint Network 2011). This places further stress on the oceans. Demand for food, raw materials, and transportation has also increased, leaving the oceans 'heavily overfished and polluted and increasingly being tapped as the Earth's

P. Singh (✉)
Research Centre for European Environmental Law, University of Bremen, Bremen, Germany

International Research Training Group INTERCOAST – 'Integrated Coastal Zone and Shelf-Sea Research, University of Bremen, Bremen, Germany and University of Waikato, Waikato, New Zealand
e-mail: pradeep@uni-bremen.de

A. Jaeckel
Macquarie University, Sydney, NSW 2019, Australia

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_32

last great source of raw materials' (WBGU 2013: 21). Thus, humans have in the last 50 years 'triggered bigger changes in the oceans than have otherwise been seen in millions of years' (WBGU 2013).

This increase in human activity occurs against a background of fragmentation of governance and regulatory regimes, knowledge gaps, insufficient cooperation between states and other institutions, as well as largely ineffective enforcement mechanisms. These challenges are likely to increase both quantitatively and qualitatively in the future with new and emerging ocean uses, such as deep seabed mining and marine geoengineering, adding additional stress on the marine environment.

While there is a strong economic incentive for states to govern ocean activities in areas within their jurisdiction (compounded by the fact that it is comparatively easy to do so), there is also a growing realization that careful consideration needs to be placed on common resources in areas beyond national jurisdiction. Furthermore, the preamble of the 1982 UN Convention on the Law of the Sea (UNCLOS) notes that 'the problems of ocean space are closely interrelated and need to be considered as a whole', thereby affirming that all areas of the oceans should be given equally serious attention and treated as a shared concern.

Living up to this aim of integrated ocean management in the future will require several changes to the status quo. Any change must be in line with UNCLOS, which attempts to balance the competing uses of the oceans through the cooperation of states and international organization (Rothwell and Stephens 2016: 507). In other words, cooperation lies at the heart of governing common ocean spaces and resources now and into the future.

Against this background, this chapter aims to provide an outlook on the future prospects of marine environmental governance. The next section provides the context for this chapter, while section three then outlines the future prospects of ocean governance followed by some final observations in the conclusion.

32.2 Ocean Governance: Development, Norms and Tools, and Challenges

Before discussing the future prospects of ocean governance, it is necessary to first provide the context for this chapter. In doing so, this section summarizes (1) the development of the concept of ocean governance, (2) the key norms and tools currently used, as well as (3) the challenges to achieving adequate governance (see Chaps. 28–31). Accordingly, this section is divided into three parts.

32.2.1 Legal and Institutional Development of Ocean Governance

International law of the sea is largely separated into sectoral and geographical regimes. However, marine species, pollution, and the effects of climate change on the oceans, to name but a few issues, do not follow arbitrary borders drawn up by lawyers and diplomats (Tanaka 2015: 258). Similarly, migratory mammals or fish species cannot be managed in isolation from their habitat, food sources, and interferences with their migratory routes through shipping and other industries. In short, the fragmentation of the regulation and management of ocean spaces and resources is inadequate to respond to the complexities of managing and governing the oceans. Some preliminary steps have been taken to overcome this fragmentation and achieve coherent governance, which occurred against the background of the law of the sea increasingly recognising the interconnectivity of ocean spaces as outlined in the following paragraphs.

Rothwell and Stephens (2016: 516–517) identify three significant phases in the development of the law of the sea framework which has facilitated ocean governance. In the first phase, the period up until the adoption of the Geneva regime of 1958, limited attention was given to cross-cutting issues, as the focus was on coastal states' rights to exploit resources. The second phase, from 1959 up until 1982, witnessed the growing concern about marine environmental protection as well as the realization that a strict zonal approach would not be able to address competing uses and transboundary impacts. First steps were taken towards addressing those concerns through instruments such as the 1972 Stockholm Declaration on the Human Environment and the 1973/1978 International Convention for the Prevention of Pollution from Ships (MARPOL). The year 1982 marked the beginning of the third phase, in which the international community made strides towards viewing the oceans as a whole. The need for human interaction with the oceans to be governed through one single document was accepted, thus giving birth to UNCLOS, or otherwise known as the 'constitution for the oceans'. UNCLOS sought to set out a regulatory framework for *all* aspects of the law of the sea, including marine environmental protection. This effectively marked the shift from the primary focus on sovereignty, jurisdictional rights, and freedoms towards the incorporation of a shared responsibility to protect and preserve the marine environment (Freestone 2008: 387). With the conclusion of UNCLOS in 1982 and its subsequent widespread acceptance, the foundational framework for managing and governing the oceans in an integrated manner was firmly established and continues to be supplemented by an array of treaties and soft law instruments (Rothwell and Stephens 2016: 517). Most recently, in September 2015, UN General Assembly adopted the Sustainable Development Goals (SDGs'), in which the target set for Goal 14C is to:

> 'enhance the conservation and sustainable use of oceans and their resources by implementing international law as reflected in UNCLOS, which provides the legal framework for the conservation and sustainable use of oceans and their resources, as recalled in paragraph 158 of The Future We Want.'

Parallel to the advancements in the law of the sea, the concept of ocean governance developed through the involvement of a wide range of institutions, including: the International Maritime Organization; the International Tribunal for the Law of the Sea; the International Seabed Authority; regional fisheries management organization; regional seas organizations, such as the Commission for the Conservation of Antarctic Marine Living Resources; as well as administrative and facilitative entities, such as the UN Division for Ocean Affairs and the Law of the Sea; and scientific and technical advisory bodies, such as the Intergovernmental Oceanographic Commission of UNESCO (see Chap. 29). Against this background, and given the existence of a host of relevant organizations, it is time to achieve cross-sectoral as well as regional and global ocean governance, to work towards the conservation rather than the dimishment of our global commons.

32.2.2 Pertinent Norms and Tools

Ocean governance involves the application of a number of governance norms and principles as well as management tools in an integrated and cross-sectoral manner. Implementation as well as the institutional integration and coordination of these norms and tools pose significant challenges and are, thus, discussed in the next section. This section examines some of the overarching management norms that shape the goals as well as the necessary area-based tools to achieve them (see also Chaps. 30 and 31). With respect to the former category, two prominent examples are: (1) ecosystem-based management; and (2) the precautionary approach. With respect to the latter category, the area-based tools commonly used are: (1) marine spatial planning and (2) marine protected areas. Together, these components are necessary for effective management and governance of the oceans (Scott 2015: 481; Freestone 2008).

Ecosystem-based management (or 'ecosystems approach') is becoming the dominant frame of reference in the discourse of ocean governance. Under this concept, the focus is on the protection of the ecosystem itself, including the structure, processes and functions of the community of biological organisms and the interactions between them as well as between them and non-living components within a particular marine area (Secretariat of the Convention on Biological Diversity 2004: 6). An associated strategy complementing and supporting ecosystem-based management is to open one's view to managing 'large marine ecosystems', i.e. identifying large marine areas for their ecological importance, including the reproduction of living resources and functions of ecosystem services they perform (Vousden 2015: 387–389). Essentially, the wisdom behind this concept is that if the ecosystem is intact, the integrity and functions of the ecosystem will be preserved, which is ultimately reflected in the beneficial outcomes that follow.

The precautionary approach has become a core concept of international environmental law and is now an essential element of ocean governance (Scott 2015: 482; Marr 2003; Chap. 30). In short, it requires that action be taken to address environmental threats, even in the absence of full scientific certainty as to the extent and effect of the threat (Tanaka 2015: 40; Trouwborst 2006). The precautionary approach is closely connected to the ecosystems approach and, as such, they complement each other (Trouwborst 2009; Tanaka 2008: 82). Similarly, environmental impact assessment is linked to both concepts, as it supports the identification of potential harm, the value of the ecosystem in question, and prudent management measures to minimize the harm (regarding the legal status of the requirement to conduct an environmental impact assessment under international customary law see Chap. 30).

Marine spatial planning is based on the premise that human activities and their associated stresses on the marine environment can be geographically mapped. This allows the locations of the potential harm to be estimated, as well as their vulnerabilities to particular types of harm, based on the best available science and information (Zacharias 2014: 292; Chap. 53). This useful planning tool allows for activities to be carried out in those locations where the extent of the harm has the least serious consequences, which in turn can help to preserve ecosystem integrity (Markus et al. 2015: 164). By utilizing marine spatial planning strategies, opportunities could be identified for different sectors of marine activities, while maintaining and preserving the overall health and productivity of the area of concern (Zacharias 2014: 293).

Marine protected areas (MPAs) are essentially areas of environmental interests that are protected from certain activities, such as fisheries or mineral exploitation (Chaps. 44 and 45). They are an important management tool, not least to protect breeding grounds and other important locations from disturbances. However, because of the fragmentation of ocean governance, each competent organization can only designate MPAs with respect to the activity it regulates. For example, an MPA designated by a regional fisheries management organization can still be subject to deep seabed mineral mining under the auspices of the International Seabed Authority.

In addition to MPAs, a number of other spatial concepts exist within particular governance regimes. For example, the International Maritime Organization may designate 'special areas' and 'particularly sensitive sea areas' to protect them from pollution from shipping (Kachel 2008). Similarly, the International Seabed Authority has designated 'areas of particular environmental interests' and the regime under the Convention on Biological Diversity works with 'ecologically or biologically significant marine areas' (Chap. 44).

Despite the existence and acceptance of these norms, principles, and tools, the degradation of the global oceans through human activities not only persists but is increasing exponentially, which is compounded by the fact that several challenges continue to linger on as obstacles to ocean governance (Scott 2015: 463–464). The next section turns to these challenges.

32.2.3 Challenges

UNCLOS provides the framework for ocean governance and, as the previous section demonstrates, a number of norms and tools already exist to enable the management of numerous ocean uses. However, the challenges for achieving ocean governance are, nonetheless, numerous.

As noted at the outset, the core challenge for achieving integrated ocean governance is fragmentation (see also Chap. 28; Harrison 2015a: 73). Individual sectors as well as regions are subject to different rules, often institutionalised through a regional organization, such as regional fisheries management organizations, or international organizations with competencies to regulate and manage a particular activity. For example, the International Seabed Authority regulates deep seabed mineral mining on the entire seabed beyond national jurisdiction, which lies directly underneath most of the high seas where fishing, shipping, vessel-based pollution and other activities take place.

Against this background, achieving coherent and integrated ocean governance will require several changes, each of which is challenging in its own right. First, there is an urgent need to significantly increase our understanding of marine ecosystems and their interactions and vulnerabilities to impacts, as well as the longitudinal and cumulative effects of human activities. At present, only around 5% of the oceans have been systematically explored by humans (Williams et al. 2011: 2). This portion becomes infinitesimal when assessing only seabed environments (Widdicombe and Somerfield 2012: 1). In fact, although research efforts have been increasing (Ramirez-Llodra et al. 2010), the deep sea 'is the largest and least known ecosystem on the planet' (Williams et al. 2011: 4).

Second, the assessment, regulation, and management of ocean activities need to take into account not only their own direct effects on the marine environment but also the cumulative effects of numerous different impacts (Gjerde 2010; Chang 2012: 57; Chap. 28).

Third, the aforementioned norms and tools of ocean governance, such as ecosystem-based management and the precautionary approach, need to be implemented in practice by all organizations involved, including states and international organizations with competencies over ocean activity (UN Doc A/61/65, para. 33). Regulations need to give effect to these norms and create avenues that enable these tools to be deployed. Fourth, at present, different protection standards exist with respect to activities in areas within national jurisdiction as compared to areas beyond national jurisdiction. These would need to be checked for their compatibility in order to achieve protection of the ecosystems that extend to both sides of the divide. While many coastal states have established environmental governance and assessment structures for marine areas within their national jurisdiction—although these are not always enforced—these structures are only just beginning to emerge and develop for areas beyond national jurisdiction (Warner 2015: 291–292).

Fifth, a wide knowledge gap currently exists between the various regimes. As marine regimes are sectoral and activity-specific, they develop and operate in isolation (Warner 2016: 397–401). Crucial scientific knowledge as well as governance experience from existing regimes, which could be adopted by emerging regimes, are often unavailable, forcing the latter to invent and develop its own mechanisms which subsequently adds to the problem of inconsistency and incoherence.

Sixth, and crucially, the fragmentation in governance needs to be addressed, e.g. through better coordination between the actors who coordinate different ocean uses in a given area. In general, the lack of international cooperation in ocean activities presents a challenge to ocean governance. This includes cooperation between states and institutions, and covers not only regulatory aspects but also implementation and enforcement. A case in point is the need for multipurpose marine protected areas. As discussed above, MPAs are currently focused on a single use, which limits their efficacy. Moreover, enforcing MPAs would require coordination amongst several agencies and organizations.

32.3 Future Outlook on Ocean Governance

Achieving cross-sectoral ocean governance is an ambitious aim requiring high levels of cooperation and coordination amongst states and a range of national, regional and international organizations. Unfortunately, in the future the challenges will increase both quantitatively and qualitatively. In principle, the rise in the world population as well as the continuous focus on economic growth equate to even higher numbers of shipping fleets, fishing vessels, and oil and gas exploitation (Chap. 27). What is more, the increasing pressures on the ocean in the future will not be limited to traditional uses but will also include entirely new human activities. Examples are: wind, wave, and tidal energy generation; deep seabed mineral mining; bioprospecting; and geoengineering (Chaps. 42, 43 and 52).

In addition, human activities could move further into the deep oceans in the future. While the surface and the upper zone of the water column have been subject to numerous human activities, the dark and high pressure environment of the deep ocean is extremely challenging to navigate. However, approximately 90% of the oceans are deep sea, generally defined as below 200 m, and around 50% of the oceans are below 3000 m depth (Ramirez-Llodra et al. 2010: 2852–2854). In the quest for resources, humans have been advancing into the deep ocean, for example for fisheries, hydrocarbon, and mineral resources. This compounds the challenges for achieving ocean governance, not least because scientific understanding about the deep oceans is in its infancy, making it necessary to manage human activities in the face of very high levels of uncertainties. In this context, a number of scientists have been calling for deep ocean stewardship, ahead of expanding and emerging uses of the deep sea (Mengerink et al. 2014).

A number of suggestions have been made for achieving ocean governance against the background of these growing challenges. The idea of a single forum or organization to address all law of the sea issues was rejected during negotiations in the twentieth century. Such a forum would, inter alia, risk developing ‘excessively uniform standards’ to wide-ranging activities and sectors without considering the dissimilar interests concerned (Harrison 2015b: 391; Francois 1956, para. 9).

Even though a single forum might create more problems than it solves, the idea of an overarching, integrated set of rules to govern the oceans at large, implemented by specialised sectoral and regional regimes, offers an alternative. After all, just as the oceans are vast ecosystems with intrinsic connections between various habitats, so too should the legal and policy response interconnect all ocean management regimes. However, overarching rules could blur the distinction between areas under national jurisdiction and areas beyond national jurisdiction. As Treves realistically identifies, at present, states are not prepared to consider legal rules ‘that could be perceived as taking away parcels of their newly-acquired sovereign rights and jurisdiction over adjacent seas', however desirable that may be (Treves 2010: 12). In other words, sovereignty interests operate as an impediment to designing laws that correspond to the ecological reality of oceans. Therefore, as observed by Harrison (2015b: 391), perhaps the question should be 'not how we can avoid fragmentation, but how we can manage it'.

One suggestion for managing fragmentation is to achieve a level of coherence between the various ocean regimes through shared conservation and management principles. An example is offered by the *IUCN 10 Principles for High Seas Governance*, developed in 2007 (IUCN; Freestone 2012: 199–200), which include a science-based approach to management, public availability of information, an ecosystem approach and a precautionary approach. A coherent application of such legal principles can play a key part in reducing the current fragmentation of the law of the sea, by melting the bases of the various piecemeal regimes into a solid, principled foundation. These principles could be applied not only to present uses but also to new and emerging ocean uses, even in absence of a specific legal regime to regulate these uses. However, the success of this suggestion will depend on all states and organizations fully implementing governance principles in practice (Fisher et al. 2006; Jaeckel 2017).

Closely linked to shared conservation and management principles is the adoption of shared environmental protection strategies. One such example is the Arctic Environmental Protection Strategy of 1991. This option has been underutilized and could be given more attention in the future, particularly by emerging regimes. Through an instrument like this, a detailed strategy to address environmental concerns can be outlined, including the identification of competing uses and measures to manage them in order to minimize environmental impacts. Such an instrument could be developed together by regimes whose functions overlap, with a view to enhance cooperation, address knowledge gaps, and carry out joint monitoring of activities. This could be particularly effective on the international seabed, legally known as the Area, where activities pertaining to mining, bioprospecting and utilization of living resources, laying of submarine cables, and marine scientific research will be carried out. A challenge would be to effectively implement and enforce such a strategy, especially if it is not legally binding.

An important suggestion, complementing the aforementioned options, is that of enhancing cooperation in decision-making, implementation, and enforcement. As noted by Tanaka (2015: 34), the principle of cooperation is one of the pillars of marine environmental law (see also Chap. 30). In fact, 'international cooperation is a prerequisite to marine environmental protection' and covers not only cooperation between states but also between international and regional institutions (Tanaka 2015: 52–53). What is more, cooperative maritime surveillance and enforcement, both regionally and internationally, is essential to ocean governance (Gullett and Shi 2016). UNCLOS specifically provides for cooperation between states as well as international organizations (UNCLOS, preamble) with respect to numerous issues, such as navigation and transport (e.g. arts. 41(5), 43, 129), fisheries (e.g. arts. 61(2), 64, 66, 117, 118), preventing piracy and drug-trafficking (e.g. arts. 100, 108), marine scientific research (e.g. arts 143, 242–244), marine environmental protection (e.g. arts. 197–201), management of the common heritage of mankind (e.g. arts. 138, 150, 169), and enforcement and further development of law of the sea (e.g. art 235).

Cooperation can take several forms, one of which is the establishment of multipurpose marine protected areas, which protect the environment not only from one activity but also from other impacts. Tentative steps towards such cooperation can be observed, for example in the North-East Atlantic. The North-East Atlantic Fisheries Commission (NEAFC) and the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic have both declared a number of areas, which are safeguarded from adverse impacts associated with specific activities within their mandate, including pollution and bottom fishing, and which overlap with the protected areas by the respective other organization (OSPAR Commission 2013). Building on this collaboration, in 2014, both Commissions concluded a *Collective Arrangement Between Competent International Organizations on Cooperation and coordination regarding selected areas in Areas Beyond National Jurisdiction in the North-East Atlantic*. This arrangement focuses on MPAs designated by either party in order to commit them to 'cooperate and seek coordination to ensure that suitable measures for the conservation and management of these areas are implemented [...]' (ISBA/20/C/15 2014, enclosure II, para. 5). This collaboration, although non-binding, could broaden the existing cooperation between both organizations to include a general, mutual recognition of MPAs adopted by either party with respect to the sectoral activities within their competencies. Other organizations, such as the International Maritime Organization and the International Seabed Authority, both of which have some jurisdiction in the North-East Atlantic, are currently considering whether to join the collective arrangement between the NEAFC and the OSPAR Commission (ISBA/21/C/9). Increasing collaborative initiatives such as this one would go some way towards addressing the fragmentation challenge.

A further suggestion that has been made is to facilitate scientific advice in marine environmental decision-making by

> 'creating a United Nations Oceans Commission (UNOC) in order to provide both scientific and policy advice to the decision-making organs of the UN system on the long-term health of the oceans, their ability to sustain marine life, their complex interrelationship with climate futures and associated weather patterns, and their future as a reliable source of global protein requirements' (Rudd 2016: 52).

A commission such as this, which is solely tasked to provide scientific and policy advice, could help to address the concerns regarding knowledge gaps and contribute to better ocean governance. States would be more amenable and receptive to this as opposed to a single, all-encompassing, regulatory forum for ocean affairs. Closely connected to this point is the need for greater transparency and participation in the decision-making processes for ocean governance, which would inter alia help enhance legitimacy (Christiansen et al. 2016; Ardron et al. 2014).

With these suggestions in mind, the prospect of a future agreement on marine biodiversity in areas beyond national jurisdiction (ABNJ), a topic which fits squarely within the challenges earlier mentioned and anticipated to be in the forefront of ocean governance in the near future, warrants specific consideration.

Marine biodiversity is subject to numerous stressors from various industries, yet there is no regulatory or governance framework to address biodiversity protection from the various human activities on and in the oceans (UN Doc A/67/95 2012, paras. 34–45; Gjerde et al. 2008a). The need to close these gaps has been highlighted by numerous scholars (Matz 2002; Molenaar 2007; Rayfuse and Warner 2008; Gjerde et al. 2008b; Warner 2009; Chap. 44). As Freestone summarizes, 'the case for a new instrument, perhaps based on agreed principles, to pull together all the various themes and sectoral responsibilities and to provide some overarching system of governance of the high seas, is becoming very difficult to resist' (Freestone 2012: 204). In the context of this discussion, there is consensus on the fact that the gaps need to be addressed with a science-based, precautionary approach, with environmental legal principles at the core of any answer (UN Doc A/61/65 2006, para 33, annex I para 5; Rio + 20 UN Conference on Sustainable Development 2012, paras. 158, 162; Freestone 2008: 391; Treves 2010: 21).

A number of states and non-governmental organizations have been lobbying for a new international agreement, possibly an implementing agreement to UNCLOS, to regulate the protection of marine biodiversity in ABNJ (UN Doc A/69/780* 2015, para. 42). However, opinions over the desirability of such an agreement diverge (UN Doc A/67/95 2012, paras 41–47; Druel et al. 2013: 23–33). Momentum was gained in 2011, when for the first time the EU and the Group of 77 plus China and Mexico agreed on a common position favouring a 'package deal' addressing issues concerning marine scientific research, marine protected areas, environmental impact assessments, capacity-building and the transfer of marine technology (UN Doc A/66/119 2011, paras 17, 42).

In 2015, following lengthy negotiations in the *United Nations Working Group to Study Issues Relating to the Conservation and Sustainable Use of Marine Biological Diversity Beyond Areas of National Jurisdiction*, the UN General Assembly adopted a formal recommendation to develop a legally binding agreement (UN Doc A/69/780* 2015; UN Doc A/RES/69/292 2015). As a result, a Preparatory Committee worked in 2016 and 2017 to '*make substantive recommendations to the General* Assembly on the elements of a draft text of an international legally binding instrument under [UNCLOS]' (UN Doc A/69/780* 2015, para. 1(e)). This process has been completed and the Preparatory Committee has since forwarded its findings to the UN General Assembly. Subsequently, the UN General Assembly will 'decide on the convening and on the starting date of an intergovernmental conference, under the auspices of the United Nations, to consider the recommendations of the preparatory committee on the elements and to elaborate the text of an international legally-binding instrument under the Convention' (ibid). It will likely take several years until an agreement is reached. However, a new agreement, if and when it will be adopted, could provide a momentous opportunity to address some of the governance gaps regarding marine biodiversity in ABNJ and contribute to integrated ocean governance based on shared environmental legal principles.

32.4 Conclusion and Perspectives

This chapter has demonstrated the pressing need to address the challenges of the adverse effects of fragmentation in marine environmental governance, which can be done through a number of measures, including shared governance principles and management tools as well as increased cooperation between states and regional and international organizations. In addition, it is also expected that the role of science will increase in the future. In this context, the integration of scientific advice in environmental decision-making will become more widespread. This will be particularly pertinent as human activities venture further into the deep oceans that remain largely unexplored and, thus, necessitate environmental management in the face of very high levels of uncertainty. It will also be necessary for scientific advice to have a certain degree of uniformity. For instance, advice regarding the environmental management of deep seabed mineral mining should ideally be consistent with the advice regarding the emerging regime on the exploitation of living resources in areas beyond national jurisdiction. Again, cooperation between regimes will facilitate the exchange of scientific advice.

Finally, in the future, we might see greater attention being paid to ocean-atmosphere interaction, even in the deep ocean. The 10 year 'Census of Marine Life' project found that:

> 'past impacts in the deep sea were mainly from disposal of waste and litter. Today, fisheries, hydrocarbon, and mineral extraction have the greatest impact. In the future, climate change is predicted to have the greatest impact' (Williams et al. 2011: 3).

As a result, a further set of challenges will be posed by mitigating the effects of climate change, potentially enhancing the use of oceans as carbon sinks through geoengineering methods such as ocean fertilization and carbon storage, as well as addressing the problem of ocean acidification and other climate-related effects, which ignore jurisdictional boundaries and sectoral divides.

In conclusion, governing our oceans will likely become more difficult, not less, in the future. As our uses of the oceans increase, so, too, does the pressing need for governance solutions.

References

Ardron J et al (2014) Tracking twenty-four years of discussions about transparency in international marine governance: where do we stand? Stanford Environ Law J 33(2):167

Chang Y (2012) Ocean governance: a way forward. Springer, Heidelberg

Christiansen S et al (2016) Towards transparent governance of deep seabed mining IASS Policy Brief 2/2016. http://www.iass-potsdam.de/en/content/towards-transparent-governance-deep-seabed-mining

Druel E et al (2013) A long and winding road—international discussions on the governance of marine biodiversity in areas beyond national jurisdiction. Studies No 07/13. IDDRI

Fisher F et al (2006) Implementing the precautionary principle: perspectives and prospects. In: Fisher E et al (eds) Implementing the precautionary principle: perspectives and prospects. Edward Elgar, Cheltenham
Francois JPA (1956) Regime of the high seas and regime of the territorial sea, Doc. A/CN.4/97*. Yearbook of the International Law Commission II
Freestone D (2008) Principles applicable to modern oceans governance (editorial). Int J Mar Coastal Law 23(3):385
Freestone D (2012) International governance, responsibility and management of areas beyond national jurisdiction. Int J Mar Coastal Law 27(3):191
Gjerde KM et al (2008a) Current legal developments—IUCN workshop on high seas governance for the 21st century. Int J Mar Coastal Law 23(2):359
Gjerde KM et al (2008b) Regulatory and governance gaps in the international regime for the conservation and sustainable use of marine biodiversity in areas beyond national jurisdiction. IUCN, Gland
Gjerde KM (2010) Modalities for advancing cross-sectoral cooperation in managing marine areas beyond national jurisdiction: draft for discussion. UNEP Briefing paper, UNEP (DEPI)/RS.12 /8. http://www.unep.org/regionalseas/globalmeetings/12/wp08-managing-marine-areas-beyond-national-jurisdiction.pdf
Global Footprint Network (2011) Carbon footprint. http://www.footprintnetwork.org/en/index.php/GFN/page/carbon_footprint/
Gullett W, Shi Y (2016) Cooperative maritime surveillance and enforcement. In: Warner R, Kaye S (eds) Routledge handbook of maritime regulation and enforcement. Routledge, New York
Harrison J (2015a) Actors and institutions for the protection of the marine environment. In: Rayfuse R (ed) Research handbook on international marine environmental law. Edward Elgar, Cheltenham
Harrison J (2015b) The law of the sea convention institutions. In: Rothwell D, Elferink A, Scott K, Stephens T (eds) The Oxford handbook on the law of the sea. Oxford University Press, Oxford
ISA, ISBA/20/C/15 (1 July 2014)
ISA, ISBA/21/C/9 (3 June 2015)
IUCN. 10 principles for high seas governance. http://cmsdata.iucn.org/downloads/10_principles_for_high_seas_governance___final.pdf
Jaeckel A (2017) The International Seabed Authority and the precautionary principle. Brill, Leiden
Kachel M (2008) Particularly sensitive sea areas: the IMO's role in protecting vulnerable marine areas. Springer, Berlin
Markus T, Huhn K, Bischof K (2015) The quest for seafloor integrity. Nat Geosci 8:164–165
Marr S (2003) The precautionary principles and the law of the sea: modern decision-making in international law. Martinus Nijhoff, Leiden
Matz N (2002) Marine biological resources: some reflections on concepts for the protection and sustainable use of biological resources in the deep sea. Non-State Actors Int Law 2:279
Mengerink KJ et al (2014) A call for deep-ocean stewardship. Science 344(6185):696
Molenaar EJ (2007) Managing biodiversity in areas beyond national jurisdiction. In: Nordquist MH et al (eds) Law, science and ocean management. Martinus Nijhoff, Leiden
OSPAR Commission (2013) 2012 Status report on the OSPAR network of marine protected areas. http://www.ospar.org/documents/dbase/publications/p00618/p00618_2012_mpa_status%20report.pdf
Ramirez-Llodra E et al (2010) Deep, diverse and definitely different: unique attributes of the world's largest ecosystem. Biogeosciences 7:2851
Rayfuse R, Warner R (2008) Securing a sustainable future for the oceans beyond national jurisdiction: the legal basis for an integrated cross-sectoral regime for high seas governance for the 21st century. Int J Mar Coastal Law 23:399
Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area, Advisory Opinion, 2011, ITLOS Decision No 17
Rothwell D, Stephens T (2016) The international law of the sea, 2nd edn. Hart Publishing, Oxford

Rudd K (2016) UN 2030: rebuilding order in a fragmenting world. In: Chair's Report, Independent Commission on Multilateralism. International Peace Institute, New York
Scott KN (2015) Integrated oceans management: a new frontier in Marine environmental protection. In: Rothwell D, Elfreink A, Scott K, Stephens T (eds) The Oxford handbook on the law of the sea. Oxford University Press, Oxford
Secretariat of the Convention on Biological Diversity (2004) The ecosystem approach (CBD guidelines). https://www.cbd.int/doc/publications/ea-text-en.pdf
Tanaka Y (2015) Principles of international marine environmental law. In: Rayfuse R (ed) Research handbook on international marine environmental law. Edward Elgar, Cheltenham
Tanaka Y (2008) A dual approach to ocean governance: the cases of zonal and integrated management in international law of the sea. Routledge, New York
Tetzlaff K (2016) The role of regional organizations. In: Warner R, Kaye S (eds) Routledge handbook of maritime regulation and enforcement. Routledge, New York
The Future We Want. UN Doc A/CONF.216/L.1 (19 June 2012)
Treves T (2010) Principles and objectives of the legal regime governing areas beyond national jurisdiction. In: Oude Elferink AG, Molenaar EJ (eds) The international legal regime of areas beyond national jurisdiction: current and future developments. Martinus Nijhoff, Leiden
Trouwborst A (2006) Precautionary rights and duties of states. Martinus Nijhoff, Leiden
Trouwborst A (2009) The precautionary principle and the ecosystem approach in international law: differences, similarities and linkages. Rev Euro Commun Int Environ Law 18(1):26
UN Doc A/61/65 (20 March 2006)
UN Doc A/66/119 (30 June 2011)
UN Doc A/67/95 (13 June 2012)
UN Doc A/69/780* (13 February 2015)
UN Doc A/RES/69/292 (19 June 2015)
UN Population Division (2015) World population 2015. https://esa.un.org/unpd/wpp/Publications/Files/World_Population_2015_Wallchart.pdf
Vousden D (2015) Large marine ecosystems and associated new approaches to regional, transboundary and 'high seas' management. In: Rayfuse R (ed) Research handbook on international marine environmental law. Edward Elgar, Cheltenham
Warner R (2009) Protecting the oceans beyond national jurisdiction: strengthening the international law framework protecting the oceans beyond national jurisdiction: strengthening the international law framework. Martinus Nijhoff, Leiden
Warner R (2015) Environmental assessment in marine areas beyond national jurisdiction. In: Rayfuse R (ed) Research handbook on international marine environmental law. Edward Elgar, Cheltenham
Warner R (2016) Developing new regulatory paradigms for the conservation and sustainable use of marine biodiversity in areas beyond national jurisdiction. In: Warner R, Kaye S (eds) Routledge handbook of maritime regulation and enforcement. Routledge, New York
WBGU, German Advisory Council on Global Change (2013) World in transition: governing the marine heritage. http://www.wbgu.de/fileadmin/templates/dateien/veroeffentlichungen/hauptgutachten/hg2013/wbgu_hg2013_en.pdf
Widdicombe S, Somerfield PJ (2012) Marine biodiversity: its past development, present status, and future threats. In: Solan M, Aspden RJ, Paterson DM (eds) Marine biodiversity and ecosystem functioning: frameworks, methodologies, and integration. Oxford University Press, Oxford
Williams M et al (2011) Scientific results to support the sustainable use and conservation of marine life: a summary of the census of marine life for decision makers. Census of Marine Life International Secretariat
Zacharias M (2014) An introduction to governance and international law of the oceans. Routledge, New York

Part VII
Traditional Marine Management Topics

Chapter 33
The International Legal Framework for Conservation and Management of Fisheries and Marine Mammals

Andrew Serdy

Abstract The record and ever-present danger of overfishing of living resources requires there to be a legal framework for the international management of these oceanic resources. The chapter opens with a history of the legal fisheries regime as it has developed since the late nineteenth century when the negative impact of overfishing on stocks was first noticed, highlighting how the remedial measures have had limited success because they have been biologically rather than economically grounded, including the pivotal concept, maximum sustainable yield. It then turns to an examination of the fisheries regime in the 1982 UN Convention on the Law of the Sea, both in the exclusive economic zone, where the bulk of fisheries take place, and on the high seas. The following section then deals with six major innovations by which the 1995 UN Fish Stocks Agreement attempts to overcome these problems for stocks that straddle the boundary between national zones and the high seas or are highly migratory; this is complemented by the 1993 FAO Compliance Agreement covering some of the same ground. Non-economic uses have in recent decades become dominant as regards marine mammals. The framework for these is briefly introduced. Finally, a concluding section on current issues and future developments concentrates on the perennial problem of allocation among States of limited participatory rights in international fisheries and on the composite concept of illegal, unreported and unregulated fishing, which, because it is usually treated as a single undifferentiated phenomenon, threatens to obscure the important distinction between fishing that is unlawful and fishing that is merely unregulated.

Keywords Maximum sustainable yield • IUU (illegal unreported and unregulated) fishing • Rights-based management • Whaling • High seas • Exclusive economic zone • UNCLOS • UN Fish Stocks Agreement

---

A. Serdy
University of Southampton, Southampton, UK
e-mail: A.L.Serdy@soton.ac.uk

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_33

33.1 Introduction: Conservation of Marine Living Resources Before the UN Convention on the Law of the Sea

This chapter describes the main elements of the global legal framework for the conservation and management of marine capture fisheries[1] as well as marine mammals. The law seeks to combat overfishing, but has done so with only limited success, because it approaches the problem mainly from the biological perspective, having neglected until relatively recently the economic factors that make overfishing all but inevitable if ignored, chiefly the "tragedy of the commons" phenomenon (Hardin 1968: 1243–1248), by which, in the absence of property rights, it becomes rational for individual participants in a fishery to deplete stocks despite the damage this does to the common interest. The human impact on stocks was first noticed in the late nineteenth century in the North Sea, through falling catches consisting of younger (i.e. smaller) fish. At this stage, regulation took the form of minimum length of fish that could lawfully be retained and minimum mesh size of nets. But this proved insufficient, as improving technology enabled the warning signs from local depletion of stocks to be ignored; the fleets would simply go further afield, giving rise to the still existing phenomenon of distant-water fishing.

Even the purely biological approach has oversimplified the real world, notably though the central concept of maximum sustainable yield (MSY) which is predicated on a single-stock fishery, and examples of legally mandated pursuit of the ecosystem approach, taking account of predator-prey and competitive relationships among coexisting species, are rare.

33.2 Past and Present Legal and Institutional Frameworks Governing International Fisheries

33.2.1 The Historical Background

The history of the regime's development is marked by the gradual move away from the now abandoned assumption of inexhaustibility of marine living resources, and from freedom of fishing, which to a significant degree persists and acts both as one of the main causes of overexploitation of stocks and a chief obstacle to their rebuilding. The basic regulatory mechanisms were initially simple.

Traditionally, measures were designed to inhibit fishing—a form of compulsory inefficiency, which has been criticised on economic grounds. At the beginning of international fisheries management in the early twentieth century, States interested in a fishery would jointly decide, usually on the basis of scientific advice, on what we now call input controls—broadly, numerically expressed restrictions on factors

[1] For a fuller treatment of that framework, the reader is referred to Rothwell and Stephens (2016), Chapter 13 (part III on marine living resources).

of production in fisheries, such as gear, vessel size and design, also time—necessary to avoid overfishing (see e.g. the 1946 Convention for the Regulation of the Meshes of Fishing Nets and the Size Limits of Fish). These tended not to work well, because they could easily be circumvented by what is known as “effort creep”, the substitution of unrestricted inputs for restricted ones, which themselves then become subject to restrictions in order to prevent excessive fishing pressure on the stock, a typical sequence of individual inputs successively regulated being caps on the number of vessels in a fishery, followed by limits on the size and then engine power of individual vessels, and then limits on the numbers of days per year a vessel may spend on the fishing grounds. Thus the emphasis later shifted to output controls, i.e. limits on the weight or number of fish that could be safely removed from a stock, in the form of a total allowable catch (TAC).

Though rare nowadays, formerly the prevailing trend was the so-called “Olympic” fishery, that is, one in which all participating States’ fleets could compete for the available TAC and the fishery was simply closed for the season when it was reached. In the early 1970s country quotas were introduced in the Northwest Atlantic Fishery Organisation (NAFO) (created by Art. 1 1978 Convention on Future Multilateral Cooperation in the Northwest Atlantic Fisheries) and have since spread to become the management method of choice, though their adoption had not been universal; the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR; created by Art. VII(1) 1980 Convention on the Conservation of Antarctic Marine Living Resources) is an anomalous exception.

Early regulatory attempts were not successful. In the 1893 Bering Sea arbitration against the UK (on behalf of Canada) (Arbitral Tribunal Established under the Treaty Signed in Washington, on the 29th of February 1892, between the United States and Her Majesty the Queen of the United Kingdom of Great Britain and Ireland, Decision of 15 August 1893) the claim by the US of property rights in seals found on the high seas, to protect them against pelagic sealing (on the basis that they came from rookeries on US islands) was not accepted, but this eventually led to the very successful 1911 Convention between the United States of America, Great Britain, Russia and Japan for the Preservation and Protection of Fur Seals in which the land-based producers effectively bought out their pelagic rivals. The 1930s saw the first attempts at regulating whaling (1931 Convention for the Regulation of Whaling; 1937 International Agreement for the Regulation of Whaling) as well as the entry into force of earlier US-Canada treaties on Pacific halibut (1923 Convention for the Preservation of the Halibut Fishery of the Northern Pacific Ocean) and salmon (1930 Convention for the Protection, Preservation and Extension of the Sockeye Salmon Fisheries of the Fraser River System). All of this took place against the background of freedom of fishing in customary international law, codified in the 1958 Convention on the High Seas as having to be exercised with reasonable regard to the interests of other States. The high seas at the time encompassed all the world’s ocean seaward of coastal States’ territorial seas, on whose maximum extent there was no agreement: although most States favoured a maximum of 3–12 nautical miles (nm), some Latin American States claimed 200-nm territorial seas, largely in order to control the living resources out to that distance (see generally Hollick

1977). The coastal State had complete sovereignty over its territorial sea and the fish stocks within it, but this was inadequate for proper conservation of fisheries because even with unsophisticated technology fisherfolk were able to venture beyond onto the high seas. As an area beyond the spatial jurisdiction of any State, so that each fishing vessel is subject to control only by its own State of registration (flag State), the stocks were unprotected there against depletion by unregulated vessels flagged to distant-water fishing States. These often operated just beyond the territorial sea's outer limit, visible from shore, with many complaints of their gear interfering with that of the local fleet.

States could still mutually limit their catches on the high seas by treaty, but such catch limits were binding only on those States that were in the system, and not against outsiders. It is a basic principle of treaty law that treaties are binding only on the parties to them, and on no other States (Art. 34 Vienna Convention on the Law of Treaties). Very widely accepted treaty rules of general application can become part of customary international law binding on all States (Art. 38 Vienna Convention on the Law of Treaties), but catch limits expressed in terms of X tonnes for State Y are not of general application.

Set up in 1947 by the UN General Assembly to codify and progressively develop international law, the International Law Commission (ILC) soon recognised this as a problem, but also its own lack of technical competence to deal with it. In its 1953 report the ILC proposed the following text:

> States shall be under a duty to accept, as binding upon their nationals, any system of regulation of fisheries in any area of the high seas which an international authority, to be created within the framework of the United Nations, shall prescribe as being essential for the purpose of protecting the fishing resources of that area against waste or extermination. Such international authority shall act at the request of any interested State (UN 1959).

In its comprehensive overhaul of the draft articles in the wake of the 1955 (Rome) International Technical Conference on the Living Resources of the Sea,[2] however, the ILC abandoned the idea of an international organisation, electing instead to elaborate on a statement adopted at that conference on the special interest of coastal States in the fisheries immediately beyond their territorial seas, which had been adopted by a narrow margin. The ILC's work on the law of the sea as a whole led to the convening of the [First] UN Conference on the Law of the Sea in 1958, which adopted four conventions, two of which were relevant to fishing. One was the High Seas Convention already mentioned, the other was the 1958 Convention on Fishing and Conservation of Living Resources of the High Seas, which later influenced the high seas fisheries articles (116–119) of the 1982 United Nations Convention on the Law of the Sea (UNCLOS).

[2] The Conference was convened by the UN General Assembly in its Resolution 900(IX) of 14 December 1954 in order to "study the problem of the international conservation of the living resources of the sea and to make appropriate scientific and technical recommendations." Based on this report, García Amador, a Cuban member of the ILC who had been Deputy Chairman of the Rome Conference, submitted to the ILC's 1955 session new draft articles which were adopted with minor amendments, see UN 1960, pp. 29–31.

The 1958 Conventions, however, ignored the several fisheries commissions already set up in various parts of the world to enable States to co-operate for the management and conservation of high seas fisheries in specific ocean areas (the International Commission for the Conservation of the Northwest Atlantic Fisheries (Art. II 1949 International Convention for the Northwest Atlantic Fisheries)—the predecessor of NAFO—and the Inter-American Tropical Tuna Commission (IATTC; created by the 1949 Convention for the Establishment of an Inter-American Tropical Tuna Commission) or of specific species such as the Pacific salmon and halibut bodies already mentioned. The general weakness of such commissions is that States are reluctant to transfer sovereign powers to international bodies, so even when they have management powers they have no enforcement powers, being intended only to establish and divide up catch limits. The 1958 conference also failed to adopt a compromise solution on the seaward extent of coastal States' fisheries jurisdiction, which would have produced a territorial sea of 6 nm and a further 6 nm of exclusive fisheries jurisdiction. The Second UN Conference on the Law of the Sea, called in 1960 to deal solely with this outstanding issue, fell short by a single vote of the two-thirds majority needed to adopt a modified version of this proposal. Over the next decade, many States moved nonetheless to claim 12-nm fisheries zones, and by the time of the dispute over Iceland's 1972 extension of its fisheries jurisdiction to 50 nm, the International Court of Justice (ICJ) recognised the 12-nm entitlement as having achieved the status of customary international law, though it was not prepared to endorse the Icelandic claim (Fisheries Jurisdiction Cases (United Kingdom v. Iceland; Federal Republic of Germany v. Iceland), ICJ Reports 1974: 3 and 175 respectively).

33.2.2 Living Resources Under the UN Convention on the Law of the Sea

33.2.2.1 The Exclusive Economic Zone

At the Third UN Conference on the Law of the Sea, which ran from 1973 to 1982, it was the new institution of the exclusive economic zone (EEZ) that dominated debates, while the high seas received relatively little attention. Beyond the territorial sea and any waters landward of it, where the coastal State has full sovereignty over fishing, Article 56 of UNCLOS gives the coastal State sovereign rights to explore and exploit, conserve and manage the living resources of its EEZ, which by Article 57 may extend to 200 nm, accommodating the old Latin American claims. Exclusive coastal State jurisdiction over fisheries out to 200 nm is now recognised as an entitlement under customary international law, and was used by many States even before they formally declared an EEZ (such as the United Kingdom, which in 2014 became the last eligible State outside the Mediterranean Sea—other than those few States that still claim a 200-nm territorial sea—to do so, and Australia, which claimed its fisheries rights out to 200 nm in 1979, long before its 1994 EEZ declaration).

Article 61 of UNCLOS directs the coastal State to determine the allowable catch of living resources in its EEZ. Its obligations are to avoid over-exploitation, based on the best scientific evidence available, and to cooperate with regional and global management of fisheries, as well as exchange relevant data. Specifically, it must maintain or restore populations to the levels generating the MSY (see Chap. 33 of this volume), qualified by economic and environmental considerations, such as the needs of fishing communities, taking into account any generally recommended international standards. Ecologically related species are to be maintained at or restored to levels where their reproduction is not seriously threatened.

Foreign access to the EEZ may be achieved under Article 62, directing coastal States to promote optimum utilisation of the living resources, without prejudice to Article 61. Coastal States are to determine their own harvesting capacity, and others have a right of access to the surplus, i.e. the difference between the allowable catch from Article 61 and the coastal State's own capacity, subject to regard for landlocked and geographically disadvantaged States, especially developing countries among them. Coastal State policy as to the distribution of the surplus is given wide scope: all relevant factors may be taken into account, including the significance to its own economy and its other interests, the weak obligations in Articles 69 and 70 on access for landlocked and geographically disadvantaged States, as well as the need to minimise economic disruption to States whose nationals have traditionally fished in the waters concerned and those having contributed to research. Coastal States may subject access to the surplus to a wide range of regulations, restrictions or conditions, which are enumerated in a non-exhaustive list comprising licensing of fishermen, vessels and equipment including fees; species, quotas, periods on a per vessel or per country basis; seasons and areas, type and size and amount of gear, vessel types; the age and size of fish; information to be provided including catch and effort statistics and position reports; research programmes including samples and reporting of data; placement of observers or trainees from the coastal States on board; landing of catch in coastal State ports; joint ventures and other cooperative arrangements; training and technology transfer; enforcement procedures.

While this regime appears to create preferential rather than exclusive rights for the coastal State, the compulsory dispute settlement provisions of Part XV of UNCLOS exclude by Article 297 most EEZ fisheries disputes; jurisdiction over any dispute on the discretionary determination by coastal States of the allowable catch and their own harvesting capacity thus depends on the coastal State's consent. This, combined with the open-ended and numerous criteria for granting access, renders the coastal State's rights all but exclusive in effect after all. In practice, coastal States are often content to receive revenue from fishing States for licences without first determining whether a surplus exists. Ultimately, this depends on a given coastal State's perception of its national benefit, and on its relative negotiating strength vis-à-vis fishing States.

Article 73 of UNCLOS gives the coastal State the right to board, inspect and arrest vessels in its EEZ on suspicion of violation of regulations, with the obligation to release them promptly on posting of a reasonable bond. A special procedure for obtaining this outcome under such conditions, which may be invoked on behalf of the flag

State as well as directly by it (i.e. the proceedings may be conducted by the owner or its representative, as long as it has the flag State's consent) is provided in Article 292. No imprisonment or corporal punishment of master and crew is permitted without the agreement of the flag State, which must be promptly informed of all action taken.

The effect of UNCLOS was thus to place most of the world's oceanic fisheries under the national control of coastal States which were left a wide measure of discretion in how they managed their new EEZs, subject to any more specific treaty obligations, with distant-water fishing States previously operating in areas that had once been high seas forced to come to terms with coastal States for continued access to their zones. While this was an opportunity to reduce fishing pressure on stocks and thus rebuild them as Article 61 intended, in practice most coastal States simply allowed or encouraged their local fleets to grow to the point where the displaced distant-water capacity was fully or more than fully replaced, thus producing no net long-term improvement in the health of stocks. The few exceptions are those States that have adopted ITQs or other property-like rights, Australia, Canada, Iceland, Namibia, New Zealand and Norway being prominent among them, and to a lesser extent the United States (see generally Barnes 2009), still a non-party.

33.2.2.2 The High Seas

A consequence of the foregoing was that a significant proportion of the displaced distant-water fleet migrated to the more productive parts of the high seas, namely those above the parts of continental margins extending beyond 200 nautical miles. This made the relative weakness of the high seas provisions of UNCLOS a problem. Article 87(1) reproduces the language on high seas freedom of fishing from Article 2 of the 1958 High Seas Convention, but subjects it to Articles 116–119 of UNCLOS. By Article 116, all States have the right for their nationals to engage in fishing on the high seas, subject to (a) their treaty obligations, (b) the rights and duties as well as the interests of coastal States provided for inter alia in Articles 63(2) and 64–67 (i.e. straddling and highly migratory stocks, marine mammals, anadromous and catadromous species), and (c) Articles 117–119. Article 117 imposes on all States the duty to take, or cooperate with other States in taking, such measures for their respective nationals as may be necessary for the conservation of the high seas' living resources. By Article 118, States must cooperate with each other in the conservation and management of those resources. States whose nationals exploit identical living resources, or different living resources in the same area, must negotiate on taking measures necessary to conserve those resources and cooperate to establish subregional or regional fisheries organisations to this end.[3] Article 119 provides that allowable catch and other conservation measures for the high seas must be designed to maintain or restore populations of harvested species to the level that produces MSY as qualified by relevant environmental and economic factors,

[3] Frustratingly, there has never been a judicial decision on what precisely the obligation to cooperate, found in Articles 63, 64, 117 and 118, entails.

while maintaining or restoring populations of associated or dependent species above levels at which their reproduction may become seriously threatened. Scientific information, catch and fishing effort statistics, and other data relevant to the conservation of fish stocks must be contributed and exchanged on a regular basis through competent international organisations. The States concerned must ensure that conservation measures and their implementation do not discriminate in form or in fact against the fishermen of any State.

Most high seas fishing also is in fact regulated under Part V of UNCLOS on the EEZ, because few stocks are completely oceanic; most fish caught on the high seas are either straddling stocks (Article 63(2)) or highly migratory species (Article 64). Straddling stocks are those that occur both within the EEZ of one or more States and in an adjacent area of high seas. Highly migratory species (listed in Annex I to UNCLOS) may spend periods of their life cycles in EEZs but migrate to the high seas, sometimes across oceans. This reflects the compromise "species approach" of UNCLOS, which distinguishes between different types of fish, placing most fisheries under the control of coastal States, but subjecting the fishing of wide-ranging species to specific rules. Thus, by Article 66, for anadromous species[4] the primary responsibility for management is with the State of origin; normally, they may be exploited only within the EEZ, but where others have traditionally fished there, international consultations to enable continuance of this are envisaged. Cooperation is required where the fish migrate through neighbouring EEZs. Similarly, for catadromous species[5] Article 67 gives responsibility for management to the States in whose waters the species spends most of its life—harvesting takes place only in their EEZs, in cooperation with their neighbours. Sedentary species by cross-reference in Article 68 to Article 77(4) fall within the exclusive rights of the coastal State on its continental shelf, thus escaping the application of Article 62.

Comparing these provisions with the 1958 Convention, conservation is no longer defined as such,[6] but the objective is now qualified MSY, paralleling their position in the EEZ as outlined above, and Articles 64 and 118 explicitly endorse fisheries commissions. The dispute settlement provisions, a prominent feature of the 1958 Fishing Convention, are subsumed in the general UNCLOS Part XV provisions on this subject establishing compulsory jurisdiction leading to binding decisions, although under Article 297(3) fisheries within the EEZ are one of the most important exceptions to this. Most fundamentally, though, coastal States have been left with no greater right than others to fish on the high seas (the 1958 special interest is replaced in effect by the EEZ), despite high seas fishing now being only a residual freedom, subject to the rights, duties and interests of coastal States in the EEZ, in other words the open access problem—i.e. the inability of States jointly regulating

[4] Anadromous species are spawned in rivers but migrate to the ocean where they spend their adult lives; the various species of salmon are the best known of these.

[5] Catadromous species, such as eels, do the opposite.

[6] In Art 2 of the relevant 1958 Convention, it was defined as "the aggregate of the measures rendering possible the optimum sustainable yield from those resources so as to secure a maximum supply of food and other marine products."

a fishery on the high seas to exclude newcomers from States outside the arrangement—remains, in only slightly attenuated form.

33.3 The UN Fish Stocks Agreement and the FAO Compliance Agreement

Unsurprisingly, therefore, UNCLOS did not solve the international fisheries management crisis. The cooperation requirement was too vague to solve the overfishing problem—in 1992 the Bering Sea pollock fishery in the "doughnut hole" (an area of high seas surrounded by the EEZs of the United States and Russia) and Northwest Atlantic cod stocks (a straddling stock found on the Grand Banks of Newfoundland, parts of which extend beyond the Canadian EEZ onto the high seas) collapsed, without any State having clearly breached its duty. A further conference (1993–1995) on straddling and highly migratory stocks was thus convened, to reinforce and elaborate on the UNCLOS provisions to enable more effective conservation and management of these stocks. The result was the 1995 UN Fish Stocks Agreement (UNFSA). Its objective is to ensure long-term conservation and sustainable use of straddling and highly migratory fish stocks by strengthening the legal regime, especially through global, regional and subregional fisheries management organisations (RFMOs).

Among its main innovations are Articles 5 and 6 and Annex II on the precautionary approach to fisheries, which states that fisheries should be managed by target and limit reference points; MSY is henceforth a limit, not a target, with preagreed action if the limit is approached or breached, so that the situation does not deteriorate further while the States argue over how to respond to it, as occurred in the above examples. Thus Annex II, paragraph 6(4) says States must ensure that when limits are approached they are not exceeded; and if they are exceeded, then specified restorative action must be taken without delay. The risk of exceeding limits must be very low, and target points should not be exceeded on average. RFMOs are gradually adopting management strategies based on this approach, but for the moment implementation remains patchy. For example the Western and Central Pacific Fisheries Commission (WCPFC; created by Art. 3(1) of the 2000 Honolulu Convention on the Conservation of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean) adopted a process to develop harvest strategies with target and limit reference points for six of its species at its 2014 meeting (WCPFC 2014), and in 2015 adopted a target reference point for skipjack tuna (WCPFC 2015), while some of NAFO's stocks are also subject to particular strategies using the Annex II parameters (see NAFO 2016, Art. 7 (cod) and 8 (American plaice)).

Equally significant is Article 7 on compatibility of high seas and EEZ conservation and management measures. Parties must cooperate, either directly or through RFMOs, to achieve compatible conservation and management measures for straddling and highly migratory stocks, taking into account both the measures applied for the same stocks by coastal States in their EEZs and previously agreed measures applied on the high seas for the same stocks by relevant States and RFMOs, whose effectiveness is not to be undermined. States must make every effort to agree on such compatible measures within a reasonable time. If they fail, any State concerned may invoke the Part VIII dispute settlement procedures. Pending agreement on compatible conservation and management measures, the States concerned must make every effort to enter into provisional arrangements of a practical nature. Again, the Part VIII procedures are available if they fail, this time for the purpose of obtaining provisional measures. Coastal States and States fishing on the high seas must also regularly inform each other, either directly or through appropriate RFMOs, of the measures they have adopted for straddling and highly migratory fish stocks within areas under their national jurisdiction or for regulating the activities of vessels flying their flag which fish for such stocks on the high seas.

Part III of UNFSA makes RFMOs the main mechanisms for international cooperation to conserve and manage straddling and highly migratory stocks. States having a real interest in the fishery must cooperate in relation to those stocks, either directly or through appropriate RFMOs. By Article 8(3) and (4), States must give effect to their duty to cooperate by becoming members of any RFMO competent to establish conservation and management measures for such stocks, or applying the measures established by such bodies, or refrain from fishing for the stocks concerned. Relatedly, Article 17 states that parties that are non-members of RFMOs or similar arrangements, and do not agree to apply their conservation and management measures, must still cooperate in the conservation of relevant fish stocks. In particular, they must not authorise their vessels to engage in fishing for straddling and highly migratory stocks subject to conservation and management measures of an RFMO. There are also provisions on participatory rights (Article 10(b)) including for new entrants (Article 11), and on transparency (Article 12).

Article 10, supplemented by Article 28, lays stress on efficacious decision-making, whose absence has been a notable weakness of how RFMOs operate. Most fisheries treaties prevent any party being bound to particular conservation measures against its will by one of two means: (1) consensus, i.e. each party has a veto, so agreement is reachable only on the lowest common denominator in terms of conservation, risking the collapse of the stock; (2) qualified majority with objection procedure—those who agree are bound, but the minority can escape obligations, and if any invokes the procedure, then others too can withdraw—the measure thus unravels, defeating its conservation purpose (as has happened in NAFO and the International Commission for the Conservation of Atlantic Tunas (ICCAT; created by Art. III of the International Convention for the Conservation of Atlantic Tunas). The Estai, a Spanish vessel controversially seized by Canada in 1995 on the high seas part of the Grand Banks of Newfoundland, was fishing under objection to a NAFO measure.[7] Recent attempts to overcome this problem have involved subjecting objections to stronger disciplines, such as requiring objecting States to explain

[7] The facts are related in the ICJ's decision dismissing for lack of jurisdiction the case brought by Spain: Fisheries Jurisdiction (Spain v. Canada), Jurisdiction of the Court, Judgment, ICJ Reports 1998, p. 432.

their reasons.[8] The South Pacific Regional Fisheries Management Organisation (created by the 2009 Auckland Convention on the Conservation and Management of the High Seas Fishery Resources of the South Pacific Ocean), whose decisions are made by three-quarters majority once all efforts at consensus have been exhausted (Art. 16 of the 2009 Convention), combines this with the review procedure pioneered by the WCPFC. Under the latter, decisions other than on allocation and budgetary questions, for which consensus applies, bind any member which voted against it or missed the meeting at which the decision was made unless, within 30 days of its adoption, it seeks a review of the decision by a panel constituted in accordance with Annex II to the Honolulu Convention on the grounds that the decision is inconsistent with the provisions of that Convention, UNFSA or UNCLOS; or unjustifiably discriminates in form or in fact against the member. If the review panel upholds the decision, it becomes binding 30 days from the date of communication by the Executive Director of the panel's findings and recommendations. If instead the review panel recommends that the decision be modified, amended or revoked, the WCPFC must, at its next annual meeting, modify or amend it in order to conform with those findings and recommendations, or revoke the decision (Art. 20(6), (8) and (9) of the 2000 Honolulu Convention).

Under SPRFMO's objection procedure, the objecting State is under an obligation to specify in detail the reason for its objection and enact an alternative measure equivalent in effect to the one to which it objected. The only grounds for objection are that the decision unjustifiably discriminates in form or in fact against the objecting State or is otherwise inconsistent with UNCLOS, UNFSA or the SPRFMO's constitutive treaty. A review panel process similar to the WCPFC's is then automatically triggered (Art. 17 of the Auckland Convention). In 2013 Russia objected under this process to the SPRFMO's very first decision, on jack mackerel. The panel made recommendations, which Russia subsequently indicated it would accept (see Proceedings Conducted by the Review Panel Established under Article 17 and Annex II of the Convention on the Conservation and Management of the High Seas Fishery Resources of the South Pacific Ocean with regard to the Objection by the Russian Federation to a Decision of the Commission of the South Pacific Regional Fisheries Management Organisation, 2013). The equivalent WCPFC process remains unused.

Duties of the flag State are set out comprehensively in Articles 18 and 19 of UNFSA. States whose vessels fish on the high seas must ensure these comply with regional conservation and management measures, in particular to: permit only authorised vessels to fish on the high seas; impose conditions necessary to meet RFMO obligations; ensure their vessels do not fish without authorisation in other

[8] See Article XIV of the overhauled text of NAFO's constitutive treaty in NAFO doc NAFO/GC Doc. 07/4, Amendment to the Convention on Future Multilateral Cooperation in the Northwest Atlantic Fisheries. The amendment is not yet in force. Rather than similarly amend its own treaty, the North-East Atlantic Fisheries Commission (NEAFC, created by the Convention on Future Multilateral Cooperation in the Northeast Atlantic Fisheries) adopted a binding measure in 2004 requiring an objecting party to give a statement of its reasons and a declaration of its intentions, including a description of any alternative conservation and management measures that it intends to take or has already taken; see NEAFC 2004, Volume I, pp. 37–38; Volume II, Annexes.

States' EEZs; establish a national record of fishing vessels authorised to fish on the high seas; collect and verify fishing vessel position and catch data. Thus, contrary to the general position of States in international law regarding their nationals, States Parties to UNFSA are now indirectly responsible for their fishing vessels' activities on the high seas, in the sense that they must regulate them in a way that will allow their obligations to other RFMO members to be met, with the normal international law consequences applying if their catch or effort limits are breached. By Article 19, parties must ensure that vessels flying their flag comply with conservation and management measures established by RFMOs and investigate alleged violations of them by those vessels, wherever they occur. If there is sufficient evidence, they must institute proceedings under their own laws and detain the vessel or apply other sanctions severe enough to discourage violations and deprive offenders of the benefits of illegal fishing. Flag States must also ensure that vessels involved in a serious violation of conservation or management measures do not restart fishing on the high seas until they have complied with sanctions imposed.

New powers on compliance and enforcement are introduced by Articles 20–22. States conducting investigations must provide information on their progress and outcome to other States that have an interest in, or are affected by, an alleged violation. If a coastal State requests the flag State of a vessel on the high seas to investigate allegations that the vessel has fished unauthorised in its EEZ, the flag State must cooperate with the coastal State in taking enforcement action, and may authorise the coastal State's authorities to board and inspect the vessel on the high seas. The regime for boarding and inspection of fishing vessels on the high seas in any RFMO area is a major departure from the default rule of exclusivity of flag State jurisdiction on the high seas (Art. 92(2) of UNCLOS). In the area covered by the RFMO, a party to UNFSA being a member of that RFMO may board and inspect vessels flagged to another party, whether or not that other party is also a member, to ensure compliance with regionally agreed measures and UNFSA. The inspectors must notify the vessel's flag State at the time of boarding, not interfere with the master's ability to communicate with the flag State authorities, minimise interference with fishing operations, avoid use of force, and promptly leave the vessel if no evidence of serious violation is found. For its part, the flag State must require vessel masters to cooperate and facilitate inspection. If the master refuses the flag State's direction to allow boarding and inspection, the vessel's authorisation to fish must be suspended. Where there is clear evidence of a serious violation, the inspecting State must notify the flag State and invite it to investigate and take enforcement action against the vessel. If the flag State does not do so, an inspecting State may remain on board the vessel and direct it to the nearest appropriate port, or the flag State may authorise the inspecting State to investigate and also take enforcement action against it. RFMOs may develop their own boarding and inspection procedures; these must be consistent with the basic procedures of Article 22 and not discriminate against non-members.

Dispute settlement is dealt with in Part VIII of UNFSA. Article 30 imports the compulsory dispute settlement provisions of Part XV of UNCLOS to govern disputes about its interpretation or application, and extends them to any other treaty establishing an RFMO which lacks compulsory procedures, although most modern ones include them, such as the South East Atlantic Fisheries Organisation (created by the 2001 Convention on the Conservation and Management of the Fishery Resources in the South East Atlantic Ocean). This could potentially reverse the much criticised result of the Southern Bluefin Tuna arbitration of 2000, where the tribunal found it lacked jurisdiction because the non-compulsory mechanism of the treaty specific to southern bluefin tuna overrode the compulsory one of UNCLOS (Arbitral Tribunal constituted under Annex VII of the United Nations Convention on the Law of the Sea, Southern Bluefin Tuna Case (Australia and New Zealand v. Japan), Jurisdiction and Admissibility, Award of 4 August 2000, RIAA XXIII, 1, 43–44 (paras. 56–59).[9]

UNFSA entered into force in 2001, and by mid-2017 had 86 parties including the European Union and all 28 of its Member States, as well as the United States, which is possible even though it is not party to UNCLOS, the result of internal political obstacles that did not similarly affect the fisheries agreement. The most prominent non-parties are China and several Latin American States that fear (wrongly) Article 7 on compatibility as a threat to their exclusive control over their EEZs.

Highly migratory tunas are covered by one or more of the Commission for the Conservation of Southern Bluefin Tuna (CCSBT; created by the 1993 Convention for the Conservation of Southern Bluefin Tuna), the Indian Ocean Tuna Commission (created by the 1993 Agreement Establishing the Indian Ocean Tuna Commission), ICCAT, the IATTC and the WCPFC. For straddling stocks RFMOs now exist in most parts of the world's oceans and new ones are being created to fill the gaps in those high seas areas remaining unregulated, e.g. a 2012 treaty establishing a north-western Pacific RFMO entered into force in 2015 (2012 Convention on the Conservation and Management of High Seas Fisheries Resources in the North Pacific Ocean) leaving the Southwest Atlantic (and most of the Arctic Ocean) as the largest remaining areas lacking such a body. They devise catch limits and other conservation and management measures for fish stocks harvested on the high seas with a view towards ensuring their long-term survival. But these measures are binding only on States that are members of the relevant RFMOs, and hence only affect those fishing vessels that operate under their flags.

To evade compliance with international measures, some owners of fishing vessels reflag them to States running open registries that do not participate in or cooperate with RFMOs (often incorrectly termed as "flag-of-convenience" States, despite this phrase having a different meaning in UNCLOS Article 92). The owners often have little or no connection with the flag State, which does not monitor its vessels' activity and provides no catch and effort data to RFMOs, so management decisions are taken on the basis of less than optimal knowledge. To deter reflagging as a means of avoiding compliance with conservation and management measures

[9] In a similar situation outside the fisheries context, a differently composed Annex VII tribunal declined to follow the Southern Bluefin Tuna reasoning: South China Sea Arbitration (Philippines v. China), Award on Jurisdiction and Admissibility (29 October 2015), Permanent Court of Arbitration Case No 2013-13 <https://pcacases.com/web/sendAttach/1506>.

for the high seas, the Food and Agriculture Organization of the United Nations (FAO) adopted the 1993 Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas as the binding part of the broader non-binding Code of Conduct on Responsible Fishing.[10] It provides the basis for improved international cooperation, particularly through the collection and dissemination of information on the activities of fishing vessels on the high seas. Because it covers some of the same ground as UNFSA, it was seen as less pressing, so States were slower to become parties to it and it came into force only in 2003. At the end of 2016 it had 40 parties, including the US, Canada, Australia, Japan, South Korea and the European Union (to the exclusion of its member States).

Article III concentrates on flag-State responsibilities. Parties must ensure that their vessels fishing on the high seas do not undermine the effectiveness of international conservation and management measures (whether or not they are members of the relevant RFMO). They must not authorise a vessel to fish on the high seas unless satisfied that their responsibilities in respect of it under the Agreement can be effectively met, and must cancel a vessel's high seas permit if it ceases to be flagged. In most cases they must also refuse registration to any vessel previously registered with another party that has undermined the effectiveness of such measures. Article VI obliges parties to report promptly to the FAO activity of this kind by their vessels, including information on the vessel's identity and any action taken against it. Article VII requires them to take cooperative action to deter fishing vessels flagged to non-parties from engaging in activities that undermine those measures, and exchange information regarding non-party fishing vessels that engage in such activities.

33.4 Marine Mammals

The International Whaling Commission (IWC), established by the 1946 International Convention for the Regulation of Whaling (ICRW), failed to maintain its stocks—the scientific advice was in retrospect insufficiently conservative, but even that was rarely heeded; blue and humpback whales were not protected until they were nearly extinct (see Holt in Shotton 2001). There has been a moratorium on commercial whaling since 1986, although Article VIII of the ICRW allows whaling for scientific

[10] Space does not permit a description of this or the FAO's other soft-law instruments, the International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries, the International Plan of Action for the Conservation and Management of Sharks and the International Plan of Action for the Management of Fishing Capacity and the International Plan of Action to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing, adopted by the FAO's Committee on Fisheries at its 24th Session on 2 March 2001 and endorsed by the 120th Session of the FAO Council on 23 June 2001. The first and last of these have more recently been supplemented by treaties, the 2001 Agreement for the Conservation of Albatross and Petrels (negotiated outside the FAO) and the 2009 Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing.

purposes. In anticipation of this, UNCLOS Articles 65 and 120 (for the EEZ and high seas respectively) allow stricter regulation than for fish, i.e. there is no need to aim for MSY. UNFSA does not apply to marine mammals.

The IWC was originally representative of whaling States, but now has several dozen members recruited by both pro- and anti-whaling camps for support in votes. The debate is polarised and both sides' arguments have become politicised and lacking in legal rigour. Minke whales are plentiful, but the ultra-conservative revised management procedure that has been under development for many years is being blocked by anti-whaling States wanting all whaling to cease for ever. In 2010 Australia launched a case in the ICJ against Japan, alleging that its scientific whaling in the Antarctic was in breach of the ICRW and two other treaties (but not UNCLOS); by the time the decision was handed down in 2014 the claim had been narrowed to breach of the ICRW only. The Court found that, although the Japanese whaling programme was potentially eligible to benefit from the scientific whaling exemption under Article VIII, because of certain flaws in its implementation it was not "for the purposes of" science and therefore was not authorised after all by that exemption, so that by default it was commercial whaling which was prohibited under the moratorium (Whaling in the Antarctic (Australia v. Japan; New Zealand Intervening), ICJ Reports 2014, p.226). This reasoning is rather strained and has left the way open for Japan to recommence Antarctic whaling under a new programme; Japan's whaling in the northern hemisphere was not at issue in the litigation and can thus be expected to continue unless a separate legal challenge to it is made and succeeds. Australia's legal victory may thus prove to be largely pyrrhic in practice.

The ICRW covers only large whales, but regional agreements apply to some smaller marine mammals: such as the 1972 Convention for the Conservation of Antarctic Seals, the 1992 Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas and the 1996 Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area.

33.5 Current Issues and Future Developments

It is unlikely that there are many stocks for which the target set in 2002 at the World Summit on Sustainable Development of rebuilding them to the biomass generating the MSY by 2015 "where possible" (UN 2002, Annex, para 23, subpara 31(a)) has been met. (see Chap. 33). A decade later, the equivalent document produced at the Conference on Sustainable Development merely contains a pledge to intensify efforts to meet the target "on an urgent basis…with the aim of achieving these goals in the shortest time feasible" (UN 2012, para 168). It admits the need for transparency and accountability in their management of the fisheries concerned (UN 2012, para 172) and reaffirms the 2002 commitment to eliminate subsidies that contribute to illegal, unreported and unregulated fishing and overcapacity and to conclude multilateral disciplines on fisheries subsidies in the World Trade Organization (WTO) Doha Round, where progress has been slow, encouraging States to eliminate subsidies that contribute to overcapacity and overfishing, and to refrain from introducing new subsidies of this kind and extending existing ones (UN 2012 para 173). Subsidies are considered pernicious because their effect is either to raise prices for fish, adding to the economic incentives to catch them and thus exacerbating the depletion of sought-after stocks, or to lower the costs of fishing, which makes it artificially profitable and means that in unregulated fisheries even more surplus capacity is attracted and the degree of depletion which must be reached before profit is competed away, deterring further entrants, similarly worsens (WTO 1999).

Issues of this kind have drawn the attention of the Organisation for Economic Co-operation and Development (OECD), which concluded from the empirical evidence it gathered for a study it conducted in 1997 that:

> management regimes which limit the total catch, or the number of fishing vessels, or which restrict the efficiency of the harvesting sector, including technical measures and TACs, have generally yielded poor results when used in isolation…The main reason …is that these regimes do not give the fisher the incentive to account for all the costs of his fishing activity (OECD 1997: 9–10).

The study's findings supported the introduction of "rights-based management systems" such as individual quotas, which would require governments to establish and maintain a legal framework for the rights. The recommended objective of regulation was to create economic incentives or legal sanctions to reduce externalities, i.e. costs that can be imposed on others—in this case on other fishing operators, the rest of society and the environment (OECD 1997: 10–12).

Sixteen years after the entry into force of UNFSA, it is apparent that the problems now are not with anything in that UNFSA regime, but rather with the slowness of States to implement its requirements. An exception is the rule in Article 8(3) and (4) of UNFSA requiring openness of RFMOs to those with a "real interest" (undefined), who must either join or cooperate or refrain from fishing for the stocks in question, which if anything is being overimplemented. Many RFMOs have created a formal status of cooperating non-member as a way of facilitating this (see the list of such formalised procedures in Serdy 2016: 73–74). On the other hand, RFMOs have since the entry into force of UNFSA displayed a tendency to want to reserve the high seas fisheries for which they are competent for their own members and cooperating non-members. This is at the expense of outsiders, who may find themselves excluded from membership by an overly strict interpretation of the "real interest" criterion in Article 8(3) in which applicant States without a catch history from the relevant stock are told that they lack a real interest and therefore have no business fishing it, although coastal States by virtue of their geographical location are conceded to have a real interest (see e.g. "ICCAT Criteria for the Allocation of Fishing Possibilities" in ICCAT 2001: 211).

This problem of allocation when new entrants emerge in an existing fishery has long plagued international fisheries law, given the problem of the non-opposability of treaty provisions to States not party to them discussed earlier (see Hollick 1977; see also Oda in Alexander 1968: 29). Here the obligation on parties is to cease fishing once an overall limit has been reached, so it is not obvious how non-parties can be compelled to refrain from fishing, at least before this happens. For this one would have to argue that the rule in UNFSA strengthening the role of RFMOs, by requiring States fishing for the stocks they cover either to join them or cooperate with their management measures (Art. 8(3), (4) and (17)(1), (2) UN Fish Stocks Agreement), has achieved customary status. This is not impossible, one review of State practice showing that most RFMOs now "demand either membership, cooperation or abstention [from fishing] from non-members" who in turn have in several ways "acquiesced in these assertions of jurisdiction" (Rayfuse 2004: 373).[11] Related to this is the elaboration of the concept of illegal, unreported and unregulated (IUU) fishing by vessels flagged to non-member States.[12]

Fisheries on the high seas are also likely to be affected by the mid-2015 decision of the UN General Assembly to launch negotiations for a third implementing agreement (after UNFSA and the unrelated 1994 agreement on deep seabed mining) on conservation of biological diversity in sea areas beyond national jurisdiction (UN 2015). A foreseeable issue will be how decisions to institute marine protected areas, which may prevent fishing in sensitive areas, can be enforced against States that do not become party to the future instrument, and what roles existing RFMOs will play in the future framework (Tladi 2015). Meanwhile, as heavy trawling gear is known to scrape and plough up the seabed which not only stirs up the sediments but also destroys animals living on the sea floor, the General Assembly has called on RFMOs with the competence to regulate bottom fisheries to adopt and implement measures to prevent their significant adverse impacts on vulnerable marine ecosystems (UN 2007, paras 83–86). In this way the General Assembly, even though it does not itself have the power to legislate, can supply evidence of any emerging consensus among States that practices such as these may be prohibited by customary international law.

The gradual strengthening of RFMO control can be foreseen, and there seems to be little enthusiasm for revival of the ILC's early 1950s idea of a world fisheries organisation, but that may change if stocks suddenly collapse—high seas fisheries might then become the common heritage of mankind, like the mineral resources of the deep seabed, with RFMOs allocating quota directly to individual operators sponsored by their member States, which ideally would guarantee their performance as a motivation to choose wisely whom they sponsor. Though a precedent for this exists in the UNCLOS deep seabed mining regime (Art. 153(2)(b) and Annex

[11] The likeliest explanation is that many more States than in the past now have a stake in one or more international fisheries and see on balance more benefit from shoring up their position by excluding newcomers from those, even at the price of their own exclusion from fisheries they have not themselves yet entered.

[12] The term has its origin in an agenda item at CCAMLR's 1997 meeting, but was not defined there: see CCAMLR (1997), pp. 8–13. This blurring is understandable in its original CCAMLR context where it serves the purpose of avoiding the issue as to whether or not there are any coastal States in Antarctica, but its later extension to international fisheries generally was criticised in Serdy (2016), Chapter 3 for conflating unregulated with illegal, risking making the bargain in Article 8 UNFSA, meaningless because newcomers are not guaranteed any share of the benefits. The strong rhetoric against IUU fishing globally continues in annual UN General Assembly Resolutions, and see also UN 2012, para 170.

III, Art. 4(3) and (4) UNCLOS), States have no incentive to relinquish their valued role as middlemen, so the likeliest outcome is that business as usual will continue for quite some time yet.

Bibliography

1911 Convention between the United States of America, Great Britain, Russia and Japan for the Preservation and Protection of Fur Seals (Washington DC, 7 July 1911). United States Treaty Series No 564

1923 Convention for the Preservation of the Halibut Fishery of the Northern Pacific Ocean (Washington, 2 March 1923). 32 League of Nations Treaty Series 93

1930 Convention for the Protection, Preservation and Extension of the Sockeye Salmon Fisheries of the Fraser River System (Washington, 26 May 1930). 184 League of Nations Treaty Series 305

1931 Convention for the Regulation of Whaling (Geneva, 24 September 1931). 155 League of Nations Treaty Series 351

1937 International Agreement for the Regulation of Whaling (London, 8 June 1937). 190 League of Nations Treaty Series 79

1946 Convention for the Regulation of the Meshes of Fishing Nets and the Size Limits of Fish (London, 5 April 1946). 231 United Nations Treaty Series 199

1946 International Convention for the Regulation of Whaling (ICRW) (Washington, 2 December 1946). 161 United Nations Treaty Series 72

1949 Convention for the Establishment of an Inter-American Tropical Tuna Commission (Washington, 31 May 1949). 80 United Nations Treaty Series 3

1949 International Convention for the Northwest Atlantic Fisheries (Washington, 8 February 1949). 157 United Nations Treaty Series 157

1958 Convention on Fishing and Conservation of Living Resources of the High Seas (Geneva, 29 April 1958). 559 United Nations Treaty Series 285

1958 Convention on the High Seas (Geneva, 29 April 1958). 450 United Nations Treaty Series 11

1969 Vienna Convention on the Law of Treaties (Vienna, 23 May 1969). 1155 United Nations Treaty Series 331

1972 Convention for the Conservation of Antarctic Seals (London, 1 June 1972). 1080 United Nations Treaty Series 175

1978 Convention on Future Multilateral Cooperation in the Northwest Atlantic Fisheries (Ottawa, 24 October 1978), 1135 United Nations Treaty Series 369

1980 Convention on the Conservation of Antarctic Marine Living Resources (Canberra, 20 May 1980), 1329 United Nations Treaty Series 47

1982 United Nations Convention on the Law of the Sea (Montego Bay, 10 December 1982). 1833 United Nations Treaty Series 3

1992 Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas (New York, 17 March 1992). 1772 United Nations Treaty Series 217

1993 Agreement Establishing the Indian Ocean Tuna Commission (Rome, 25 November 1993). 1927 United Nations Treaty Series 329

1993 Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas (Rome, 25 November 1993). 2221 United Nations Treaty Series 189

1993 Convention for the Conservation of Southern Bluefin Tuna (Canberra, 10 May 1993). 1819 United Nations Treaty Series 359

1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of

Straddling Fish Stocks and Highly Migratory Fish Stocks (New York, 4 December 1995). 2167 United Nations Treaty Series 3

1996 Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (Monaco, 24 November 1996). 2183 United Nations Treaty Series 303

2000 Convention on the Conservation of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean (Honolulu, 5 September 2000). 2275 United Nations Treaty Series 43

2001 Agreement for the Conservation of Albatross and Petrels (Canberra, 19 June 2001). 2258 United Nations Treaty Series 257

2001 Convention on the Conservation and Management of the Fishery Resources in the South East Atlantic Ocean (Windhoek, 20 April 2001). 2221 United Nations Treaty Series 189

2009 Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (Rome, 22 November 2009). http://www.fao.org/fileadmin/user_upload/legal/docs/1_037t-e.pdf. Accessed 23 Mar 2016

2009 Convention on the Conservation and Management of the High Seas Fishery Resources of the South Pacific Ocean (Auckland, 14 November 2009). (Electronic version). https://www.sprfmo.int/assets/Basic-Documents/Convention-web.pdf. Accessed 23 Mar 2016

2012 Convention on the Conservation and Management of High Seas Fisheries Resources in the North Pacific Ocean (Tokyo, 24 February 2012). Reproduced in United States Senate, Treaty Doc 113–2, Message from the President of the United States transmitting Convention on the Conservation and Management of High Seas Fisheries Resources in the North Pacific Ocean, done at Tokyo on February 24, 2012, and signed by the United States on May 2, 2012″, 113th Congress, 1st session (22 April 2013). https://www.congress.gov/113/cdoc/tdoc2/CDOC-113tdoc2.pdf. Accessed 23 Mar 2016

Arbitral Tribunal Established under the Treaty Signed in Washington, on the 29th of February 1892, between the United States and Her Majesty the Queen of the United Kingdom of Great Britain and Ireland (Relating to the Rights of Jurisdiction of the United States in the Bering's [sic] Sea and the Preservation of Fur Seals). Award of the Arbitral Tribunal: Decision of 15 August 1893. XXVIII Reports of International Arbitral Awards, 263

Arbitral Tribunal constituted under Annex VII of the United Nations Convention on the Law of the Sea, Southern Bluefin Tuna Case (Australia and New Zealand v. Japan), Jurisdiction and Admissibility, Award of 4 August 2000. XXIII Reports of International Arbitral Awards, 1

Barnes R (2009) Property rights and natural resources. Hart Publishing, Oxford

Boyle A (2001) Problems of compulsory jurisdiction and the settlement of disputes relating to straddling fish stocks. In: O. Schram Stokke (ed.), governing high seas fisheries: the interplay of global and regional regimes, 91. Oxford: Oxford University Press

CCAMLR (1997) Report of the Sixteenth Meeting of the Commission, Hobart, Australia, 27 October–7 November 1997. https://www.ccamlr.org/en/system/files/e-cc-xvi.pdf. Accessed 23 Mar 2016

Colson DA, Hoyle P (2003) Satisfying the procedural prerequisites to the compulsory dispute settlement mechanisms of the 1982 Law of the Sea Convention: did the Southern Bluefin Tuna tribunal get it right? Ocean Dev Int Law 34:59

FAO (1999) The International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries. The International Plan of Action for the Conservation and Management of Sharks. The International Plan of Action for the Management of Fishing Capacity. ftp://ftp.fao.org/docrep/fao/006/x3170e/X3170E00.pdf. Accessed 23 Mar 2016

FAO (2001) International Plan of Action to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing. www.fao.org/DOCREP/003/y1224e/y1224e00.HTM. Accessed 23 Mar 2016

Hardin G (1968) The tragedy of the commons. Science 162:1243

Hollick AL (1977) The origins of 200-mile offshore zones. Am J Int Law 71:494

Holt SJ (2001) Sharing the catches of Whales in the Southern Hemisphere. In: Shotton R (ed) Case studies on the allocation of transferable quota rights in fisheries. Rome, FAO

ICCAT (2001) ICCAT, Report for biennial period 2000-01 Part II (2001)—Vol. 1. Annex 8 to Proceedings of the 17th Regular Meeting of the International Commission for the Conservation of Atlantic Tunas (Murcia, Spain—November 12 to 19, 2001)): ICCAT Criteria for the Allocation of Fishing Possibilities. Madrid: ICCAT

International Court of Justice, Whaling in the Antarctic (Australia v, Japan; New Zealand Intervening), ICJ Reports 2014, p 226

Merrills J (2011) International dispute settlement, 5th edn. Cambridge University Press, Cambridge

NAFO (2007) NAFO/GC Doc. 07/4, Amendment to the Convention on Future Multilateral Cooperation in the Northwest Atlantic Fisheries. http://archive.nafo.int/open/gc/2007/gcdoc07-04.pdf. Accessed 19 Mar 2016

NAFO (2016) NAFO/FC Doc. 16/01, Northwest Atlantic Fisheries Organization Conservation and Enforcement Measures 2016. http://archive.nafo.int/open/fc/2016/fcdoc16-01.pdf. Accessed 19 Mar 2016

NEAFC (2004a) Report of the 23rd Annual Meeting of the North-East Atlantic Fisheries Commission[,] 8–12 November 2004, Volume I: Main Report. http://archive.neafc.org/reports/annual-meeting/am_2004/docs/23neafc_annualmeeting_report_2004.pdf. Accessed 19 Mar 2016

NEAFC (2004b) Report of the 23rd Annual Meeting of the North-East Atlantic Fisheries Commission[,] 8–12 November 2004, Volume II: Annexes. http://archive.neafc.org/reports/annual-meeting/am_2004/docs/23neafc_annualmeeting_annexes_2004.pdf. Accessed 19 Mar 2016

Oda S (1967) Distribution of fish resources of the high seas: free competition or artificial quota? In: Alexander LM (ed) The law of the sea: the future of the sea's resources: proceedings of the second annual conference of the law of the Sea Institute, June 26–29, 1967. University of Rhode Island, Kingston

OECD (1997) Towards sustainable fisheries: economic aspects of the management of living resources. OECD, Paris

Oxman BH (2001) Complementary agreements and compulsory jurisdiction. Am J Int Law 95:277

Rayfuse RG (2004) Non-flag state enforcement in high seas fisheries. Martinus Nijhoff, Boston

Review Panel Established under Article 17 and Annex II of the Convention on the Conservation and Management of the High Seas Fishery Resources of the South Pacific Ocean with regard to the Objection by the Russian Federation to a Decision of the Commission of the South Pacific Regional Fisheries Management Organisation. In Proceedings Conducted by the Review Panel Established under Article 17 and Annex II of the Convention on the Conservation and Management of the High Seas Fishery Resources of the South Pacific Ocean with regard to the Objection by the Russian Federation to a Decision of the Commission of the South Pacific Regional Fisheries Management Organisation: Findings and Recommendations of the Review Panel[,] 5 July 2013[,] The Hague, the Netherlands. http://archive.pca-cpa.org/20130705_Findings_and_Recommendations_of_the_Review_Panel_%28ENG%292af4.PDF?fil_id=2289www. pca-cpa.org. Accessed 19 Mar 2016

Rothwell DR, Stephens T (2016) The International Law of the Sea, 2nd edn. Hart Publishing, Oxford

Serdy A (2016) The New Entrants Problem in International Fisheries Law. Cambridge University Press, Cambridge

Tladi D (2015) The proposed implementing agreement: Options for Coherence and Consistency in the Establishment of Protected Areas beyond National Jurisdiction. Int J Mar Coastal Law 30:654

United Nations (1960) Report of the International Law Commission covering the work of its seventh session, 2 May–8 July 1955 (UN doc A/2934), reprinted in Yearbook of the International Law Commission 1955, Vol II. United Nations, New York

United Nations (2002) Report of the World Summit on Sustainable Development, Johannesburg, South Africa, 26 August-4 September 2002 (UN doc A/CONF. 199/20). Annex: Resolution 2.

Plan of Implementation of the World Summit on Sustainable Development. United Nations, New York

United Nations (2007) Sustainable fisheries, including through the 1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, and related instruments (UN doc A/RES/61/105). New York: United Nations

United Nations (2012) The future we want (UN doc A/RES/66/288). United Nations, New York

United Nations (2015) Development of an international legally binding instrument under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (UN doc A/RES/69/292). United Nations, New York

United Nations (1953) Report of the International Law Commission covering the work of its fifth session, 1 June–14 August 1953 (UN doc A/2456), reprinted in Yearbook of the International Law Commission 1953, Vol II. United Nations, New York, p 1959

WCPFC (2014) Conservation and management measure 2014–06, conservation and management measure on establishing a harvest strategy for key fisheries and stocks in the western and central Pacific Ocean. https://www.wcpfc.int/system/files/CMM%202014-06%20Conservation%20and%20Management%20Measures%20to%20develop%20and%20implement%20a%20harvest%20strategy%20approach%20for%20key%20fisheries%20and%20stocks%20in%20the%20WCPO.pdf. Accessed 19 Mar 2016

WCPFC (2015) Conservation and management measure 2015–06, conservation and management measure on a target reference point for WCPO (Western and Central Pacific Ocean) Skipjack Tuna. https://www.wcpfc.int/system/files/CMM%202015-06%20CMM%20on%20a%20Target%20Reference%20point%20for%20WCPO%20Skipjack%20Tuna.pdf. Accessed 19 Mar 2016

Wolfrum R (2006) Das Streitbeilegungssystem des VN-Seerechtsübereinkommens. In: Graf Vitzthum W (ed) Handbuch des Seerechts. C. H. Beck, Munich, p 461

World Trade Organization (1999) On the environmental impact of fisheries subsidies: A short report by the Icelandic Ministry of Fisheries (WTO doc WT/CTE/W/111). World Trade Organization, Geneva

Chapter 34
Aqua- and Mariculture Management: A Holistic Perspective on Best Practices

Marc H. Taylor and Lotta C. Kluger

Abstract This chapter presents an overview of some of the main issues facing the development of aqua- and mariculture, and provides a framework for improving sustainability from socio-economic and ecological perspectives. We review present global trends in productivity and the institutional and legal frameworks that may affect policy and trade in the coming years. Focus is placed on summarizing recent trends in socio-ecological approaches, such as the "Ecosystem Approach to Aquaculture", which emphasizes development within the constraints of ecosystem functioning and social well-being. A framework of best practices for long-term sustainability is proposed, which is comprised of steps involving risk assessment, monitoring, and adaptive management. From this holistic perspective, we discuss the future prospects for aquaculture development in terms of its promise of improved food security, nutrition and income.

Keywords Sustainable development • Ecosystem approach • Aquaculture management

34.1 Introduction: Central Issues of Aquaculture Management

Like its terrestrial agricultural counterpart, aquaculture has been viewed by many as a way to stabilize and enhance food production through the culturing of desirable species under controlled conditions. Cultured species may be chosen based on a variety of characteristics; including productivity (i.e. food conversion rates), ease of maintenance, availability, market value etc. Aquaculture has developed from being

M.H. Taylor (✉)
Thünen Institute of Sea Fisheries, Palmaille 9, 22767 Hamburg, Germany
e-mail: marc.taylor@thuenen.de

L.C. Kluger
Leibniz Center for Tropical Marine Research, Fahrenheitstrasse 6, 28359 Bremen, Germany

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_34

a primarily small scale, low-tech activity, such as simple fish ponds referenced as early as 500 BC in China and possibly 2500 BC in Egypt (Pillay and Kutty 2005), to one that includes modern, highly-industrialized farms where all stages of husbandry, feed production, grow-out, and processing are included.

The implementation and expansion of aquaculture has provided improvements to livelihoods through increased food security and income. However, negative aspects can include ecosystem degradation and conflicts between stakeholders; for example, spatial disputes may arise during the shift from open-access of resources to one involving user-rights. Additional impacts of aquaculture include the loss of critical habitats (e.g. mangrove and wetland conversion to fish pond culture), excess nutrient loading, introduction of non-native or genetically-altered species, and an over-dependence on wild fisheries for feed (see also Chap. 5). The accurate assessment of the real costs and benefits from an aquaculture operation to society is crucial for informed decision making relating to its sustainable development. The complexities involved with assessing the benefits of a given aquaculture project are far from trivial, and require a broad vision of best practices that allow for informed decision making in planning and management.

This chapter aims to provide a brief summary of some of the present trends in aquaculture and to highlight management best practices for making aquaculture a value adding activity. We first provide an overview on global trends in production and products (Sect. 34.2), followed by examples of practices that can jeopardize the ecological and socioeconomic sustainability of aquaculture (Sect. 34.3). We then provide examples of institutional and legal frameworks that are applicable to aquaculture, including recent attempts at international guidelines (Sect. 34.4). The following section outlines central management instruments and strategies that can aid in the success and sustainability of aquaculture (Sect. 34.5), which is followed by best practices (Sect. 34.6). Finally, we look at the present status of management efforts and provide a prospectus for the future, including additional steps that need to be realized for continued improvement.

34.2 Global Trends in Aquaculture Development

For many regions of the developing world, aquaculture production represents an increasingly important source of protein, especially within the context of a growing global population combined with fully- or over-exploited wild fisheries. In contrast, aquaculture production continues to grow exponentially, in excess of 6% per year over the last decade (FAO 2014), and has recently surpassed wild fisheries production (Fig. 34.1). Most of this trend is attributable to the dramatic increase in production in Asia, and in particular China, where increased production from inland finfish aquaculture has been especially important. Globally, 66.6 million tonnes of production (excluding aquatic plants) were produced in 2012, of which two-thirds (44.2 million tonnes) came from finfish species originating from inland aquaculture (38.6 million tonnes) and mariculture (5.6 million tonnes) (FAO 2014) (Table 34.1; Fig. 34.2).

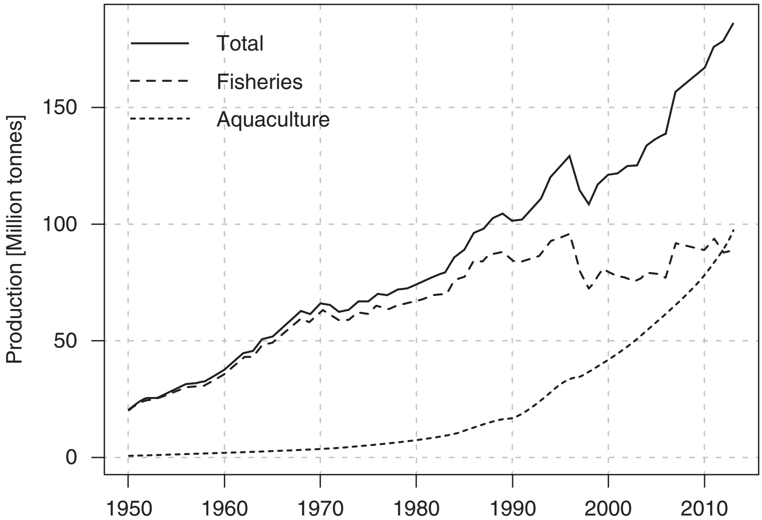


Fig. 34.1 Global production from wild fisheries and aquaculture (including aquatic algae) (FAO 2016)

Table 34.1 World production of farmed species groups (excludes aquatic plants) from inland aquaculture and mariculture in 2012 (reproduced from FAO 2014)

	Inland aquaculture	Mariculture	Quantity subtotal		Value subtotal	
	tonnes (Million)	tonnes (Million)	tonnes (Million)	% (by volume)	US$ (Million)	% (by value)
Finfish	38.599	5.552	44.151	66.3	87,499	63.5
Crustaceans	2.530	3.917	6.447	9.7	30,864	22.4
Molluscs	0.287	14.884	15.171	22.8	15,857	11.5
Other species	0.530	0.335	0.865	1.3	3512	2.5
Total	**41.946**	**24.687**	**66.633**	**100**	**137,732**	**100**

There are several reasons for the expansion of aquaculture in recent decades, although a dominant factor has been an increased demand for 'food fish' (i.e. fish and shellfish) in most producing countries. Exceptions to this trend exist in the more industrialized producers, notably the United States of America, Spain, France, Italy, Japan and the Republic of Korea, for which production has decreased in recent years. A main driver for these decreases is the inability to compete with the lower production costs in developing countries, resulting in a shift from production to import (FAO 2014). This trend in production has been similarly observed for other sectors where labour represents a dominant fraction of production costs. As a consequence, developed countries tend to have turned their focus towards the production of higher value species requiring more technologically-oriented culture methods.

An attractive characteristic of aquaculture-produced fish food products is their relative production efficiencies. For example, fish and shellfish, and other

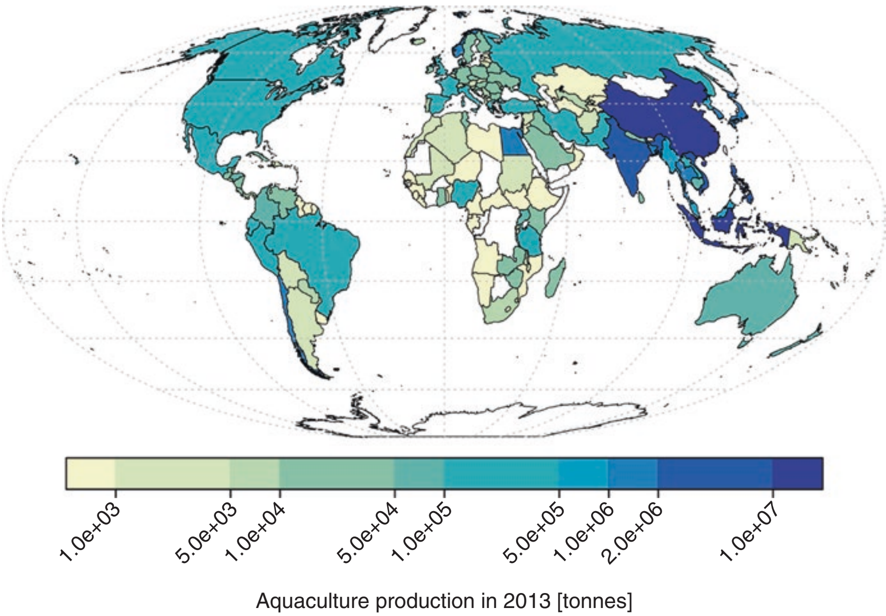


Fig. 34.2 Aquaculture production by country in 2013 (FAO 2016)

cold-blooded species, have been shown to have higher feed conversion efficiencies (i.e. the ratio of feed required per unit produced) when compared to warm-blooded, such as cattle, sheep and poultry. This not only makes their production more cost-effective, but can also reduce impacts to the environment by minimizing pollution in the form of excess nutrient run-off to marine and aquatic ecosystems (Phillips et al. 1978; Goodland 1997; Costa-Pierce 2002). Nevertheless, there are plenty of examples where intensive aquaculture can have grave impacts on the environment through elevated nutrient loading beyond natural limits of the ecosystem.

In light of the concerns with increased nutrient loading, there has been an increasing trend in the use of aquaculture in conjunction with other agricultural activities as a means to enhance overall production (i.e. 'integrated aquaculture'). Several examples for integrated aquaculture systems exist (see Table 12.11 in Costa-Pierce 2002 for examples), but the most sustainable are those that most resemble natural ecosystem functioning. For example, effluent produced through fish production can be used as a valuable organic fertilizer in neighbouring agriculture or grazing fields, and several examples of integrated aquaculture attempt to benefit from this material in order to enhance agricultural production while saving on the cost of external fertilizers. On the other hand, when fish feed is primarily derived from external sources, local accumulation of nutrients can occur, with negative long-term effects on productivity and water quality. More successful examples include freshwater dike-pond water systems that integrate aquaculture with agriculture in a way that minimizes the need for external inputs through improved retention of nutrients and maintenance of production levels that can be tolerated by the natural environment (Korn 1996).

34.3 The Need for a Socio-Ecological Perspective

In addition to ecological considerations, there is a growing recognition that aquaculture management must also consider social and economic issues as integral components to sustainability. Furthermore, socio-economic considerations also need not be at odds with ecological considerations; for example, integrated aquaculture can offer substantial economic benefits through increased efficiency and production of complementary products, and these factors may have been the driving motivation of its implementation in many cases. Although the incredible growth in aquaculture during the past 20–30 years has had profound positive effects on food production and security, there are many examples where this growth has been poorly planned at the expense of the larger ecosystem and economy. For example, it is estimated that more than 33% of global mangrove area has been lost since 1950, and conversion for pond aquaculture (e.g. for shrimp and fish) is identified as one of the ongoing high-level threats for this trend (Alongi 2002). More recent studies estimate an even higher level of loss (52%; Hamilton 2013), with 28% (544,000 ha) attributed to clearing for commercial aquaculture (Hamilton 2013). These consequences are directly related to an undervaluation of other services that are provided by mangroves; e.g. waste treatment through nutrient cycling, coastal protection, silviculture, fisheries and as important nursery areas for many marine organisms. The acknowledgement that coastal planning initiatives need to better account for these other services has existed for several decades already, but they have been rarely put into practice due to the level of socio-economic and ecological knowledge required.

Guidance on the improved integration of ecological and social aspects in aquaculture were outlined in an international workshop titled, "Ecosystem Approach to Aquaculture" (EAA) (FAO 2008a). This work takes inspiration from similar approaches outlined for management in wild capture fisheries, such as the "Ecosystem Approach to Fisheries" (EAF; García et al. 2003) and the "Ecosystem-Based Fisheries Management" (EBFM; Pikitch et al. 2004). EAA was defined by three main principles, suggesting that aquaculture should: (1) be developed in the context of ecosystem functions and services with no degradation of these beyond their resilience capacity; (2) improve human wellbeing and equity for all relevant stakeholders; and (3) be developed in the context of (and integrated to) other relevant sectors. The first principle deals largely with the concepts of ecosystem services mentioned previously, and is in line with several of the Malawi principles of the ecosystem approach (UNEP/CBD/COP/4/Inf.9) (see Annex 1, García et al. 2003). The latter two principles focus more on the human element, and provide guidelines for the effective planning of aquaculture in order to maximize long-term success, equity and sustainability. EAA and EAF emphasize the placement of man within the ecosystem rather than as an externality that might have been previously managed in a more top-down approach. Even though such considerations are increasingly recognized in management, there are relatively few examples where all of the principles are followed or legally enforced, some of which are highlighted in the following section.

34.4 Existing Institutional and Legal Framework

Given the relatively new expansion of aquaculture, many issues relating to its regulation have arisen in a short period of time, and the legal and institutional frameworks to deal with these issues are still under development or lacking at many levels. Furthermore, institutional frameworks may not be well coordinated with each other on aquaculture related issues; for example, in the United States aquaculture falls under the jurisdiction of a number of federal departments and agencies, that implement various federal laws: U.S. Departments of Agriculture and the Interior (U.S. Fish & Wildlife Service); U.S. Coast Guard; U.S. Army Corps of Engineers; Food and Drug Administration; and Department of Commerce via the National Oceanographic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS). Individual states also play significant roles within their aquatic and marine jurisdictions, which may further complicate coordination (Powers and Smith 2008).

In many countries, institutional and binding legal frameworks only exist at the national level. In some cases, existing laws that were not originally written to address aquaculture have been applied to cover issues relevant for management, such as the control of pollution from farms and protection of sensitive habitats from aquaculture development. National jurisdiction may nevertheless be insufficient to deal with the growing issues raised by aquaculture expansion. For example, higher associated costs with offshore mariculture (e.g. fish culture in net pens) have typically restricted operations to within the coastal zone; however, there is now a growing interest to expand further offshore into the Exclusive Economic Zone (EEZ), although regulatory structures often remain unclear and may conflict with competing uses of public waters (Powers and Smith 2008; Fry et al. 2014).

Where aquaculture activities have been conducted within national EEZs, global commons questions have not yet become important issues; however, it is recognized that management must also consider international partners to ensure sustainability (Powers and Smith 2008). Just as straddling fish stocks or highly migratory fish stocks require coordinated management of fishing among nations sharing these resources, aquaculture management must also consider that impacts may not be restricted to the country of origin; therefore, coordination between states is important for the protection of transboundary aquatic systems. International institutional collaboration has become important in issues involving pollution from aquaculture run-off or the introduction and spread of (non-native) or genetically-modified species escaped from aquaculture farms. A recent example of this is the case of cobia (*Rachycentron canadum),* which is a non-native, highly migratory fish that was introduced to Ecuadorian Pacific waters in 2015 for aquaculture purposes. In the same year, several individuals escaped from one of the culture cages, and were later on recorded as far as 600 km away in Colombian waters (Castellanos-Galindo et al. 2016). Due to its predatory lifestyle the species may alter trophic pathways and potentially impact local fisheries if it was to establish itself in the region (Castellanos-Galindo et al. 2016).

Binding international agreements are rare, but many soft law instruments may be adopted by international organizations. For example, the FAO's "Code of Conduct on Responsible Fisheries" (FAO 1995) contains a section on aquaculture development (Article 9) and includes language regarding the protection of fisheries and ecosystems of others. Although voluntary, some aspects relating to the avoidance of harm against other nations may also be covered by international law (e.g. United Nations Convention on the Law of the Sea). Even with a lack of binding international agreements, national legislation may indirectly influence aquaculture practices in other countries through import standards, e.g. with respect to sanitary requirements.

Developments from the European Union (EU) can serve as an example of how an international institutional framework has developed during the growth of aquaculture. Aquaculture is covered by the EU's Common Fisheries Policy (CFP) within the context of sustainable development, which states that its development must take into account environmental, economic and social aspects in a balanced manner. Besides defining a general guideline on how EU members should promote a sustainable and economically viable fisheries and aquaculture industry, the EU's Basic Regulation on fisheries provides no further mention of aquaculture nor the European Union's specific function in relation to aquaculture. Nevertheless, without this specificity, a considerable amount of EU law exists in various pieces of legislation concerning aquaculture, much of which has been implemented post-2006 and primarily in the form of Directives (Churchill and Owen 2010).

The EU outlined a strategy (EU Commission 2002) relating to aquaculture whereby the aim was to achieve stability for the aquaculture industry, guarantee security and employment, and ensure protection for the environment. Given the sector's increasing economic importance, this strategy specifically aims to provide mechanisms that promote and facilitate growth. Actions in line with this strategy exist at various levels (EU, Member states, and the industry itself), but the EU has focused on the creation of a framework of support for sustainable aquaculture and structural funds.

Churchill and Owen (2010) outline several areas pertaining to aquaculture where existing EU legislation may apply: (1) require authorization for establishment and operation of aquaculture installation; (2) preventing and controlling disease; (3) regulating possible pollution damaging to, or resulting from aquaculture; (4) controlling use of alien species or genetically modified species; (5) marketing and trade; (6) tuna farming; (7) public financial assistance. Some of the major areas of overlap in legislation relate to environmental impact, habitat and species conservation, human health, and public financing related to improving various aspects of the industry. Financing assistance was specifically highlighted as an important factor for aiding development and helping comply with the listed areas of legislation; e.g. through improved product diversification, working conditions, hygiene, human and animal health, quality, and environmental impact.

34.5 Central Management Instruments and Strategies

34.5.1 Harmonization with Development Planning

Before any aquaculture development project begins, it is important that managers are able to define the goals of the project and to align these with the larger coastal development plans at regional or national levels (Pillay and Kutty 2005). National planning directives are likely to differ considerably from country to country and will depend on the desired benefits to be gained from aquaculture. For example, some developing countries may focus on food production, while others may prioritize the opening up of new markets through products not offered by capture fisheries. In Europe, for example, there is a push towards further development in the coastal zone, termed ‘Blue Growth’, which includes aquaculture conducted in combination with other emerging industries, such as off-shore energy production from wave and wind energy (e.g. offshore “wind farms”) (EU Commission 2012).

National planning should take into account both ecological and socio-economic factors, and is likely to cover several scales. With this in mind, the EAA defines three scales of consideration for aquaculture: (1) the farm, (2) the water-body and its watershed/aquaculture zone, and (3) the global, market-trade scale. Such a broad perspective requires extensive end-to-end knowledge of the factors required for the establishment of a given aquaculture operation and its long-term sustainability.

Planning of aquaculture development projects will also need to integrate itself within the strategies of other economic development activities, including capture fisheries. Whether the focus is on food production or other products, an underlying important consideration is whether there is a market for the cultured species—i.e. ‘market-oriented production’. This may differ from production-oriented marketing of capture fisheries, and requires basic information on consumer preferences and demand, both for national and international markets (Pillay and Kutty 2005). This aspect is especially important given the fact that many capture fisheries throughout the world are at or above full exploitation, and information on supply/demand imbalances can help in ensuring a market for aquaculture products. This harmonization may also allow for job opportunities for fishers that have lost their jobs due to decreased catches. Some have even suggested that the expansion of aquaculture may have the added benefit of reducing the overall fishing effort by shifting fishers into aquaculture, with possible rises in catch per unit effort, thus increasing profitability (Pillay and Kutty 2005).

On a global scale there is little evidence that aquaculture expansion has had the effect of limiting fishing pressure or slowing the rate of over-exploitation, however some local cases exist. One example is that of the scallop fishery in Sechura Bay, Peru, which has been transformed from an open-access activity to a mariculture operation that accounts for about 50% of South American scallop production. A capture-based aquaculture technique (also called 'sea ranching') is used, in which juvenile individuals (i.e. 'seed') are collected from wild scallop banks and transported to growout areas where they are further cultivated to marketable sizes. The approach is advantageous due to the low operational costs of direct culture on the seafloor combined with favourable growth conditions of the shallow bay (Mendo et al. 2016). The increase in scallop production has had a profound effect on the development of an organized production chain and export market that has been a benefit to culturists of differing scales. Market-based incentives for larger individuals (i.e. higher market prices) indirectly regulated compliance with minimum size requirements and has therefore allowed scallops to reproduce before harvest, likely aiding in future supply of seed. In this particular case, the transition from a previously open-access fishery, to one where artisanal fishermen associations may obtain exclusive use rights to areas of the bay for bottom scallop culture, has created an incentive to reduce fishing pressure in the stock in the bay. However, the situation is still developing and the dependence on the extraction of wild-caught juveniles remains a major bottle-neck to future production.

34.5.2 Integrated Coastal Zone Management

Aquaculture is only one of many human activities in coastal zones. Coastal settlement and respective transport links, as well as important economic operations related to tourism, food production (i.e. agriculture, fishery, mariculture) and energy generation—to name a few—interact in a complex way (Chap. 28). For effective, long-term sustainable management of these activities, all concerned stakeholders need to be involved, e.g. through an integrated coastal zone management (ICZM) approach (also called 'integrated coastal management'). Ideally, ICZM is a continuous and dynamic decision making process for the cooperative management of coastal regions in order to achieve sustainable development of coastal areas, while reducing vulnerability of respective socio-ecological systems, maintaining essential ecological processes, and biological diversity in these zones (Clark et al. 1992; EU Commission 1999; Cicin-Sain and Belfiore 2005). The concept therefore aims at balancing benefits from economic development with the protection and sustainable use of natural resources (Stead et al. 2002). Several reports and strategies for the implementation of ICZM can be found in the literature in regard to international (Clark et al. 1992) and European contexts (EU Commission 1999; MAP 2012). Within ICZM, aquaculture has an important role to play for the long-term sustainable use of coastal resources, and for the economic development of associated communities and industries (Stead et al. 2002), but goals, decisions and activities of the aquaculture sector should be coordinated with that of all other actors (Hovik and Stokke 2007). An ICZM-process may, for example, lead to the definition of specific zones suitable for the different important socio-economic activities (Gowing et al. 2006) in order to decrease or avoid spatial conflicts in coastal settings. As an example, Hovik and Stokke (2007) compare the effectiveness of regionally-implemented ICZM strategies of three Norwegian regions, where aquaculture is an important sector (e.g. salmon). The authors conclude that the intensity of commitment of regional authorities to act as facilitator in the ICZM planning and implementation process determines the level of integration achieved during the process. Other examples of successful decentralized applications of integrated coastal management are outlined by McCleave et al. (2003).

34.6 Best Practices

34.6.1 Risk Assessment

With the expansion of the aquaculture sector, the need for risk assessment as an objective and standardized means of assessing the likelihood of negative consequences, has become essential for the successful realization of any project. These include risks to the surroundings, e.g. environmental degradation due to pollution, consequences as resulting from the introduction of invasive species, as well as negative social or economic impacts. The focus of the risk assessment may differ according to the type of the aquaculture operation, and the respective focus of management.

The recognition that risk assessment is an important aspect for the future of aquaculture is not new; for example, in 1991 the Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP), an international advisory body, formulated a paper on ‘Reducing Environmental Impacts of Coastal Aquaculture’ in which they also addressed the issues of human health and socio-economic considerations (GESAMP 1991; GESAMP 2008) and provided guidelines and strategies for the risk assessment. Relatedly, the EU Commission provided guidelines for aquaculture conduct the reformed Common Fisheries Policy (CFP), the European Maritime and Fisheries Fund (EMFF), and the EU’s Blue Growth agenda for economic growth and employment, which singled out the aquaculture sector as one of its five priorities (EU Commission 2012). To support the national planning in EU countries, the Commission issued ‘Strategic Guidelines for the Sustainable Development of EU Aquaculture’ in 2013 (EU Commission 2013), though most of these strategies lack consistency within and across national borders. The most important guideline for the application of risk assessment is that proposed by the FAO (FAO 2008b), suggesting a strategy focusing on the importance and application of risk analysis to seven major risk sectors of aquaculture production: pathogen risks, food safety and public health risks, ecological (pests) risks, genetic risks, environmental risks, financial risks and social risks.

The potential risks of an aquaculture operation and related activities for the ecosystem will depend on the type and species of culture, as well as on site-specific environmental settings, and should accordingly be carefully identified and assessed on an individual case level. The methods and frameworks for the assessment will accordingly differ depending on the risk on which the analysis focuses. The application of a single risk analysis framework across all sectors is neither possible nor desirable.

34.6.2 Minimizing and Predicting Impacts

Aquaculture operations may affect the environment in diverse ways: e.g. alteration of water regimes (i.e. culture facilities can modify currents); increased waste loading through the discharge of nutrients, excess feed and excrement; spreading of diseases and parasites; discharge of antibiotics and/or other hazardous chemicals (e.g. antifouling agents); degradation of ecosystem structure, functioning, and resilience through the alteration of species composition (FAO 2008b: 3–8). However, the type and degree of impact depends on site-specific characteristics such as water residence time and water depth, as well as the type and intensity of culture.

When already in place, aquaculture performance may be evaluated through indicator-based assessments that help to optimize operations, e.g. with respect to culture densities as a means of decreasing impacts to the environment. For each potential source of impact the individual system will hold a specific tolerance range, i.e. a certain carrying capacity threshold that needs to be defined in order to minimize culture impacts. Each type of aquaculture (e.g. finfish, bivalves, shrimps etc.) has its own set of considerations regarding best practices in regards to environmental or social impact, and these considerations have been used to develop specific certification standards. For example, specific standards have been defined for bivalve culture regarding 'acceptable levels' of nutrient loading that can be tolerated by a given benthic environment, as inferred by the accumulation of free sulfide concentrations (Bivalve Standards, Aquaculture Stewardship Council, http://www.asc-aqua.org/).

Predictive modelling should be applied if the aquaculture operation is still in the planning phase in order to select aquaculture sites as to minimize impacts, optimize harvests, and to otherwise foresee potential sources of conflict. As an example, the DEPOMOD model (Cromey et al. 2002) was developed to assessment the possible impacts of finfish aquaculture to the benthic environment due to increases in nutrient loading. It simulates the dispersal of particulate waste originating from farm sites and subsequent alterations to benthic faunal communities. Integrating independently validated particle tracking, resuspension and benthic response models are essential for the complete impact assessment of fish farms. DEPOMOD has been applied to a range of different fish farms in Scotland (Cromey et al. 2002) and to three mussel culture sites in Canada (Weise et al. 2009).

On the farm level, the concept of carrying capacity is now recognised as an important component for EAA, though the definition and implementation of respective thresholds is not straightforward (Ross et al. 2010) and may be based on ecological or social considerations (Inglis et al. 2000; McKindsey et al. 2006). In its simplest form, the concept of carrying capacity describes the maximum of a (cultured) population in relation to a determining variable (e.g. the resources on which it depends, Inglis et al. 2000), aiming at maximizing production without compromising ecosystem health. Originating from terrestrial resource management (Odum and Odum 1959; Shelby et al. 1987, both cited in Inglis et al., 2000), the concept was first applied to bivalve aquaculture (e.g. Carver and Mallet 1990; Dame and Prins 1998; Smaal et al. 1998; Inglis et al. 2000), but further adapted to fit a wide range of aquaculture settings (including finfish and shellfish) (Stigebrandt et al. 2004; Gečcek and Legović 2010; e.g. Stigebrandt 2011). The concept may be applied to existing aquaculture sites, although in this case the estimation of limits to cultures may be biased by changes that existed before monitoring was initiated. Ideally, these approaches should be applied during the planning process in order to estimate an area's potential while maintaining ecosystem functioning.

The characterisation of carrying capacity involves in any case the sound understanding and description of the relationship between culture levels and its environmental effects, as well as the identification of "acceptable" limits to culture induced environmental changes (i.e. the carrying capacity; Inglis et al. 2000). Modelling approaches for the determination of thresholds may evaluate different variables or parameters, which differ in spatial and temporal resolution, while applied methods can vary in their complexity from simple indices to spatially discrete and complex ecosystem models. Accordingly, the type of output and applicability of the model to management issues can vary greatly (Ferreira et al. 2013).

As an example, the FARM (Farm Aquaculture Resource Management) model integrates physical and biogeochemical models for the optimization of ecological and economic aspects of culture practices, while simultaneously assessing farm-related eutrophication implications, and may be used for the identification of the system's carrying capacity to aquaculture (Ferreira et al. 2007; Ferreira et al. 2009). More recent work has estimated carrying capacity through a trophic modelling approach, defining ecological carrying capacity based on thresholds of impact to other components of the food web (Kluger et al. 2016).

34.6.3 Adaptive Management

Socio-ecological systems are inherently complex and managers must accept a high degree of initial uncertainty regarding its processes and functioning. However, this uncertainty can be reduced over time through adaptive management. Adaptive management is an iterative process that updates policy and management strategies given a set of objectives and expected outcomes. It requires much more than simple monitoring and subsequent response to unexpected management impacts; rather, adaptive management should begin with the integration of existing interdisciplinary experience and information into predictive dynamic models that are able to assess the impacts of a given policy (Holling 1978; Walters 1986; Walters 1997). From this perspective, modelling holds a key role in the adaptive management process. In particular, Walters (1997) identifies three main functions for the modelling step: (1) clarification of problems and enhanced communication among scientists, managers, and other stakeholders; (2) policy screening to eliminate options that are most likely incapable of doing much good, because of inadequate scale or type of impact; and (3) identification of key knowledge gaps that make model predictions suspect.

This emphasis on modelling is meant to serve more as a framework for hypothesis testing than as an endorsement for a specific mechanistic or statistical modelling approach. It is especially relevant the case of complex socio-ecological systems, where we may only have qualitative indicators (e.g. stakeholder well-being, income, species diversity, etc.). Indicators should be based on sound hypotheses relating their performance to the defined objectives of a given aquaculture operation or national development plan, and the iterative process of adaptive management implies that these objectives may be continually updated to reflect changing perceptions or updated information.

The concept of adaptive management has been defined as the "best practice" approach to EAA, and specific emphasis was placed on its use in promoting social system resilience in the face of changes caused by aquaculture (Bailey 2008). Specifically, the author identified seven main issues that may be affected by aquaculture development: (1) entrepreneurial opportunity and employment generation; (2) gender relations; (3) economic diversification; (4) infrastructural development; (5) food supply; (6) user conflicts; and (7) balances in wealth, income, and power. Due to production-oriented focus for aquaculture, social considerations are often ignored or marginalized; for example, it has been observed that many developing countries have prioritized the development of capital-intensive aquaculture devoted to global markets as a basis for national economic development programs, which has resulted in weak investment in the poorer factions of society, often resulting in their marginalization or exit from the sector (EJF 2003; Toufique and Gregory 2008; Krause et al. 2015). Krause et al. (2015) termed this disconnect between aquaculture industry, policymakers, and the people who depend on aquaculture for a job and/or food source as the "people-policy gap". They suggested that this shortcoming in the exchange of knowledge between actors has led to the suboptimal development of aquaculture in terms food security, nutrition and income. A framework based on adaptive management was put forth as a way to guide and improve policy-relevant assessments by making best use of existing data and scientific tools for decision-making.

34.7 Status and Results of Management Efforts, Perspectives and Next Steps to be Taken

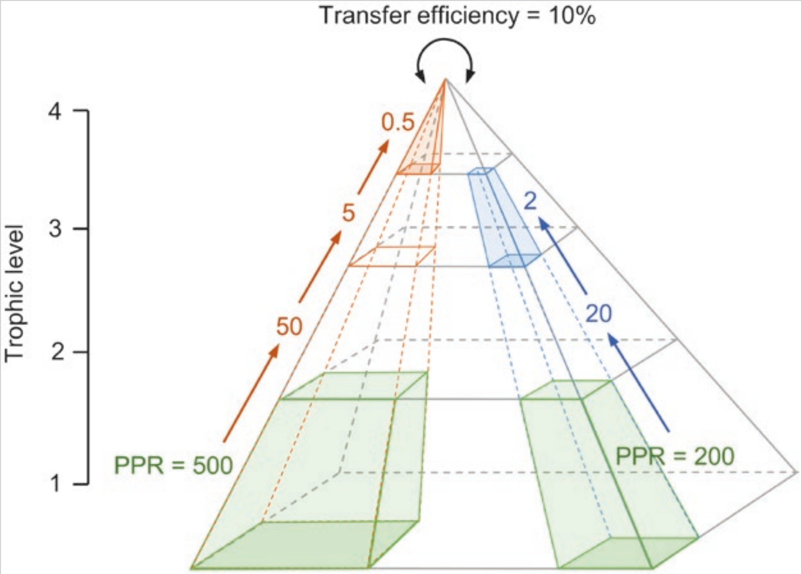
The exponential rise in aquaculture production over the past decades has had many effects on aquatic ecosystems and the people that depend on them for their livelihood. Some of these effects have been overwhelmingly positive, such as the increases in food production, yet there are many examples where these benefits have been overshadowed by unsustainable practices and poor planning to integrate aquaculture into the larger socio-ecological system. The following sections highlight some trends in aquaculture through the use of more holistic indicators, such as the "ecological footprint". This is followed by a recapitulation of EAA, highlighting the factors most associated with its successful implementation.

34.7.1 Reducing Aquaculture's Ecological Footprint

Initial work towards an ecological perspective to aquaculture focused largely on economic and ecological considerations. For example, the concept of an 'ecological footprint' (Rees and Wackernagel 1994; Wackernagel and Rees 1998), which attempt to measure the physical area required to sustain a given activity, was applied to an aquaculture context (Folke et al. 1998). In addition, the concept of 'economic engineering' was used to illustrate examples where aquaculture can be integrated within the functioning of natural environments for the enhancement of productivity within the ecological limits of the ecosystem (Folke and Kautsky 1991; Folke and Kautsky 1992). An important background to these approaches is the ability to accurately measure the costs and benefits of a given aquaculture operation. This requires expert knowledge into the functioning of aquatic ecosystems, including physical, geochemical, and biological processes, which are often difficult to measure. Some attempts have been made to quantify important ecosystem services in economic terms (Costanza et al. 1997), even in cases of non-market services where valuation is less straightforward (e.g. cultural value). Indirect valuation methods such as 'willingness to pay' may be gained through surveys of stakeholders' perception, while the value of other non-market services might be estimated through comparison to the cost of technological replacement (e.g. cost of levees to replace coastal protection function of mangroves). These methods provide an interesting basis for the improved valuation of an aquaculture development project, but their emphasis on precise quantifiable values may be overly prohibitive to practical use. Semi-quantitative or qualitative indicators, which reflect favourable attributes, may be more useful for the achievement of long-term sustainability goals.

One example of using indicators for addressing aspects of the ecological footprint concept concerns the issue of aquaculture's dependence on feed derived from wild caught fish. Some types of aquaculture are more additive in terms of protein production, such as the integrated pond culture conducted throughout Asia, which require little external inputs for their production. However, most other types of finfish and crustacean aquaculture operations are still overly dependent on capture fisheries as feed sources (e.g. fish meal) (Tacon and Metian 2008) or as sources of brood stocks for grow-out. One index that has been illustrative for the ecological impact of aquaculture and fisheries is primary production required (PPR) to sustain catches or production (see Box 34.1). Under this perspective, species that feed at higher levels in the food web (i.e. 'trophic level', TL) contribute far greater amounts to PPR.

Box 34.1: Transfer Efficiency (TE) and Primary Production Required (PPR)



Flows of energy within an aquatic ecosystem can be imagined as a pyramid with volume representing units of energy and the vertical dimension representing trophic level (TL). Primary producers, such as plants and phytoplankton, are the starting point for energy production, and form the base of the pyramid. Subsequent levels represent energy that flows through animal consumers further up the food web. Each transfer of energy through consumption implies a step upwards in TL. Primary producers are assigned a TL 1, consumers of primary production are TL 2, etc., with highest level predators usually occupying TL 4 or greater. Species with a mixed diet (i.e. with items from different TLs) are assigned intermediate TL values based on the relative proportions of the diet items, multiplied by their respective TLs, plus one; for example, the TL of a consumer having with a diet consisting of 50% phytoplankton (TL 1) and 50% zooplankton (TL 2) is calculated as follows: $(0.5 \times 1) + (0.5 \times 2) + 1 = 2.5$.

A large portion of energy is lost between TLs as one goes up the food web, due to use in baseline metabolic processes (i.e. respiration) as well as other inefficiencies. This is reflected by the tapering of the pyramid with decreasing energy, which ultimately limits the total number of TLs that can be supported. On average, aquatic ecosystems are estimated to transfer only about 10% of energy across discrete TLs (i.e. 'transfer efficiency', TE) (Christensen and Pauly 1993; Pauly and Christensen 1995). TE is visualized by the angle of tapering in pyramid, with higher or lower mean system TEs resulting in steeper or squatter pyramids, respectively. Similar visualizations have been used to facilitate comparison between ecosystems or ecosystem states (e.g. El Niño vs. La Niña conditions, Tam et al. 2008; Taylor et al. 2008).

Given the TL of a harvested species, the amount of basal primary production that was needed per unit of production ('primary production required', PPR) can be back-calculated assuming TE = 10%. As an example, the above figure shows the consequence of targeting production from TL 3 versus TL 4 (blue and orange shaded areas, respectively) in terms of PPR. Although the amount harvested from TL 4 is 25% that of TL 3 (0.5 vs. 2), its higher TL translates to a greater overall impact in terms of PPR (500 vs. 200). This highlights the difference in energy required for consuming, for example, fish coming from high TLs (e.g. tuna, ~4.5) versus lower TLs (e.g. carp, ~2.5). Similarly, aquaculture that is able to produce species from lower TLs, or which uses feed derived from lower TLs, will result in a reduced ecological footprint in terms of PPR.

The methodology was applied to fisheries by Pauly and Christensen (1995), who estimated that about 8% of global aquatic primary production was required to sustain fisheries. Similar PPR calculations for aquaculture are complicated by differences in diet and feeding efficiency between wild versus cultured populations; however, important information on the *relative* impact of aquaculture across time and space has been inferred from patterns in the mean TL of cultured species (Pullin et al. 2007; Tacon et al. 2010). These studies point to a relatively flat trend in the mean TL of aquaculture production through time on a global scale, although large differences exist regionally due to the species being cultured. Ideally, estimates of TL and PPR as indicators of ecological impact should also consider changes in diet and feeding efficiencies occurring through time. As an illustration of the influence of these considerations, we will take a closer look at the case of Norwegian salmon aquaculture, which has grown tremendously over the past 30 years to production levels now exceeding 1.2 million tonnes per year.

Historically, salmonid aquaculture has depended largely on fishmeal and oil as major feed components, although their contribution has been reduced to about 30% in recent years along with improvements in feeding efficiency (Ytrestøyl et al. 2015) (Fig. 34.3a). Despite these improvements, it is estimated that salmonid aquaculture worldwide still uses around 27 and 68% of the global fish meal and oil production, respectively (Ytrestøyl et al. 2011). Decreased dependence on fish feed through the substitution of plant-sourced feed components (e.g. proteins and oils) has likely enabled the industry to continue to grow at such a rapid rate in recent years. As a rough estimate of the trend in historical PPR for Norwegian salmon aquaculture, we combine production levels (FAO 2016) with estimates of the fish required to sustain this production. Specifically, "fish in, fish out" (FIFO) ratios, provided by Ytrestøyl et al. (2015) (Fig. 34.3b), allow for the conversion of the required fish meal and fish

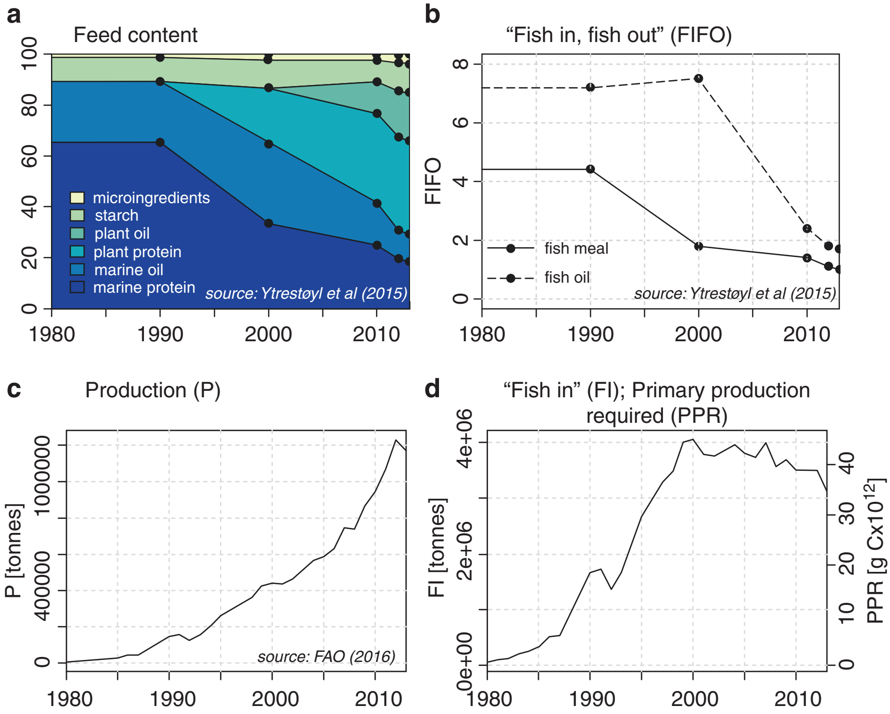


Fig. 34.3 Historical changes of Atlantic salmon aquaculture in Norway in terms of (**a**) feed content, (**b**) "fish in, fish out" (FIFO) ratios for fish meal and fish oil use per unit produced, (**c**) total production (P), (**d**) total "fish in" (FI) and associated primary production required (PPR). PPR is only estimated for the FI component of the diet. Specific data values from Ytrestøyl et al. (2015) are shown as points with interpolated intermediate year values as lines (**a**, **b**)

oil per unit of production into original wet weight. Since salmon feed uses a higher oil to meal ratio than is typically found in the raw fish, a portion of the FIFO oil is discounted to prevent double counting in the estimation of raw fish required ("fish in", FI). Finally, FI is converted to PPR assuming a TL = 3, which is typical of the foraging fish used in fish meal and oil production (Espinoza and Bertrand 2008), and assuming a TE = 10%. The plant source diet proportion is not considered here due to unknown conversion factors for estimating their original wet weight biomass units; however, under the assumption of TE = 10%, fish source feed components (TL = 3) contribute about 100× the PPR per unit produced as compared to plant source components (TL = 1), and thus comprise a large majority of the total. Finally, wet weight units were converted to carbon using a ratio of 9:1, allowing for comparison with estimates of PPR for wild fisheries as estimated by Pauly and Christensen (1995).

The results show that, while production levels have continued to grow at an exponential rate (Fig. 34.3c), the reduction in FIFO ratios has had a dramatic effect on slowing the increasing trend in FI and PPR, with a maximum value reached in the year 2000 (Fig. 34.3d). The trend is helpful for visualizing the overall reduction in dependence on fish meal and oil, and provides a much more realistic estimate than one which assumes a constant diet based on wild populations. Although simplistic, the PPR index is illustrative in demonstrating the impacts of aquaculture, especially in cases where the ecological costs are spatially removed from the operations. The index would ultimately be used in combination with others that stress differing aspects of sustainability.

The growth of aquaculture has had an important role in fulfilling the increasing demand for protein in recent decades, especially in the case of culture of low trophic level species. To the contrary, culture of high TL species cannot make the same claim since they require higher amounts of fish than they produce (e.g. FIFO). In the past there has been a lack of a market for small foraging fish species typically destined for fish meal production, and their use towards the production of more marketable species has been viewed as value adding. Recently, however, there has been a more concerted effort to reduce this inefficient use of high quality protein by increasing the amount of direct human consumption (e.g. in Peru) (Fréon et al. 2014). For Norwegian salmon production, the reduced dependence on foraging fish illustrates the important progress that has been made in the industry, although the scale of production still has a large overall footprint on wild fisheries. As protein demand continues to grow, it is likely that the direct use of foraging fish production may become increasingly attractive.

34.7.2 Making Ecological Aquaculture a Reality

The implementation of EAA is still a work in progress. As mentioned earlier, this perspective differs from previous ones that viewed aquaculture from an ecosystem engineering viewpoint, to one where socio-economic issues as emphasized as key drivers of sustainability. Costa-Pierce (2002) takes the view that 'ecological aquaculture' should, in the best cases, incorporate a global view by integrating information from the best science to promote innovation and efficiency while incorporating social and environmental costs, rather than externalizing them. Closed-system approaches, such as lower impacting, integrated aquaculture systems, may be viewed as best case scenarios. Furthermore, ecological aquaculture should be value adding by enhancing and creating jobs within various aspects of the production network. Six main characteristics of ecological aquaculture are put forth (reproduced from Costa-Pierce 2002):

1. Preservation of the form and functions of natural ecosystems. Sites do not disrupt or displace valuable natural ecosystems; but if local displacement/degradation does occur, active research and development programs for ecosystem rehabilitation and enhancement are initiated and sustained.
2. It practices trophic level efficiency as the world's most efficient protein producer, relying on plant, waste animal or seafood processing wastes, with fish meal used in the production process not as the major protein or energy source but to solve issues of diet palatability only.

3. It practices nutrient management by not discharging any nutrient or chemical pollution, and does not use chemicals or antibiotics harmful to human or ecosystem health in the production process.
4. It uses native species/strains and does not contribute to "biological" pollution; but if exotic species/strains are used, complete escapement control and recovery procedures are in place, and active research and development programs provide complete documentation and public information.
5. Is integrated in communities to maximize job creation and training for displaced "sea workers", and is a good community citizen; exporting to earn profits, but also marketing products locally to contribute to community development.
6. It is a global partner, producing information for the world, avoiding the proprietary.

In addition, managers and policy makers have also begun to place more emphasis on the scale of aquaculture operations and how it should reflect the emphasis of development goals. Small-scale aquaculture general provides more employment opportunities per unit of capital invested than larger farms (Pillay and Kutty 2005), and may also be more inclusionary of local communities, while large scale aquaculture projects may be more appropriate when production (e.g. protein demand) is the goal. An interesting side-debate has arisen regarding whether or not aquaculture development has a role to play in situations involving the preservation of traditional livelihoods, with contrarian views often coming from coastal communities and environmentalists that see aquaculture as external to traditional activities. Adversaries cite that such opinions stem from misplaced moral authority on the part of 'affluent urban environmentalists' and that ecological aquaculture can aid in rescuing coastal communities from becoming 'museum curios' in poorly planned, ecotourism schemes (see Costa-Pierce 2002 and citations within). In the case of Europe, the European Fisheries Fund (EFF) (2007–2013) included financing support for aquaculture projects that improved the sustainability, supported coastal communities in diversifying their economies and create new jobs. Financing was available to small, micro and medium-sized businesses with less than 750 employees (with some exceptions). It is noteworthy that its follow-up program, the European Maritime and Fisheries Fund (EMFF) (2014–2020), has an even stronger emphasis on promoting smaller-sized operations by limiting financing to small, micro and medium-sized businesses with less than 250 employees.

The degree to which the principles of ecological aquaculture are being implemented is difficult to assess at a global level. While legal frameworks promoting these standards have been implemented, many exist within soft law instruments and are unbinding at international levels. Recent initiatives in certification schemes (e.g. Aquaculture Stewardship Council, ASC; Global Aquaculture Alliance, GAA; GLOBALG.A.P.) have focused on attracting consumers to products with a record of sustainable practices. Standards for certification typically deal with many of the principles of ecological aquaculture, including standards relating to social-responsibility and community interactions. Critiques of these certification programs cite, among others, that auditing is often reliant on private contractors, the majority of costs fall on the farm, and standards are formulated too vaguely. Furthermore,

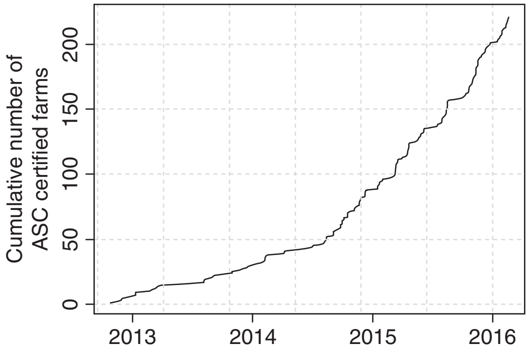


Fig. 34.4 Cumulative number of farms certified by the Aquaculture Stewardship Council (ASC) (as of Feb 2016, http://www.asc-aqua.org/)

certification schemes have been criticized as focusing too heavily on species that are predominantly consumed in the EU and US, with limited coverage of Asian markets (Jonell et al. 2013). Interestingly, most of these issues are more directed at implementation rather than the standards themselves, which are generally in line with many of the best practices outlined here. While certification still covers a relatively small portion of aquaculture production, the number of certifications has been growing steadily (e.g. ASC, Fig.34.4).

34.8 Conclusion

Despite aquaculture's long history as a means of increasing local food production, its recent expansion and promotion has also been driven by both local and international market forces. Aquaculture's profile has been elevated to that of a growth industry, and is being actively promoted in many countries as a means to improve livelihoods (e.g. EU Commission 2013; NOAA 2015). While the promise of aquaculture as a source of increased food production has been partially fulfilled, many examples of unsustainable practices continue, and it remains to be seen whether aquaculture can continue to expand without jeopardizing the natural systems and societies in which they are situated.

In this chapter we have focused on summarizing the main issues facing the long-term sustainability of the aqua- and mariculture sector. We find that, while ecological issues have dominated discussions of sustainability historically, newer guidelines, such as the Ecosystem Approach to Aquaculture (EAA), place increased emphasis on the importance of socio-economic considerations. From both ecological and socio-economic perspectives, examples from small-scale aquaculture may show the most promise for sustainability due to a greater ease of integration with other economic activities and ecosystem functioning. Nevertheless, large-scale operations will no doubt continue, and it will be increasingly important that binding national and international legal frameworks can be strengthened in order to minimize negative effects. Best practices for long-term sustainability include effective planning, long-term monitoring of indicators, and the adaptive management. While the theoretical basis for these practices is often quite strong, their successful implementation will likely to depend on the political will of governing institutions.

References

Alongi DM (2002) Present state and future of the world's mangrove forests. Environ Conserv 29:331–349. doi:10.1017/S0376892902000231.

Bailey C (2008) Human dimensions of an ecosystem approach to aquaculture. In: Soto D, Aguilar-Manjarrez J, Hishamunda N (eds) Building an ecosystem approach to aquaculture. Food and Agriculture Organization of the United Nations, Rome, pp 37–46

Carver CEA, Mallet AL (1990) Estimating the carrying capacity of a coastal inlet for mussel culture. Aquaculture 88:39–53. doi:10.1016/0044-8486(90)90317-G

Castellanos-Galindo G, Baos R, Zapata L, (2016) Mariculture-induced introduction of cobia Rachycentron canadum (Linnaeus, 1766), a large predatory fish, in the Tropical Eastern Pacific. BioInvasions Records 5(1):55–58

Christensen V, Pauly D (1993) Flow characteristics of aquatic ecosystems. In: Christensen V, Pauly D (eds) Trophic models of aquatic ecosystems. International Center for Living Aquatic Resources Management, Manila, pp 338–352

Churchill R, Owen D (2010) The EC Common fisheries policy. Oxford University Press, Oxford

Cicin-Sain B, Belfiore S (2005) Linking marine protected areas to integrated coastal and ocean management: A review of theory and practice. Ocean Coast Manage 48:847–868. doi:10.1016/j.ocecoaman.2006.01.001

Clark JR, Garcia SM, Caddy JF (1992) Integrated management of coastal zones. FAO, Rome

Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Maeem S, O'Neill R, Paruelo J, Raskin R, Sutton P, van den Belt M (1997) The value of the world's ecosystem services and natural capital. Nature 387:253–260. doi:10.1038/387253a0

Costa-Pierce BA (2002) Ecology as the paradigm for the future of aquaculture. In: Costa-Pierce BA (ed) Ecological aquaculture: the evolution of the Blue revolution. Blackwell Science Ltd., Oxford

Cromey CJ, Nickell TD, Black KD (2002) DEPOMOD — modelling the deposition and biological effects of waste solids from marine cage farms. Aquaculture 214:211–239. doi:10.1016/S0044-8486(02)00368-X

Dame RF, Prins TC (1998) Bivalve carrying capacity in coastal ecosystems. Aquat Ecol 31:409–421

Environmental Justice Foundation (2003) Risky business: vietnamese shrimp aquaculture—impacts and improvements. Environmental Justice Foundation, London

Espinoza P, Bertrand A (2008) Revisiting Peruvian anchovy (Engraulis ringens) trophodynamics provides a new vision of the Humboldt Current system. Prog Oceanogr 79:215–227

EU Commission (1999) Towards a European Integrated Coastal Zone Management (ICZM) Strategy: General principles and policy options

EU Commission (2002) A strategy for the sustainable development of European aquaculture: Communication from the Commission to the Council and the European Parliament

EU Commission (2012) Blue Growth: Opportunities for marine and maritime sustainable growth: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, European Commission

EU Commission (2013) Strategic Guidelines for the sustainable development of EU aquaculture: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, European Commission

FAO (1995) Code of conduct for responsible fisheries. Food and Agriculture Organization of the United Nations, Rome

FAO (2008a) Building an ecosystem approach to aquaculture. FAO/Universitat de les Illes Balears Expert Workshop, Palma de Mallorca, Spain, 7–11 May 2007

FAO (2008b) Understanding and applying risk analysis in aquaculture. Food and Agriculture Organization of the United Nations, Rome

FAO (2014) The State of world fisheries and aquaculture: opportunities and challenges. Food and Agriculture Organization of the United Nations, Rome

FAO (2016) Fishery and Aquaculture Statistics: Global capture production 1950–2014 (FishStatJ). Food and Agriculture Organization of the United Nations, Rome

Ferreira JG, Grant J, Verner-Jeffreys DW, Taylor NGH (2013) Modeling frameworks for determination of carrying capacity for aquaculture. In: Christou P, Savin R, Costa-Pierce BA, Misztal I, Whitelaw B (eds) Sustainable food production. Springer, New York, pp 417–448

Ferreira JG, Hawkins AJS, Bricker SB (2007) Management of productivity, environmental effects and profitability of shellfish aquaculture—the Farm Aquaculture Resource Management (FARM) model. Aquaculture 264:160–174. doi:10.1016/j.aquaculture.2006.12.017

Ferreira JG, Sequeira A, Hawkins AJS, Newton A, Nickell TD, Pastres R, Forte J, Bodoy A, Bricker SB (2009) Analysis of coastal and offshore aquaculture: application of the FARM model to multiple systems and shellfish species. Aquaculture 292:129–138. doi:10.1016/j.aquaculture.2008.12.017

Folke C, Kautsky N (1991) Ecological economic principles for aquaculture development. In: Cowey CB, Cho CY (eds) Nutritional strategies and aquaculture wastes. University of Guelph Press, Guelph, ON, pp 207–222

Folke C, Kautsky N (1992) Aquaculture with its environment: prospects for sustainability. Ocean Coast Manag 17:5–24. doi:10.1016/0964-5691(92)90059-T

Folke C, Kautsky N, Berg H, Jannson A, Troell M (1998) The ecological footprint concept for sustainable seafood production: a review. Ecol Appl 8:63–71. doi:10.2307/2641363.

Fréon P, Sueiro JC, Iriarte F et al (2014) Harvesting for food versus feed: a review of Peruvian fisheries in a global context. Rev Fish Biol Fish 24:381–398. doi:10.1007/s11160-013-9336-4

Fry JP, Love DC, Shukla A, Lee RM (2014) Offshore finfish aquaculture in the United States: an examination of federal laws that could be used to address environmental and occupational public health risks. Int J Environ Res Public Health 11:11964–11985. doi:10.3390/ijerph111111964

García SM, Zerbi A, Aliaume C et al (eds) (2003) The ecosystem approach to fisheries: issues, terminology, principles, institutional foundations, implementation and outlook. Food and Agriculture Organization of the United Nations, Rome

Geček S, Legović T (2010) Towards carrying capacity assessment for aquaculture in the Bolinao Bay, Philippines: a numerical study of tidal circulation. Ecol Model 221:1394–1412. doi:10.1016/j.ecolmodel.2010.02.005

GESAMP (1991) Reducing environmental impacts of coastal aquaculture. Food and Agriculture Organization of the United Nations, Rome

GESAMP (2008) Assessment and communication of environmental risks in coastal aquaculture. Food and Agriculture Organization of the United Nations, Rome

Goodland R (1997) Environmental sustainability in agriculture: diet matters. Ecol Econ 23:189–200

Gowing JW, Tuong TP, Hoanh CT (2006) Land and water management in coastal zones: dealing with agriculture-aquaculture-fishery conflicts. In: Hoanh CT, Tuong TP, Gowing JW, Hardy B (eds) Environmental livelihoods in tropical coastal zones: managing agriculture-fishery-aquaculture conflicts. CABI Publishing, London, pp 1–16

Hamilton S (2013) Assessing the role of commercial aquaculture in displacing mangrove forest. Bull Mar Sci 89:585–601. doi:10.5343/bms.2012.1069

Holling CS (ed) (1978) Adaptive environmental assessment and management. International Institute for Applied Systems Analysis, New York

Hovik S, Stokke KB (2007) Balancing aquaculture with other coastal interests: A study of regional planning as a tool for ICZM in Norway. Ocean Coast Manag 50:887–904. doi:10.1016/j.ocecoaman.2007.05.003

Inglis GJ, Hayden BJ, Ross AH (2000) An overview of factors affecting the carrying capacity of coastal embayments for mussel culture. NIWA Client Report CHC00/69, Christchurch

Jonell M, Phillips M, Rönnbäck P, Troell M (2013) Eco-certification of farmed seafood: will it make a difference? Ambio 42:659–674. doi:10.1007/s13280-013-0409-3

Kluger LC, Taylor MH, Mendo J et al (2016) Carrying capacity simulations as a tool for ecosystem-based management of a scallop aquaculture system. Ecol Model 331:44–55. doi:10.1016/j.ecolmodel.2015.09.002

Korn M (1996) The dike-pond concept: sustainable agriculture and nutrient recycling in China. Ambio 25:6–13

Krause G, Brugere C, Diedrich A et al (2015) A revolution without people? Closing the people–policy gap in aquaculture development. Aquaculture 447:44–55

MAP (2012) The ICZM process—a roadmap towards coastal sustainability

McCleave J, Xiongzhi X, Huasheng H (2003) Lessons learned from "decentralized" ICM: an analysis of Canada's Atlantic Coastal Action Program and China's Xiamen ICM Program. Ocean Coast Manag 46:59–76. doi:10.1016/S0964-5691(02)00121-7

McKindsey CW, Thetmeyer H, Landry T, Silvert W (2006) Review of recent carrying capacity models for bivalve culture and recommendations for research and management. Aquaculture 261:451–462. doi:10.1016/j.aquaculture.2006.06.044

Mendo J, Wolff M, Mendo T, Ysla L (2016) Scallop fishery and culture in Peru. In: Shumway SE, Parsons GJ (eds) Scallops: biology, ecology, aquaculture, and fisheries. Elsevier Science Ltd, Toronto

NOAA (2015) Marine aquaculture strategic plan: 2016–2020. NOAA, Washington, DC

Odum EP, Odum HT (1959) Fundamentals of ecology. W.B. Saunders Company, Philadelphia

Pauly D, Christensen V (1995) Primary production required to sustain global fisheries. Nature 374:255–257. doi:10.1038/374255a0

Phillips JM, Harlan AD, Krumhar KC et al (1978) Studies of potential biological components of closed life support systems for large space habitats: research and technology development requirements, costs, priorities and terrestrial impacts. NASA Ames Research Center, Tucson

Pikitch EK, Santora C, Babcock EA et al (2004) Ecosystem-based fishery management. Science 305:346–347. doi:10.1126/science.1098222.

Pillay TVR, Kutty MN (2005) Aquaculture: principles and practices. Blackwell Publishing, Oxford

Powers A, Smith O (2008) Emerging ocean uses. In: Baur DC, Eichenberg T, Sutton M (eds) Ocean and coastal law and policy. American Bar Association. American Bar Association, Chicago, pp 443–476

Pullin RS, Froese R, Pauly D (2007) Indicators for the sustainability of aquaculture. In: Bert TM (ed) Ecological and genetic implications of aquaculture activities. Springer, Dordrecht, pp 53–72

Rees WE, Wackernagel M (1994) Ecological footprints and appropriated carrying capacity: measuring the natural capital requirements of the human economy. In: Jansson A, Hammer M, Folke C, Costanza R (eds) Investing in natural capital: the ecological economics approach to sustainability. Island Press, Washington, DC, pp 223–248

Ross LG, Telfer TC, Falconer L et al (2013) Carrying capacities and site selection within the ecosystem approach to aquaculture. In: Ross LG, Telfer TC, Falconer L, Soto D (eds), Site selection and carrying capacities for inland and coastal aquaculture, Rome, FAO, pp 19–46

Shelby B, Heberlein TA et al (1987) Carrying capacity in recreation settings. Oregon State University Press, Corvallis

Smaal AC, Prins TC, Dankers N, Ball B (1998) Minimum requirements for modelling bivalve carrying capacity. Aquat Ecol 31:423–428

Stead SM, Burnell G, Goulletquer P (2002) Aquaculture and its role in Integrated Coastal Zone Management. Aquac Int 10:447–468. doi:10.1023/A:1023926421723.

Stigebrandt A (2011) Carrying capacity: general principles of model construction. Aquac Res 42:41–50. doi:10.1111/j.1365-2109.2010.02674.x

Stigebrandt A, Aure J, Ervik A, Hansen PK (2004) Regulating the local environmental impact of intensive marine fish farming: III. A model for estimation of the holding capacity in the Modelling-Ongrowing fish farm-Monitoring system. Aquaculture 234:239–261. doi:10.1016/j.aquaculture.2003.11.029.

Tacon AGJ, Metian M (2008) Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. Aquaculture 285:146–158. doi:10.1016/j.aquaculture.2008.08.015

Tacon AGJ, Metian M, Turchini GM, De Silva SS (2010) Responsible aquaculture and trophic level implications to global fish supply. Rev Fish Sci 18:94–105. doi:10.1080/10641260903325680

Tam J, Taylor MH, Blaskovic V et al (2008) Trophic modeling of the Northern Humboldt Current Ecosystem, Part I: Comparing trophic linkages under La Niña and El Niño conditions. Prog Oceanogr 79:352–365. doi:10.1016/j.pocean.2008.10.007

Taylor MH, Wolff M, Mendo J, Yamashiro C (2008) Changes in trophic flow structure of Independence Bay (Peru) over an ENSO cycle. Prog Oceanogr 79:336–351. doi:10.1016/j.pocean.2008.10.006

Toufique KA, Gregory R (2008) Common waters and private lands: Distributional impacts of floodplain aquaculture in Bangladesh. Food Policy 33:587–594. doi:10.1016/j.foodpol.2008.04.001

Wackernagel M, Rees W (1998) Our ecological footprint: reducing human impact on the Earth. New Society Publishers, Gabriola Island

Walters C (1986) Adaptive management of renewable resources. Macmillan Publishing Company, Laxenburg

Walters C (1997) Challenges in adaptive management of riparian and coastal ecosystems. Conserv Ecol 1:1

Weise AM, Cromey CJ, Callier MD et al (2009) Shellfish-DEPOMOD: modelling the biodeposition from suspended shellfish aquaculture and assessing benthic effects. Aquaculture 288: 239–253. doi:10.1016/j.aquaculture.2008.12.001

Ytrestøyl T, Aas TS, Åsgård T (2015) Utilisation of feed resources in production of Atlantic salmon (Salmo salar) in Norway. Aquaculture 448:365–374. doi:10.1016/j.aquaculture.2015.06.023

Ytrestøyl T, Aas TS, Berge GM et al (2011) Resource utilisation and eco-efficiency of Norwegian salmon farming in 2010. Nofima, Tromso

Chapter 35
Offshore Oil and Gas Exploitation

Henning Jessen

Abstract The extraction of oil and gas resources—both onshore and offshore—still serves to meet the major share of global energy needs. For decades, exploring and exploiting hydrocarbon resources offshore ranks among the traditional commercial uses of the continental shelf of coastal States. However, this activity creates significant potential threats to the marine environment, as evidenced, in particular by the 2010 *Deepwater Horizon* disaster in the Gulf of Mexico but also by the 2009 *Montara* oil spill which heavily affected Indonesia although the blow-out occurred in Australian waters. Nevertheless, and surprisingly, the offshore oil and gas industry is not regulated by a global multilateral framework even though there are some generally applicable rules of public international law and of regional organizations. Rather, the offshore oil and gas industry is predominantly regulated by national laws. Furthermore, it is subject to a largely self-regulating industry which traditionally applies its own contractual solutions in a highly capital-intensive sector. This article intends to give a bird's-eye view and a more "hands on" (i.e. less academic) approach to discuss the somewhat unique regulatory framework for offshore oil and gas operations and of the contractual system under which this industry performs its services.

Keywords Offshore oil and gas • Continental shelf • UNCLOS • Upstream oil and gas contracts • Safety of offshore oil and gas operations

35.1 The Commercial Background of the Offshore Oil and Gas Sector

The market share of renewable energy resources which are, for example, generated by offshore windfarms or via solar power is continuously rising. Nevertheless, crude oil (petroleum) and gas are still among the world's most actively traded

H. Jessen
World Maritime University (WMU), P.O Box 500, Fiskehamnsgatan 1, Malmö 20124, Sweden
e-mail: hj@wmu.se

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_35

commodities. For a number of countries, for example, for Russia, Saudi Arabia or Qatar, the domestic oil and gas production (onshore and/or offshore) represents by far the most important pillar of the national economy. Norway is a good example for a country even actively managing to limit its domestic offshore oil and gas developments: In the past, Norway had produced vastly more oil and gas than needed domestically, and it has strategically chosen to limit the pace of development to ensure a long-term benefit to the country and to the Norwegian society as a whole.

Crude oil and refined products—such as gasoline (petrol) and heating oil—as well as gas are bought and sold all over the world. Most commonly, the oil price appearing in European media reports will refer to the price of a barrel of Brent blend crude oil from the North Sea which is now being sold exclusively at online platforms (formerly at the London International Petroleum Exchange, now, for example, at the "*ICE Futures Europe/Brent Crude Futures*").

35.1.1 Oil Companies

Most countries with an active oil and gas industry have a national oil company. In some countries, this national oil company is given a monopoly on oil and gas developments. In Saudi Arabia, "*Saudi Aramco*" is the national oil and gas company which also represents the largest oil and gas company in the world. In other countries, the national oil company is a passive participant in the industry, taking revenues but not contributing capital, e.g., "*Sonangol*" in Angola. In a small number of countries, the national oil company is a full commercial player in the oil and gas industry, paying its full share of capital costs and taking its share of revenues, e.g. "*Statoil*" in Norway. And finally, international oil companies are commercial players that are widely known globally as "oil majors", e.g., Exxon, Shell, Total, BP, Chevron, ConocoPhillips, Marathon Oil and others. There is no strict definition of these major oil companies, but they tend to be vertically integrated—involved in oil and gas exploration, production, refining and sale to the end consumer. There are also some independent oil companies but these companies tend to have a very tight geographical focus.

35.1.2 Contractual Partners of Oil Companies

For the commercial background to offshore oil and gas exploitation, it also important to note that the international oil and gas industry creates a lot of work and job opportunities for service providers. These are specialist companies that provide highly specialised equipment, operating personnel and design engineers, thus delivering niche services to the offshore oil and gas industry. Examples include, e.g., cementing companies that provide high-pressure pumps and specialised cements to cement the steel casing in wells (to isolate the oil production from the surrounding rock), jet engine maintenance companies that service and maintain the huge fleets of gas turbine engines that drive power generators and gas compressors offshore, a wide, fragmented number of so-called “contractors” which are most commonly the companies that design, build and install offshore platforms; and “vendors” which are all companies that supply pieces of equipment, such as compressors, separators, storage tanks pumps, valves, etc.

35.1.3 The Role of Non-governmental Organisations

Finally, a number of other private non-industrial entities—mainly environmental lobby groups—help to shape and govern the oil and gas industry activity. Best known is “*Greenpeace*” which mounted a very visible campaign in 1995 to dissuade the UK government from allowing the oil major Shell to dump a decommissioned offshore facility (“*Brent Spar*”) in a deep gorge under the North Atlantic (Warbrick et al. 1995: 957–964). That campaign substantially changed public attitudes—and hence political attitudes. As a result, oil and gas installation disposal is now generally done by dismantling and disposal/recycling onshore. The World Wildlife Fund (WWF) is also actively (and quite successfully) campaigning, e.g., against any Arctic offshore oil and gas operations.

35.2 The Legal Framework for the Offshore Oil and Gas Sector

35.2.1 Public International Law: The Law of the Sea

At the international level, Articles 208, 214 of the United Nations Convention on the Law of the Sea (UNCLOS) mandate States—only—to endeavour to harmonize their policies with regard to possible pollution from seabed activities subject to national jurisdiction *“at the appropriate regional level*” and to enforce their relevant laws and regulations. However, the resulting legal situation can be described as a confusing “patchwork” of different coordination and discussion fora. A universally accepted forum or even organisation for the regulations of international offshore oil and gas activities does not exist (Hempel et al. 2014).

Nevertheless, since oil and gas companies are reluctant to invest in contested maritime areas, UNCLOS still has a high practical importance for the offshore oil and gas industry in terms of providing a legal framework for the delimitation of maritime zones (ITLOS Cases No. 16 and No. 23 2012, 2015 and 2017). Occasionally, national States also enter into bilateral agreements which affect oil and gas companies—commonly agreements which define the maritime boundaries between adjacent offshore jurisdictions. Good examples are the bilaterally agreed maritime boundaries between Russia and Norway or between the UK–Norway–Denmark–Germany–Netherlands in the North Sea (Lagoni and Vignes 2006).

35.2.2 National Laws and Regulations

It has to be kept in mind that a number of governments actively compete to attract foreign oil and gas companies and their investment potential to ensure the development of domestic oil and gas, in particular offshore. Unlike other sectors, the oil and gas industry is still almost exclusively regulated by national laws and regulations. The most common approach is that national regulatory agencies implement and enforce the domestic regulations and laws on offshore oil and gas operations. Some countries, however, have even made their national oil company itself an integral part of the domestic regulatory regime).

In most modern national offshore oil and gas safety regimes, regulatory functions are now clearly set out and functionally separated. For example, in the UK and Norway, legislation and regulation is proposed by a government department but approved by parliament. The award of oil and gas drilling licenses and related policy matters (such as depletion rates) are set by a government department. Thus, in particular as a regulatory reaction to two major offshore disasters in the North Sea, i.e. the"*Alexander Kielland*" of 1980 and of the "*Piper Alpha*" of 1988 (Gordon 2013: 187; Lloyd' List of 9 July 2013: 8), oil and gas safety matters are now overseen by two separate Norwegian regulatory agencies to avoid conflicts of interest (Bang and Thuestad 2014: 243–273).

35.2.3 Selected Regional Approaches

There are several regional approaches relevant for the offshore oil and gas sector. A first important legal source for a regional approach on regulating the safety of offshore oil and gas installations is the 1992 Convention for the protection of the marine environment of the North-East Atlantic (the OSPAR Convention). Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, UK and the European Union are Contracting Parties. OSPAR monitors the development of offshore installations in the North-East Atlantic and maintains an OSPAR Oil and Gas Offshore inventory. The OSPAR database includes the name and ID number, location, operator, water depth, production start, current status, category and function of the installations. According to OSPAR data, more than 1350 offshore installations are operational in the OSPAR maritime area, most of them sub-sea steel installations and fixed steel installations. Since 1998 the dumping, and leaving wholly or partly in place, of disused offshore installations is prohibited within the OSPAR maritime area under OSPAR Decision 98/3 on the Disposal of Disused Offshore Installations. However, following assessment and under certain detailed circumstances, a competent national authority of a relevant Contracting Party may give permission to leave installations or parts of installations in place.

Second, the 1994 Protocol for the protection of the Mediterranean Sea against pollution resulting from exploration and exploitation of the continental shelf and the seabed and its subsoil (Offshore Protocol also known as the Madrid Protocol to the Barcelona Convention). This Protocol has only been ratified by three states (Albania, Morocco and Tunisia) and has not entered into force yet. Remarkably, in contrast to the OSPAR Convention, the Offshore Protocol to the Barcelona Convention even addresses issues of liability and compensation for offshore oil and gas accidents.

Third, the 1981 Convention (and 1985 Protocol) for co-operation in the protection and development of the marine and coastal environment of the West and Central African Region (The Abijan Convention) to which Angola, Benin, Cameroon, Cape Verde, Congo, Cote d'Ivoire, Democratic Republic of Congo, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mauritania, Namibia, Nigeria, Sao Tome and Principe, Senegal, Sierra Leone and Togo are parties. The Abijan Convention and its Protocol predominantly addresses technical co-operation among its Member States, e.g. in relation to coordinated emergency response or sharing information.

35.2.4 European Union Law

In 2013, the EU adopted Directive 2013/30/EU on safety of offshore oil and gas operations. This legal act has been broadly based on the national Norwegian and UK regulatory approaches. Thus, these two countries have been taken as policy role models for EU legislation, i.e., Rather surprisingly, the safety of offshore oil and gas operations had not been subject to any specific EU legal act before 2013—despite that fact that (in 2011) approximately a thousand offshore oil and gas platforms were operating actively in European waters (European Commission 2011: 6). The EU's Offshore Safety Directive can be understood as a response to the "wake up call" of the 2010 "*Deepwater Horizon*" ("*Macondo*") disaster (Merry 2014: 77 et seq.; Vinogradov 2013: 335 et seq.; Gordon 2013: 181 et seq.) and—less prominently, also as a reaction to the 2009 "*Montara*" oil spill, a blow-out in Australian waters which severely affected the Exclusive Economic Zone of Indonesia (Tromans 2014: 257). One of the reasons for this initiative is also the fact that—since "*Deepwater Horizon*"—the tolerance of the general public for environmental damage had reached an all-time low (Interview, Ailio, 2013).

Directive 2013/30/EU represents a good example for the necessary adherence to modernized environmental protection standards in the offshore oil and gas industry.[1] EU Members are, for example, required to enable their national competent authority to be able to carry out its functions and duties in an independent and objective way and with adequate human and financial resources (Articles 8(2) to (5) of Directive 2013/30/EU). In particular, objectivity and independence shall be ensured by preventing any kind of conflicting interests between the regulatory functions of the competent authority and the regulatory functions relating to the economic devel-

[1] Directive 2013/30/EU has supplemented the system of the (much older) EU Directive on the conditions for granting and using authorizations for the prospection, exploration and production of hydrocarbons (Hydrocarbon Licensing Directive).

opment of the offshore natural resources and licensing of offshore oil and gas operations within the EU Member State (including the collection and management of revenues from those operations).

In addition, the act mandates the EU Member States to introduce or update legal rules on different levels, relating to the safety of offshore oil and gas operations, such as: Independence and objectivity of a competent authority within EU Member States ensuring its adequate human and financial resources; efficient and early public participation in decisions with potential effects of planned offshore oil and gas exploration operations on the environment; participation of the employees in matters affecting safety and human health at work (Gordon 2013: 207); warranties and continued verifications of comprehensive concepts on environmental management and of preventing major accidents by operators/owners[2]; updated documentary obligations of the owners/operators to be verified by the competent authority; the formulation and continuous improvement of norms and strategies to prevent major accidents, in particular, analysis of causes of accidents; the introduction of coordinated internal and external emergency response plans and transboundary cooperation; international exchange of information and public transparency.

35.2.5 Private Agreements Between Operators with a Regulatory Impact in Europe

From a practical perspective, it is finally important to mention the 1975 Offshore Pollution Liability Agreement (OPOL).[3] This agreement is not an international convention but a private agreement between 16 operators in the offshore sector. The OPOL Agreement was initially an interim measure to provide a strict liability regime whilst awaiting the entry into force of a regional Convention on Civil Liability for Oil Pollution Damage resulting from Exploration for and Exploitation of Seabed Mineral Resources (CLEE), a regional convention for the Baltic, North Sea and North Atlantic areas. However, the CLEE was never ratified by any of the nine states that participated in the Diplomatic Conference which adopted the Convention and, thus, it has not come into force.

Nevertheless, OPOL continues to operate and, e.g., the instrument imposes strict liability on operators of European offshore facilities and it guarantees payment of compensation up to a limit currently set at US $ 250 million per incident. The parties to OPOL are operators of offshore facilities situated in the jurisdiction of any of the "*Designated States*" to the Agreement which are UK, Denmark, Germany, France, Republic of Ireland, Netherlands, Norway, Isles of Man, Faroe Islands and

[2] The term "*operator*" is legally defined in Article 2(5) of the Directive as "*the entity appointed by the licensee or licensing authority to conduct offshore oil and gas operations, including planning and executing a well operation or managing and controlling the functions of a production installation*"; the term "*owner*" is legally defined in Article 2(27) of the Directive as meaning "*an entity legally entitled to control the operation of a non-production installation.*

[3] See for more information: http://www.opol.org.uk/.

Greenland. Membership of OPOL is a practical condition precedent for operators seeking to obtain a license to drill. Otherwise operators would not be able to satisfy their financial responsibility verification obligations to the national regulatory agencies of the European countries mentioned above.

35.3 Central Management Instruments in Offshore Oil and Gas Exploitation

Due to the lack of a truly global or international instrument covering all aspects of offshore oil and gas operations (including safety), the industry has developed its own array of contractual solutions to the various challenges of this cost-intensive business. The industry would not call those contracts "management instruments" but, essentially, they serve equivalent functions. For example, all upstream petroleum agreements will always involve the resources holder or the owner of reserves in the ground. In most countries, the resource holder is a sovereign state entity. However, negotiations between (foreign) oil companies and sovereign power, often incorporating high values, raise difficult legal issues that do not normally arise within other agreements concluded between private commercial entities. For example, the drilling of one single exploration well, for example in the North Sea, can easily cost more than 50 million USD and approximately 90% of those exploration wells are dry holes. A further characteristic of these upstream agreements is their long duration which last typically for 20, 30 or even 50 years (driven by the length of the exploration, development and production cycle).

35.3.1 Ownership of Offshore Oil and Gas Rights

An entity wishing to explore for and produce (offshore) oil and gas must either own the petroleum rights itself or else have an agreement with the owner of those rights allowing these operations. The answer to the question of who owns the petroleum rights will depend on the law of the state where the petroleum resources are located. The "resource holder" describes the entity in which the law of the state in question vests petroleum in the ground.

The United States represents a peculiar case here because, under US law, the right to minerals (including petroleum) in the ground belongs to the landowner. Generally, petroleum rights in the US are governed by the "rule of capture" which entitles the landowner to extract whatever petroleum comes from the wells on his land, irrespective of where the oil migrated from. However, offshore petroleum rights in areas under US jurisdiction, e.g., in the Gulf of Mexico, are not subject to private ownership. Here, just like in the rest of the world, the petroleum rights belong to the sovereign state itself (or to a nominal figure, such as the British Crown) or else they may be vested in a state-owned entity such as the State Oil Company.

35.3.2 Grant of Exploration and Exploitation Rights by the State

In respect of petroleum rights for deposits found on the continental shelf of coastal states, UNCLOS (still supplemented by the United Nations Convention on the Continental Shelf of 1958) mandates that the coastal state is vested with its sovereign rights and control. Thus, the state administers the oil and gas, which is within its geographical territory and territorial sea as it deems fit. As a result, is up to the coastal state to select and adopt how it wants to go about extracting its natural resources offshore (most commonly relating to oil and gas).

The management instrument adopted by the coastal state is the contractual model for oil and gas exploration and production. There are generally three basic contractual models a state could choose from for the extraction of its oil and gas (both onshore and offshore). These are: Private leases, public concessions or licenses (i.e., a tax and royalty system) and complete state ownership (prevalent, in particular in the Gulf region).

35.3.3 Production Sharing Agreements

The production sharing agreement (PSA) is a contractual arrangement between a foreign oil company and a nation state (acting through its appropriate government agency), authorising the oil company/consortium to conduct petroleum exploration and production within a certain designated area. The foreign company provides the capital investment for exploration, development and construction of infrastructure. The foreign oil company serves as the contractor to the host State and it bears the financial risk, thus, in a situation where oil is not struck, the investment of the oil company has been totally lost. However, the foreign oil company can also recoup its cost (in oil) once production commences. The PSA is also usually for more than 20 years (although subject to relinquishment provisions) and provides for different profit allocation in different phases between the oil company, its co-ventures and the host State.

It is also possible for the state party through its National Oil Company to participate in the operations of the company. In this case it would form a joint venture operator company with the company/consortium and share in the exploration, development and infrastructure cost.

35.3.4 Regulatory Regimes for Licensing

Any person or group of persons wishing to explore, exploit or produce oil and gas within this jurisdiction has to obtain a licence from the host State government. The position on ownership of *onshore* resources is quite clear, however that of *offshore* natural resources could be more debatable. Generally, UNCLOS confers exclusive "sovereign" rights upon a coastal State over its continental shelf. However, the exact limits of the continental shelf between adjacent states are often a source of diplomatic conflict.

To give an example for a licensing regime, within the EU, the Hydrocarbon Licensing Directive still serves as the framework for the granting of petroleum licences in all EU Member States. Through the establishment of uniform rules, the Directive aims at achieving uniformity of procedures in the grant of licences for exploring, exploiting and production of hydrocarbons. The right to apply for licences is open to all EU nationals who possess the necessary expertise. Correspondingly, obligations are imposed on governments to asses and authorise such applications in a non-discriminatory manner based on criteria published in the EU Official Journal inviting applications and to be published at least 90 days before the closing date for applications (Article 3(2) of EU Hydrocarbon Licensing Directive).

35.4 Conclusion

Comparable to other sectors, UNCLOS (and its 1958 predecessor instrument on the Continental Shelf) provides the general legal framework for the regulation of offshore oil and gas. What follows on the hierarchical levels "below" UNCLOS is a very complex and largely uncoordinated array of international, regional, national and privately-based legal instruments. Some of these instruments are legally binding (in particular, of course, national laws) others have failed on the international level, are legally non-binding or are being followed by the industry on a voluntary basis. Sometimes these voluntary approaches can even result in stricter rules as compared to public law approaches. All in all, it seems impossible to coordinate those complex and varying instruments truly from a "top down approach". Nevertheless, the industry itself is highly interested to achieve and implement the highest safety standards. Public and private pressure has resulted in big regulatory and technological advancements in some sub-areas, e.g., in the area of decommissioning. Disasters like the "Deepwater Horizon" blow-up have truly shaken up the industry and have resulted in a further intensification of regulatory activity.[4] In sum, the international regulation of offshore oil and gas exploitation is both dynamic and, at the same time, globally incomplete. This unique regulatory picture will not change in the years to come.

[4] For the massive US case law resulting from the blow-out see: https://www.justice.gov/enrd/deepwater-horizon

Bibliography

Books, Academic Articles and Newspaper Articles

Bang P, Thuestad O (2014) Government-enforced self-regulation: the Norwegian case. In: Hempel Lindøe P, Baram M, Renn O (eds) Risk governance of offshore oil and gas operations. Cambridge University Press, Cambridge, pp 243–273

Gordon G (2013) The Deepwater Horizon disaster: the regulatory response in the United Kingdom and Europe. In: Caddell R, Thomas DR (eds) Shipping, law and the marine environment in the 21st century: emerging challenges for the law of the sea—legal implications and liabilities. Lawtext Publishing Ltd., Witney, pp 181–210

Hempel Lindøe P, Baram M, Renn O (2014) Risk governance of offshore oil and gas operations. Cambridge University Press, Cambridge

Lagoni R, Vignes D (2006) Maritime delimitation. Brill, Leiden

Lloyd's List of 9 July 2013, p. 8 ("*Piper Alpha remembered 25 years on*")

Merry MK (2014) Framing environmental disaster—environmental advocacy and the Deepwater Horizon oil spill. Routledge, London

Tromans (2014) Pollution from offshore rigs and installations. In: Soyer B, Tettenborn A (eds) Offshore contracts and liabilities. Informa Law, London, pp 253–273

Vinogradov S (2013) The impact of the Deepwater Horizon: the evolving international legal regime for offshore accidental pollution prevention, preparedness, and response. Ocean Dev Int Law 44:335–362

Warbrick C, McGoldrick D, Kirk EA (1997) The 1996 protocol to the London Dumping Convention and the Brent Spar. Int Comp Law Q 46:957–964

EU Legal Acts and Documents

Directive 94/22/EC of the European Parliament and of the Council of 30 May 1994 on the conditions for granting and using authorizations for the prospection, exploration and production of hydrocarbons, OJ L164/3 of 30 June 1994

European Commission: MEMO/11/740 of 27 October 2011 ("Commission proposes new rules on the safety of offshore oil and gas activities")

Directive 2013/30/EU of the European Parliament and of the Council of 12 June 2013 on safety of offshore oil and gas operations and amending Directive 2004/35/EC, OJ L 178/66 of 28 June 2013

International Instruments

UNCLOS: United Nations Convention on the Law of the Sea (adopted 10 December 1982, entered into force 16 November 1994) 1833 UNTS 3

Interview

Interview with Eero Ailio, Deputy Head of Unit Retail Markets, Coal and Oil at the European Commission. http://www.dnv.com/industry/oil_gas/publications/updates/Oil_and_Gas_Update/2013/02_2013/Preventing_major_offshore_accidents_in_Europe.asp

Case Before the International Tribunal of the Law of the Sea (ITLOS)

ITLOS Case No. 23, Dispute Concerning Delimitation of the Maritime Boundary between Ghana and Côte d'Ivoire in the Atlantic Ocean (Ghana/Côte d'Ivoire). https://www.itlos.org/cases/list-of-cases/case-no-23/

ITLOS Case No. 16, Dispute concerning delimitation of the maritime boundary between Bangladesh and Myanmar in the Bay of Bengal (Bangladesh/Myanmar). https://www.itlos.org/en/cases/list-of-cases/case-no-16/

Chapter 36
Sustainable Shipping

Ciarán McCarthy and Bénédicte Sage-Fuller

Abstract Shipping is responsible for a substantial part of the oceans' pollution through, for example, the discharge of CO_2, SO_x and NO_x air emissions, the operational and accidental discharge of oil and other hazardous substances into the sea, bio-fouling and the spread of Non-Native Indigenous Species. Sustainable shipping is therefore a priority of the international community. This chapter will examine sustainable shipping in the context of International Law and relations and will explain the principles of flag, coastal and port State jurisdiction, and the actions taken by the relevant international organisations in pursuit of this goal. The chapter will provide a brief overview of the system of Port State Control and will refer to the example of the European Union to demonstrate the regional legislative action that can be taken to consolidate and further international law. A case study of the regulation of the spread of invasive aquatic species through ballast water will show the tensions at play at international level that can act to prevent effective action. Finally, the chapter will provide an exposition of the main liability and compensation regimes.

Keywords Sustainable shipping • Pollution • International Maritime Organisation • Flag State • Port Sate • UNCLOS • Port State Control • Liability and compensation

36.1 Introduction

Sustainability is a critical part of shipping. Indeed, the transport of goods by sea is the "backbone of international trade and globalization" (UNCTAD 2015a: 22), and it is as such responsible for a substantial part of the oceans' pollution, even though the larger proportion is caused by land-based sources (80%) (UNEP n.d.). Low-grade marine

C. McCarthy, B.L. (✉)
Barrister-at-Law, Courthouse Chambers, Cork, Ireland
e-mail: ciaranmccarthy@outlook.com

B. Sage-Fuller
School of Law, University College Cork, Cork, Ireland
e-mail: b.sage@ucc.ie

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_36

fuel oil contains 3500 more times sulphur than ordinary diesel used by cars. Shipping accounts for between 15–18% of NO_x emissions (as opposed to 33% for road transport), between 13–18% of SO_x emissions (as opposed to 0% for road transport) and 3% of CO_2 emissions (12% for road transport) (Wan et al. 2016; Chaps. 6 and 25). The accidental and operational discharges into the sea of various types of pollutants are also cause for grave concern, and include hazardous and noxious substances, sewage, garbage and even packaged goods. The decommissioning of ships and their disposal is another environmental issue with far-reaching consequences. It causes the escape of extremely dangerous substances such as asbestos, heavy metals and oils, and not only severely harms the coastal and marine environment but also has devastating consequences on human health when not regulated effectively (Gwin 2014).

It can be said that there are five main areas of actions that converge towards sustainable shipping (Tsimplis 2014: 371):

- the development and application of standards for ships concerning their construction, design, equipment and manning (CDEM standards),
- the training standards for crews,
- management systems for ships and ports to manage problems and ensure the early detection of issues that could lead to incidents or accidents,
- regimes of liability and compensation in cases of pollution and
- regimes of criminal liability and fines.

In this chapter, once the issue of sustainable shipping is explained in the context of International Law and relations, the general framework of the law of the sea will detail the principles of flag, coastal and port State jurisdiction, and the actions of the relevant international organisations. There will then be a presentation of the system of Port State Control as it operates worldwide, and plays a key role in controlling the application of international standards. The example of the European Union will show what kind of regional legislative action can be taken to consolidate and further international law. A case study of the regulation of the spread invasive aquatic species by ballast water will show the tensions playing at international level that can prevent effective action to remedy such a dramatic issue. There will finally be an exposition of the main liability and compensation regimes.

36.2 Sustainable Shipping and the International Community

Sustainable shipping has been on the United Nations' agenda for at least 25 years. Already at the 1992 Rio Conference on Environment and Development, Agenda 21 had identified maritime transport as one significant source of degradation of the marine environment. In this respect it was calling on States, the International Maritime Organisation and other relevant international organisations and competent United Nations agencies to "apply preventive, precautionary and anticipatory approaches so as to avoid degradation of the marine environment, as well as to reduce the risk of long-term or irreversible adverse effects upon it" (UNCED 1992, para. 17.22(a)). Reference to the relevant international organisations is important, because States are bound by the terms of international law, and must, to a very large extent, act through such organisations, and not unilaterally when preventing or controlling pollution from ships (IMO LEG 1992: 7–8). Agenda 21 further encouraged States to ratify and implement existing international instruments applicable to international shipping, to cooperate for their enforcement and to examine the need for additional rules to "reduce the risk of accident and pollution from cargo ships" (UNCED 1992, para. 17.31). Specific actions as regards enforcement are also directed at IMO in Agenda 21 (UNCED 1992, para. 17.30(a)(i), (iii), (viii)). The IMO's strategic plan 2016–2021 shows the organisation's commitment to sustainable shipping, specifically when it states:

> "The enhancement of a sustainable environmental policy for the shipping industry remains a high-profile matter. The heightened concern about the impact of global shipping activities on the environment has given further impetus to efforts by the Organization to increase awareness, promote corporate social responsibility by the shipping industry and develop sustainable and environmentally conscious means of minimizing the negative impacts from shipping, such as those aimed at reducing atmospheric pollution; addressing climate change through enhanced energy efficiency for ships and other measures; ensuring the preservation of ecosystems and biodiversity; and preventing the introduction of polluting substances from ships into the marine environment. Concern for the environment has also extended to concerns over the safest and most effective measures for the recycling of ships, which IMO is also addressing." (IMO 2015, para. 2.7)

Other organisations contribute to the subject of maritime safety and pollution prevention and control although they are not primarily concerned with marine matters (Churchill and Lowe 1999: 22–23). Examples include the World Health Organization, the United Nations Conference on Trade and Development, the United Nations Environment Programme, and to a lesser extent the Food and Agriculture Organisation and the World Meteorological Organisation (Churchill and Lowe 1999: 8; Khee-Jin 2006: 8). Besides the IMO, the International Labour Organisation (ILO) has been active in improving working conditions for seafarers with accidents at sea being increasingly attributed to fatigue, carelessness or lack of training among crews (Khee-Jin 2006: 80; Nautilus International Telegraph 2015: 48). The ILO has co-operated with the IMO to adopt various standards relating to the recruitment, wages and hours of work of seafarers. Three significant conventions relevant to the training and working conditions of seafarers are in force, namely ILO Convention No. 147 concerning minimum living and working standards on merchant ships (ILO 147 1981), the Maritime Labour Convention (MLC 2006) and the Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW 1978). However, as an agency, the IMO has had the most substantial effect upon the law of the sea (Churchill and Lowe 1999: 23). The IMO's predecessor, the Inter-Governmental Maritime Consultative Organisation, had been principally occupied with matters pertaining to safety at sea and efficiency of navigation but following the *Torrey Canyon* tanker incident in 1967 the prevention of maritime pollution through the regulation of shipping activities assumed greater importance (Power 2014: 320–326).

The IMO consists of an Assembly, a Council and five main Committees:

- the Maritime Safety Committee (MSP);
- the Marine Environment Protection Committee (MEPC);

- the Legal Committee (LEG);
- the Technical Cooperation Committee and the
- Facilitation Committee and
- a number of Sub-Committees support the work of the main technical committees.

Although certain IMO conventions address unique subjects (such as the introduction of a universal tonnage measurement system (Tonnage Convention 1969), the majority of conventions adopted by the IMO fall into three main categories: maritime safety and security (such as SOLAS 1974, the Collision Regulation Convention (COLREG 1972) and the Search and Rescue Convention (SAR 1979)), the regulation and prevention of marine pollution (for example, the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78)), and liability and compensation (including the International Convention on Civil Liability for Oil Pollution Damage (CLC 1969) and its Protocol (CLC PROT 1992).

36.3 The International Legal Framework of Shipping

As much of the law of the sea is subject to international treaties and with regional developments, including to EU law, it is useful to consider general obligations and rights in this area, and to identify the key instruments. The section will begin with the United Nations Convention on the Law of the Sea (UNCLOS 1982; Hayes 2011).

The twentieth century saw four major inter-governmental attempts to codify the customary international law of the sea (Churchill and Lowe 1999: 14). The last of these, the third United Nations Conference on the Law of the Sea (UNCLOS III) held its first session in 1973 and finally adopted a convention in 1982. Many of the provisions in UNCLOS repeat principles enshrined in the earlier instruments and others have since become customary rules (Shaw 2003: 492). UNCLOS makes reference to the functions of the State as a Flag, Coastal or Port State. Most of these allocations of jurisdiction are not necessarily new with, for example, Flag State powers constituting traditional attributes of State power at sea. However, others have acquired novel importance as the international community has accorded or shifted emphasis to specific uses of the seas, such as environmental protection (Gavounelli 2007: 33–34).

The foundation of the maintenance of order on the high seas traditionally rested upon the concept of the nationality of the ship, and the consequent jurisdiction of the State of its registry and whose flag it was entitled to fly (Shaw 2003: 545; Barnes 2015: 304). Article 91 of UNCLOS stipulates that there must be a “genuine link” between the State and the ship (Art.91 UNCLOS; M/V Saiga (No.2), ITLOS 1999, para. 63). According to article 94(2)(b) of UNCLOS, a Flag State will assume jurisdiction under its internal law of each ship flying its flag and will take such measures as are necessary to ensure safety at sea with regard to *inter alia* construction and equipment (Art. 94(3) and (4) UNCLOS) and will adopt laws and regulations for the prevention, reduction and control of pollution of the marine environment from such vessels (Art. 211 UNCLOS). Flag States must ensure compliance by their vessels with international pollution prevention and control rules, and provide for certification to attest to this (Art. 217 UNCLOS). It is evident that while flag State jurisdiction and freedom of seas remain the fundamental principle of the Law of the Sea, it has been considerably eroded in substance by the claims of coastal and port States, but also by significant developments in marine environmental law, which have shifted the emphasis of law enforcement away from flag States (Djalal 2009; Young 2016).

Coastal States, or States bordering the sea and through whose waters shipping passes, do not exercise absolute sovereignty in their territorial seas and such sovereignty is subject to the guarantee of the right of all ships to innocent passage (Art. 17 UNCLOS). The Coastal State may take the necessary steps in its territorial sea to prevent passage which is not innocent (Art. 25 UNCLOS) and may adopt laws and regulations for the prevention, reduction and control of marine pollution from foreign vessels, including vessels exercising the right of innocent passage, within their territorial sea (Art. 211(4) UNCLOS). In the EEZ, the Coastal State may also take steps to regulate international shipping, but only by "giving effect to generally accepted international rules and standards and applicable international rules and standards" adopted through the IMO (Art. 211(5) UNCLOS; Sage-Fuller 2013: 53–54), or within a tightly controlled framework of international cooperation (Art. 211(6) UNCLOS).

The mid-twentieth century saw the advancement of the idea that free access to ports was the natural corollary of freedom of navigation on the high seas. This argument was supported by the *dicta* of at least one international arbitration (ARAMCO 1958: 117), but it was quickly abandoned. De La Fayette gives an account of the arguments posited at the plenary session of the meeting of the Institut de Droit International on the 30th March 1910 and writes that even then the idea was rather far-fetched as there was no obvious relationship between the right of a ship to navigate on the ocean and a right to enter any particular port (De La Fayette 1996: 18). In any case, more recent jurisprudence established unambiguously that "by virtue of its sovereignty that the coastal State may regulate access to its port" (Military and Paramilitary Activities in and against Nicaragua, ICJ 1986, para. 213). UNCLOS embedded this view in many of its provisions, which provide that such entry may be made conditional on certain safety, security or sanitary and customs requirements. Article 8 (1) of UNCLOS states that a Coastal State's internal waters go as far as the landward side of its baseline while Article 2 (1) provides that its sovereignty extends to its territorial sea. Coastal States may impose conditions on ships prior to their entry into their internal waters and Article 25 (2) allows them to take necessary steps to prevent breaches of these conditions. Finally, Article 211 (3) allows Coastal States to place particular requirements on foreign vessels to prevent, reduce and control pollution as a condition for their entry into the State's ports or internal waters. One of these is Port State Control and this will be examined next.

Although certain IMO conventions address unique subjects (such as the introduction of a universal tonnage measurement system through the International Convention on Tonnage Measurement of Ships) the majority of conventions adopted by the IMO fall into three main categories: maritime safety and security (such as the Safety of Life at Sea Convention); regulating and preventing marine pollution (for example, the International Convention for the Prevention of Pollution from Ships); and, liability and compensation (including the International Convention on Civil Liability for Oil Pollution Damage).

36.4 Port State Control

The single biggest issue concerning the control of shipping relates to flags of registry. Closed or "restricted" registration usually confers nationality only on ships owned by citizens of that State and which employ seafarers from that State, whereas open registries, sometimes identified as "flags of convenience", confer nationality on any ships that fulfil certain safety and technical conditions (Liying 2010: 198). "Flags of convenience" have been described as the flags of states whose governments regard registration not as a procedure necessary to impose sovereignty, but as a service to be sold to foreign ship-owners wishing to escape fiscal and other consequences of registration under their own flag (Ademun-Odeke 2005: 343). They can be seen as lacking the financial resources and manpower to enforce applicable international standards and so enabling unscrupulous ship owners to cause environmental damage by taking advantage of *inter alia* lax oversight of environmental and safety regulations with respect to merchant vessels or to use the same regulatory deficit to engage in illegal, unreported and unregulated fishing (IUU) with impunity. However, the reality is more complex, and there is not really any longer a perfect match between open registries and "flags of convenience". The UNCTAD Review of Maritime Transport 2015 (UNCTAD 2015b: 41) shows that both national and open flags of registry can be good and bad. Panama, Liberia and the Marshall Islands are the three registries that have the most world tonnage under their flag (41.8% in total as of 1 January 2015), yet Liberia and the Marshall Islands are considered by the International Chamber of Shipping as showing positive results on all performance indicators. Such indicators are relevant to assessing the likelihood of ships of a particular Flag State to cause environmental harm as they are based on that Flag State's ratification of major international maritime treaties, its collective Port State Control record, the age of its fleet, its compliance with reporting requirements to bodies such as IMO and ILO, its use of IMO-compliant recognised organisations to conduct surveys on its behalf and attendance by its representatives at IMO meetings. Panama failed to reach a positive performance indicator with respect to the US Coast Guard Port State Control indicators (and shared this characteristic with Germany), while complying with the Paris and Tokyo MOUs on Port State Control indicators. Panama also failed with regard to its classification societies, but showed positive results for all other indicators (ICS 2015–2016). For many Flag States, vessels sailing under their flags seldom sail into their ports and any potential damage caused by such ships would be to the high seas or to areas under the jurisdiction of other States (Khee-Jin 2006: 179). The converse is true for Coastal States but at the same time, broad Coastal State jurisdiction extending beyond the territorial sea may potentially interfere with the freedom of navigation. Therefore, at UNCLOS III enhanced port State jurisdiction—or the auditing of foreign ships in the ports of third-party States to verify *inter alia* their compliance with applicable international conventions—emerged as a preferred solution over the expansion of Coastal State jurisdiction (Khee-Jin 2006: 179–180). However, Port State control is a secondary enforcement system and is subordinate to the Flag State's duty as the primary enforcer of international standards (Vorbach 2001: 34).

The first regional port state control agreement was the 1982 Memorandum of Understanding on Port State Control in Implementing Agreements on Maritime Safety and Protection of the Marine Environment (the Paris MOU) (Paris MOU 1982; McDorman 2000: 209–212).[1] There are currently nine regional MOUs, essentially agreements between the maritime authorities of individual Coastal States to have suitably qualified persons carry out Port State Control inspections in accordance with the requirements of the applicable memoranda:

- the Paris MOU,
- the Viña Del Mar Agreement,
- the Tokyo MOU,
- the Caribbean MOU,
- the Mediterranean MOU,
- the Indian Ocean MOU,
- the Abuja MOU,
- the Black Sea MOU and
- the Riyadh MOU (Bang and Jang 2012: 171).

Although the Paris MOU and certain other MOUs are not considered as binding "treaties" for the purposes of international law (Bang and Jang 2012: 172), they play a vital part in the system of control and enforcement of international shipping standards of safety, environmental protection and security. Indeed, the principle of port State jurisdiction, which underpins Port State Control, is unfolded in Articles 211, 218 and 219 of UNCLOS (Keselj 1999: 131) and provided for in EU law (EU Directive 2009/16/EC on Port State Control). In recent times, port State jurisdiction has been discussed extensively as an emerging pillar to fill the gaps of flag State jurisdiction (Molenaar 2007; Molenaar 2015; Chap. 41).

The United States Coastguard operates its own Port State Control (Foreign and Offshore Compliance Division n.d.). The nine Port State control MOUs are largely similar to, and follow the model of the Paris MOU in pursuing the aim of applying a uniform set of standards contained in designated treaties. The following tables show the States party to Port State Control Agreements (Table 36.1), and the conventions enforced through the mechanism of Port State Control (Table 36.2).

[1] The current Paris MOU is the Paris Memorandum of Understanding on Port State Control Including 38th Amendment, adopted 22 May 2015 (effective date: 1 July 2015). Available at <https://www.parismou.org/system/files/Paris%20MoU%2C%20incl%2038th%20amendment%20%28final%29_0.pdf > (date accessed: 2 June 2016).

Table 36.1 States party to Port State control agreements

Agreement	State Parties (as of 8 June 2016)
Paris Memorandum of Understanding (2nd December 1980)[a]	Belgium, Bulgaria, Canada, Croatia, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Latvia, Lithuania, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Russian Federation, Slovenia, Spain, Sweden, the United Kingdom of Great Britain and Northern Ireland
Tokyo Memorandum of Understanding (1st December 1993)[b]	Australia, Canada, Chile, China, Fiji, Hong-Kong China, Indonesia, Japan, Republic of Korea, Malaysia, Marshall Islands, New Zealand, Papua New Guinea, Peru, Philippines, Russian Federation, Singapore, Solomon Islands, Thailand, Vanuatu, Vietnam
Viña del Mar Memorandum of Understanding (5th November 1992)[c]	Argentina, Bolivia, Brazil, Chile, Colombia, Cuba, Dominican Republic, Ecuador, Guatemala, Honduras, Mexico, Panama, Peru, Uruguay, Venezuela
Indian Ocean Memorandum of Understanding (5th June 1998)[d]	Australia, Bangladesh, Djibouti, Eritrea, Ethiopia (observer), France (La Réunion Island) India, Iran, Kenya, Maldives, Mauritius, Mozambique, Myanmar, Oman, Seychelles, South Africa, Sri Lanka, Sudan, Tanzania, Union of Comoros, Yemen
Mediterranean Memorandum of Understanding (11th July 1997)[e]	Algeria, Cyprus, Egypt, Israel, Jordan, Lebanon, Malta, Morocco, Tunisia, Turkey, Palestinian Authority (observer)
Caribbean Memorandum of Understanding (9th February 1996)[f]	Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Cayman Islands, Cuba, Curaçao, Dominica, Grenada, Guyana, Jamaica, Monserrat, The Netherlands, St Kitts and Nevis, St Lucia, St Vincent and Grenadines, Suriname, Trinidad and Tobago, Turks and Caicos Islands
Abuja Memorandum of Understanding (22nd October 1999)[g]	South Africa, Angola, Benin, Cameroon, Cape Verde, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea Conakry, Guinea Bissau, Liberia, Mauritania, Nigeria, Sao Tome and Principe, Sierra Leone, Senegal, Togo
Black Sea Memorandum of Understanding (1st April 2000)[h]	Bulgaria, Romania, Georgia, Russian Federation, Turkey and Ukraine
GCC Memorandum of Understanding (30th June 2004, Riyadh MoU)(Arab States of the Gulf)[i]	Kingdom of Bahrain, State of Kuwait, Sultanate of Oman, State of Qatar, United Arab Emirates and Kingdom of Saudi Arabia

[a]For more information see: http://www.parismou.org/
[b]For more information see: http://www.tokyo-mou.org/
[c]For more information see: http://www.acuerdolatino.int.ar/
[d]For more information see: http://www.iomou.org/
[e]For more information see: http://www.medmou.org/
[f]For more information see: http://www.caribbeanmou.org
[g]For more information see: http://www.abujamou.org/
[h]For more information see: http://www.bsmou.org/
[i]For more information see: http://www.riyadhmou.org/index.html

Table 36.2 Conventions referred to in Port State Control Agreements

	Paris MOU	Tokyo MOU	Indian Ocean MOU	Viñar del Mar MOU	Mediter ranean MOU	Black Sea MOU	Caribbean Mou	Abuja MOU	Riyadh MOU
Load Lines Convention	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Load Lines Protocol	X	X		X			X	X	X
SOLAS Convention	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
SOLAS Protocol 1978	X	X	X		X		X	X	X
SOLAS Protocol 1988	X	X	X	X			X	X	x
MARPOL 73/78	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
STCW Convention	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
COLREG 72 Convention	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Tonnage Convention 69	X	X	X	X		X	X	X	X
ILO 147 Convention 76	X	X	X		X	X	X	X	X
ILO 147 Protocol 1996	X		X				X		X
Maritime Labour Convention 2006	X	X	X		X	X		X	
Civil Liability Oil Pollution Damage Convention 1969	X			X				X	
Civil Liability Oil Pollution Damage Protocol 1992	X	X	X	X				X	
Convention on Civil Liability for Bunker Oil Pollution Damage 2001	X		X			X			

(continued)

Table 36.2 (continued)

	Paris MOU	Tokyo MOU	Indian Ocean MOU	Viñar del Mar MOU	Mediter ranean MOU	Black Sea MOU	Caribbean Mou	Abuja MOU	Riyadh MOU
Convention on the Control of Harmful Anti-Fouling Systems on Ships 2001	X	X	X	X		X	X	X	
Convention for the Control and Management of Ships' Ballast Water and Sediments 2004	X								

In total 145 States (including the United States of America) are party to the system of Port State Control, which is an overwhelming proportion of port States in the world.

As can be seen from Table 36.2, five conventions—SOLAS, the Load Lines Convention, MARPOL 73/78, STCW 1978 and COLREG 1972—are common to all nine Port State Control agreements, while a further four –Tonnage, ILO 147, Anti Fouling Convention 2001 and MLC 2004—benefit from strong, but not unanimous support. However, two conventions that are critical pieces in seeking to achieve sustainable shipping, CLC 1992, which sets up the system of compensation and liability for oil pollution damage, and BWC 2004 benefit only from partial support through the PSC system.

Showing then, as an example, the Paris MOU; vessels are allocated a *Ship Risk Profile*—designating them as representing a high, standard or low risk—pursuant to generic and historic parameters including *inter alia* the appearance of their Flag State on a black, grey or white list (as a result of a given proportion of the State's ships being detained following inspection), the type of ship, its age, deficiency index, detention index and company performance index (Annex 7, Paris MOU). The results of the *Profile* and any overriding or unexpected factors determine the scope, frequency and priority of inspections. If during an inspection deficiencies that are clearly hazardous to safety, health or the environment are recorded, the Port State authority will either ensure that the hazard is removed before the ship is allowed to proceed to sea or may detain the ship or require it to proceed to the nearest appropriate repair yard available (Art. 3.4 and 3.8, Paris MOU). If a ship has been detained on multiple occasions, it may be refused access to ports within the Paris MOU area; in the event that certain criteria are not addressed within a set period the ship may be permanently excluded (Art. 4, Paris MOU).

36.4.1 The European Union and Shipping

It is worth highlighting briefly the main features of the European Union's body of shipping regulations, as the EU is a significant driver of many international initiatives, both through its own body of law, and through the International Maritime Organisation. EU maritime law substantially progressed in the 1970s as new nations with strong shipping interests (the United Kingdom, Denmark) became members, and incidents such as the sinking of the tanker *Amoco Cadiz* in 1978 provoked outcry in the public (Power 2014: 320–326; Nengye and Maes 2010: 581). Initially, the then-EEC was willing to invoke "soft" law, and adopt non-binding Recommendations that Member States should ratify *inter alia* SOLAS and MARPOL (Power 2014: 326–7). However, over the course of the 1980s and 1990s, the EU became more involved in maritime safety and the soft law began to be replaced by "hard" regulations, directives, and decisions (Power 2014: 339). Tragic ferry disasters in Europe such as the *Herald of Free Enterprise* in 1987 resulted in legislation in the area of passenger ferry safety (Power 2014: 339–340). For example, Directive 1999/35/EC, as amended provided for mandatory surveys for the safe operation of "roll-on, roll-off" (Ro-Ro) ferry and high-speed passenger craft services. Directive 1998/41/EC required the registration of persons sailing on board passenger ships. In 2009, two other key pieces of EU legislation were adopted: Directive 2009/45/EC (Recast) on safety rules and standards for passenger ships and Regulation 2009/392/EC on the liability of carriers of passengers by sea in the event of accidents.

The early 2000s saw enhanced activity in the EU following serious marine incidents and terrorist activities (Mandaraka-Sheppard 2007: 995). The attacks of September 2001 in the United States resulted in Regulation 2004/725/EC which enhanced the maritime security measures contained in SOLAS and in the International Ship and Port Facility Security (ISPS) Code. In the wake of the *Erika* and *Prestige* incidents in 1999 and 2002 respectively, stronger rules on single-hull tankers, classification societies and Port State Control were put in place (EU Regulation EC/2002/417) and a European Maritime Safety Agency established (EU Directive 2002/1406/EC). Within the European Commission, DG Mobility and Transport (DG MOVE) was created in 2010, and is highly relevant, having a Maritime Safety Unit and a permanent representative on behalf of the EU to the IMO (Nengye and Maes 2010: 581). The famous *Erika I, II and III* packages were adopted as part of the extraordinary deployment of EU activity in the maritime sector (Mandaraka-Sheppard 2007: 997). The first package, *Erika I*, was to be implemented immediately and mainly consisted of amendments to the existing directives governing the inspection of ships and Port State Control and also the phasing out of single-hull tankers (EU Regulation EC/2002/417; EU Directive 2011/15/EU). *Erika II* introduced a more effective monitoring and control of ships in EU waters. Directive 2002/59/EC established a Community vessel traffic monitoring and information system (EU Directive 2002/59/EC). The European Maritime Safety Agency (EMSA) was established under Regulation 2002/1406/EC and tasked with providing technical and scientific assistance to the Commission and Member

States. Other *Erika II* measures improved the environmental damage liability and compensation regimes already in force (EU Directive 2005/35/EC). Finally, *Erika III* covered such issues as the quality of flags, classification societies, Port State control, traffic monitoring, accident investigation, liability of carriers and insurance. For example, Directive 2009/16/EC on Port State Control (Recast) and Directive 2009/18/EC (the Accident Investigation Directive). Directive 2009/15/EC (recast) and Regulation 2009/391/EC provide common rules and standards for ship inspection and survey organisations, and Regulation 2014/788/EU lays down detailed rules for the imposition of fines and periodic penalty payments and for the withdrawal of recognition of ship inspection and survey organisations. In the current decade, Directive 2014/90/EU and Directive 2014/93/EU on marine equipment continue to show the active determination of the EU to legislate for sustainable shipping (Power 2014: 355–356).

36.5 Case-Study: The Uncontrolled Spread of Non-native Aquatic Species

As was noted above, the 2004 Ballast Water Convention (BWC 2004) has not received strong support from the Port State Control system of MOUs. Although it was opened for signature in June 2004 it has not yet achieved sufficient ratifications to enter into force. However, according to the latest information available from the IMO for June 2016 (IMO n.d., Status of Conventions) 49 States representing 34.87% of the world's gross merchant tonnage (35% of the gross tonnage of the world's merchant shipping is required: Art. 18(1)) and, following the recent accessions of Belgium, Fiji and Peru and the imminent ratifications by the United Arab Emirates, Finland and possibly Panama, it would appear likely that the Convention will acquire the required ratifications in the near future (Mouawad 2016).

In order to operate safely and efficiently when sailing without cargo or while partially laden, commercial ships must load additional weight in the form of water ballast to keep hull stresses and stability within permissible limits, to ensure propeller and rudder immersion and to adjust trim, list, and draught (IMO n.d.). However, the practice results in marine organisms entering ballast tanks and remaining there until they are released into the location where the water is discharged (EMSA, Ballast Water n.d.) with serious environmental consequences through *inter alia* the introduction of invasive species. Examples where the introduction of non-native species, probably in ships' ballast water, have resulted in severe consequences include the arrival of comb jellyfish in the Black Sea (WWF, Shipping Problems: Alien Invaders n.d.) and the introduction of Chinese mitten crabs to Europe and the Americas with consequential infrastructural destruction (Owen 2003).

Although adverse effects of ballast water was first recognised after a mass occurrence of algae in the North Sea in 1903, it was not until the 1970s that the scientific community began reviewing the problem in detail (IMO Ballast Water Management n.d.). In 1991 the MEPC adopted guidelines for preventing the introduction of unwanted organisms and pathogens from ballast water and sediment (MEPC 1991). In November 1993, the IMO Assembly adopted a resolution based on the 1991 guidelines (IMO 1993) and in 1997 the Assembly adopted further guidelines to minimise the transfer of harmful aquatic organisms and pathogens (IMO 1997). Finally, the International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004 (Ballast Water Convention) was adopted by the IMO in 2004. The long delay in the coming into force of the Convention, which followed a long delay in its adoption, has prompted many countries and individual ports to unilaterally develop national or local legislation. These included Australia, Canada, Chile, Israel, New Zealand, the USA, various States within the USA and individual ports around the world, such as Buenos Aires in Argentina, Scapa Flow in Scotland and Vancouver in Canada (American Bureau of Shipping, US Ballast Water Management requirements n.d.; Australian Government Department of Agriculture, Seaports program: Australian Ballast Water Management Requirements n.d.). Ironically therefore, while the shipping industry and flag States were delaying the coming into force of the Convention, this had a negative knock on effect on the international regulation of shipping, with different requirements being imposed in different jurisdictions, instead of a harmonious international regime.

The Convention is by no means a panacea (Karim 2015: 74), but it puts in place a set of tools to combat pollution by non-indigenous aquatic species. It is based on a system of certification, firstly to be implemented by flag States, but effectively to be controlled through Port State Control, with the usual powers of inspections, warning, detention and exclusion of ships. The Convention seeks to prevent ballast water pollution by requiring that water contained in the ballast tanks of ships is replaced by clean water at sea (Ballast Water Exchange Standard), or else is treated before being discharged in port (Ballast Water Performance Standard). The aim of the Exchange Standard is to ensure that at least 95% of the water within a ballast tank is replaced by other water while at sea before being discharged in port (Reg. D-1(1), BWC). In contrast to the Exchange Standard, the Performance Standard is reached when the water being discharged contains no more than a specified number of viable organisms (Reg. D-2, BWC). The IMO will undertake reviews of the available technologies taking into account *inter alia* safety, environmental impacts, practicality, economic considerations and biological effectiveness (Reg. D-5, BWC). Among the options currently being considered by the IMO Technical Group of Experts are filtration, ultra-violet light, electric current, heat treatment and biocides.

36.6 Pollution Liability and Compensation Regimes

Civil liability regimes for pollution are a critical element of the legal management of shipping. It enables the compensation of victims of pollution as adequately as possible, beyond what the domestic standard regimes of responsibility can offer. Indeed, through specific liability and compensation regimes for marine pollution (particularly oil pollution), there is a significantly increased amount of pecuniary compensation available, and the scope of the damage covered is much extended. The oil pollution liability and compensation regime was put in place after the 1967 *Torrey Canion* oil tanker disaster. Initially based on the 1969 Civil Liability Convention and 1971 Fund Convention, it now operates through the 1992 Civil Liability Convention (CLC 1992) and 1992 International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage (IOPC Fund 1992). The CLC 1992 established the strict liability of shipowners, and requires compulsory liability insurance. The IOPC Fund 1992 set up the 1992 International Oil Pollution Compensation Fund (IOPC), which provides supplementary compensation when compensation through CLC 1992 is unavailable or insufficient. The Fund is funded by oil receivers, and not just shipowners as under the CLC 1992. Therefore under the CLC 1992 and IOPC Fund 1992, there is the principle that those who benefit from the transport of oil share the risk. The system of CLC 1992 and IOPC Fund 1992 covers pollution damage by persistent oils, defined as oil that is not non-persistent (typically crude oil, fuel oil, heavy diesel oil and lubricating oil) (Anderson 2001: 17–18; Tsimplis 2014: 375–376). The shipowner of "any seagoing vessel and any seaborne craft of any type whatsoever" (Art. XI CLC 1992) which caused damage to the territory of a contracting state, including its territorial sea and EEZ is strictly liable, that is to say that it is not necessary to show any kind of fault on his part. Only a limited number of events exempt him from strict liability: act of war, hostilities, civil war, insurrection or a natural phenomenon of and exceptional, inevitable and irresistible character, an act or omission by a third party with intent to cause damage that wholly caused the damage, and the negligence or wrongful act of a government or authority responsible for the maintenance of lights and navigational aids in the exercise of that function (Art. III 2) a-c CLC 1992). The International Oil Pollution Compensation Fund (IOPCF) Manual indicates that besides direct pollution damage, loss of earnings may be recovered by people not directly affected by the pollution, but whose businesses have suffered (for example hotel owners, fishermen affected by the closure of pollution areas). This is known as "pure economic loss", and while it is generally considered in Civil Law jurisdictions (in Continental Europe typically)(Bonassies and Scapel 2010: 334–335), English courts rejected it through a series of decisions at Common Law (Tsimplis 2014: 379–380). In total, 203 million SDR are available for compensation under the 1992 CLC/Fund system. However, the *Erika* and the *Prestige* disasters showed that this was not enough to cover the damage caused by catastrophic oil pollution accidents. Therefore a Supplementary IOPC Fund was established in 2003, increasing the total limit of funds available to 750 million SDR. The 1971 and 1992 Funds have been involved in 149 incidents so far, including the *Erika*, the *Prestige* and more recently the *Hebei Spirit* in South Korea in 2007 (IOPCF 2015: 17). Oil pollution compensation is also dealt with by a number of national regimes, which operate either alongside the international IOPC regime, or independently of it. For example, Canada is party to all international marine pollution compensation schemes, but it also has its own Ship Source Oil Pollution Fund (SOPF), which makes CAN$157.8 million available on top of what compensation can occur through

IOPC. The US are not part of IOPF, but have their own scheme, the Oil Spill Liability Trust Fund (OSLTF), based on the famous Oil Pollution Act 1990, adopted in the aftermath of the *Exxon Valdez* spill in Alaska in 1989. The amount of compensation is superior to IOPC, reaching US$ 1Bn per incident, for removal costs and damages, but no more than US$500 Million for natural resources damage. China is a party to the 1992 CLC and 2003 Bunker Convention, but not to the 1992 or 2003 Funds. It has its scheme in operation since 2012, the China Vessel-Source Oil Pollution Compensation Fund (CVOPCF), which has a maximum amount of compensation of approximately US$139 Million (Zhu et al. 2013).

Mention should also be made of the 2001 Bunker Pollution Convention and of the 1996 Hazardous and Noxious Substances Convention and 2010 Protocol (HNS Convention 2010), which aim at providing compensation to the victims of pollution respectively by bunker oil from non-cargo ships, and by substances other than oil. The 2001 Bunker Convention came into force in 2008, and imposes strict liability on the shipowner, bareboat charterer, manager and operator of the ship (Art. 1.3 Bunker Convention). The Convention also imposes compulsory insurance on the shipowner. The HNS Convention again imposes the strict liability of the shipowner, and also of the traders. It has not yet come into force.

36.7 Conclusion

Trade and shipping are activities as old as humanity. For as long as there have been people to trade and exchange goods, there have been ships, captains and sailors. International Law of the Sea has traditionally been based on the freedom of the seas, but this freedom has never quite been an absolute one (Young 2016). Since the early twentieth century, starting with the Safety of Life at Sea Convention (SOLAS) after the *Titanic* disaster in 1912, there has been a real strengthening of the international regulation of shipping, to improve the safety of life at sea, environmental protection and maritime security. The development of Port State Control since the 1980s, and the emergence of port State jurisdiction to support the enforcement of international shipping regulation show a move away from sole reliance on flag State, in an effort to achieve objectives of sustainable shipping. Climate change is having the effect of opening new shipping routes in the Arctic Ocean (Northern Sea route and Northwest Passage), where until now, the environment has been preserved from any kind of major pollution disaster. There are already moves at IMO to adopt specific regulations for Arctic shipping (the Polar Code), and there are strong calls in various NGOs, research centres and coastal States to ensure that regional cooperation between States having an interest in shipping in polar regions will ensure sustainable Arctic shipping (Huttington et al. 2015; Aksenov et al. 2015; Gavrilov 2015). This regional example might signal a fresh approach to the regulation of shipping, with a stronger emphasis on objectives of sustainability and effective enforcement means, with the definite involvement of both port and coastal States alongside flag States.

References

Ademun-Odeke (2005) An examination of bareboat charter registries and flag of convenience registries in international law. Ocean Dev Int Law 34:339–362

Aksenov Y, Popova EE, Yool A, George Nurse AJ, Williams TD, Bertino L, Bergh J (2015) On the future navigability of Arctic area routes: high resolution projection of the Arctic Ocean and sea ice. Marine Policy (in press). doi: 10.1016/j.marpol.2015.12.027

American Bureau of Shipping. US Ballast Water Management Requirements (2013, May 1) ABS Publication. https://www.eagle.org/eagleExternalPortalWEB/ShowProperty/BEA%20Repository/References/Booklets/2013/ABS_Trends_May2013. Accessed 16 June 2016 (n.d.)

Anderson C (2001) Persistent vs Non-presistent oils: what you need to know. Skuld Beacon Newslett (2). https://www.skuld.com/Documents/Library/Beacon/Beacon%202001%20No%202.pdf

ARAMCO (Saudi Arabia v. Arabian American Oil Co.), 27 International Law Reports 1958

Arbitration between Saint Vincent and the Grenadines and the Guinea (the M/V "Saiga" (No. 2), International Tribunal for the Law of the Sea (ITLOS), 120 ILR, Decision, 1 July 1999

Australian Government Departure of Agriculture. Seaports Program: Australian Ballast Water Management Requirements (Version 5). September 5, 2013. http://www.agriculture.gov.au/SiteCollectionDocuments/aqis/airvesselmilitary/vessels/ballast/ballast-water-mgmt-requirements-v5.pdf. Accessed 13 June 2016 (n.d.)

Bang H, Jang D (2012) Recent developments in regional memorandums of understanding on Port State Control. Ocean Dev Int Law 43:170–187

Barnes RA (2015) Flag States. In: Rothwell DR, Oude Elferink AG, Scott K, Stephens T (eds) The Oxford handbook of the law of the sea. Oxford University Press, Oxford, pp 304–324

Bonassies P, Scapel C (2010) Droit maritime. L.G.D.J, Paris

Churchill R, Lowe V (1999) The law of the sea. Manchester University Press, Manchester

Cowan E (1968) Oil and water: the Torrey Canyon disaster. JB Lippincott, Philadelphia

De La Fayette L (1996) Access to ports in International. Int J Maritime Law Commerce 11:1–22

Djalal H (2009) Remarks on the concept of "Freedom of Navigation". In: Nordquist MH, Koh T, Moore JN (eds) Freedom of seas, passage rights and the 1982 law of the sea convention. Martinus Nijhoff Publishers, Leiden, pp 65–75

European Maritime Safety Agency (n.d.). Ballast water. http://www.emsa.europa.eu/implementation-tasks/environment/ballast-water.html. Accessed 13 June 2016

European Union: Commission Directive 2011/15/EU amending Directive 2002/59/EC of the European Parliament and of the Council establishing a Community vessel traffic monitoring and information system. Official Journal of the European Union, 23.02.2011, L 49/33 (n.d.-a)

European Union: Commission Directive 2014/93/EU amending Council Directive 96/98/EC on marine equipment. Official Journal of the European Union, 18.07.2014, L220/1 (n.d.-b)

European Union: Commission Regulation 2014/788/EU laying down detailed rules for the imposition of fines and periodic penalty payments and the withdrawal of recognition of ship inspection and survey organisations pursuant to Articles 6 and 7 of Regulation (EC) No 391/2009 of the European Parliament and of the Council. Official Journal of the European Union, 18.07.2014, L 214/12 (n.d.-c)

European Union: Council and Parliament Directive 2002/59/EC establishing a Community vessel traffic monitoring and information system and repealing Council Directive 93/75/EEC. Official Journal of the European Union, 27.06.2002, L 208/10 amended by: Council and Parliament Directive 2009/17/EC amending Directive 2002/59/EC establishing a Community vessel traffic monitoring and information system. Official Journal of the European Union, 23.04.2009, L 131/101; Council and Parliament Directive 2009/18/EC establishing the fundamental principles governing the investigation of accidents in the maritime transport sector and amending Council Directive 1999/35/EC and Directive 2002/59/EC of the European Parliament and of the Council. Official Journal of the European Union, 23.04.2009, L 131/114; and Commission Directive 2011/15/EU amending Directive 2002/59/EC of the European Parliament and of the

Council establishing a Community vessel traffic monitoring and information system. Official Journal of the European Union, 23.02.2011, L 49/33 (n.d.-d)
European Union: Council and Parliament Directive 2005/35/EC on ship-source pollution and on the introduction of penalties, including criminal penalties, for pollution offences. Official Journal of the European Union, 30.09.2005, L 255/11, as amended by: Council and Parliament Directive 2009/123/EC amending Directive 2005/35/EC on ship-source pollution and on the introduction of penalties for infringements. Official Journal of the European Union, 21.10.2009, L 280/52; and, Council and Parliament Directive 2009/20/EC on the insurance of shipowners for maritime claims. Official Journal of the European Union, 23.04.2009, L 131/128 (n.d.-e)
European Union: Council and Parliament Directive 2009/15/EC on common rules and standards for ship inspection and survey organisations and for the relevant activities of maritime administrations (Recast). Official Journal of the European Union, 23.04.2009, L131/47 (n.d.-f)
European Union: Council and Parliament Directive 2009/16/EC on port State control (Recast). Official Journal of the European Union, 23.04.2009, L 131/57 as amended by Council and Parliament Directive 2013/38/EU amending Directive 2009/16/EC on port State control. Official Journal of the European Union, 12.08.2013, L 218/1 (n.d.-g)
European Union: Council and Parliament Directive 2009/45/EC on safety rules and standards for passenger ships (Recast), Official Journal of the European Union, 06.05.2009, L 163/1 (n.d.-h)
European Union: Council and Parliament Directive 2014/90/EU on marine equipment and repealing Council Directive 96/98/EC. Official Journal of the European Union, 23.07.2014, L 257/146 (n.d.-i)
European Union: Council and Parliament Regulation 2002/1406/EC establishing a European Maritime Safety Agency. Official Journal of the European Union, 27.06.2002, L 208/1 as amended by: Council and Parliament Regulation 1644/2003/EC amending Regulation (EC) No 1406/2002 establishing a European Maritime Safety Agency. Official Journal of the European Union, 29.09.2003, L 245/10; Council and Parliament Regulation 724/2004/EC amending Regulation (EC) No 1406/2002 establishing a European Maritime Safety Agency. Official Journal of the European Union, 31.03.2004, L 129/1; Council and Parliament Regulation 1891/2006/EC on multiannual funding for the action of the European Maritime Safety Agency in the field of response to pollution caused by ships and amending Regulation (EC) No 1406/2002. Official Journal of the European Union, 18.12.2006, L 394/1; and, Council and Parliament Regulation 100/2013/EU amending Regulation (EC) No 1406/2002 establishing a European Maritime Safety Agency. Official Journal of the European Union, 15.01.2013, L 39/30 (n.d.-j)
European Union: Council and Parliament Regulation 2002/417/EC on the accelerated phasing-in of double hull or equivalent design requirements for single hull oil tankers and repealing Council Regulation (EC) No 2978/94. Official Journal of the European Union, 18.02.2002, L 64/1 (later recast in Council and Parliament Regulation 2012/30/EU on the accelerated phasing-in of double-hull or equivalent design requirements for single-hull oil tankers (recast). Official Journal of the European Union, 21.11.2012, L172/3) providing for the accelerated phasing-in of double hull or equivalent design requirements for single hull oil tankers (n.d.-k)
European Union: Council and Parliament Regulation 2009/391/EC on common rules and standards for ship inspection and survey organisations (Recast). Official Journal of the European Union, 23.04.2009, L131/11 (n.d.-l)
European Union: Council and Parliament Regulation 2009/392/EC on the liability of carriers of passengers by sea in the event of accidents. Official Journal of the European Union, 23.04.2009, L 131/24 (n.d.-m)
European Union: Council Directive 1998/41/EC on the registration of persons sailing on board passenger ships operating to or from ports of the Member States of the Community. Official Journal of the European Union, 18.06.1998, L 188/35 provides for the registration of persons sailing on board passenger ships operating to or from ports of the Member States (n.d.-n)
European Union: Directive 1999/35/EC of the Council on a system of mandatory surveys for the safe operation of regular ro-ro ferry and high-speed passenger craft services. Official Journal of

the European Union, 29.04.1999, L 138/19, as amended by: Parliament and Council Directive 2002/84/EC amending the Directives on maritime safety and the prevention of pollution from ships. Official Journal of the European Union, 05.11.2002, L 324/53; Parliament and Council Regulation 219/2009/EC adapting a number of instruments subject to the procedure referred to in Article 251 of the Treaty to Council Decision 1999/468/EC with regard to the regulatory procedure with scrutiny. Official Journal of the European Union, 11.03.2009, L 87/109; and, Parliament and Council Directive 2009/18/EC establishing the fundamental principles governing the investigation of accidents in the maritime transport sector and amending Council Directive 1999/35/EC and Directive 2002/59/EC of the European Parliament and of the Council, Official Journal of the European Union, 23, L 131/114 (n.d.-o)

European Union: Directive 2009/16/EC of the Parliament and of the Council on Port State Control [2009], OJ L 131/57 as amended by Parliament and Council Directive 2013/38/EU amending Directive 2009/16/EC on Port State Control [2013] OJ L218/1 (n.d.-p)

European Union: Regulation 2004/725/EC on enhancing ship and port facility security. Official Journal of the European Union, 31.03.2004, L 129/6, as amended by: Commission Decision 2009/83/EC amending Regulation (EC) No 725/2004 of the European Parliament and of the Council as far as the IMO Unique Company and Registered Owner Identification Number Scheme is concerned. Official Journal of the European Union, 23.01.2009, L 29/53; and Parliament and Council Regulation 219/2009/EC adapting a number of instruments subject to the procedure referred to in Article 251 of the Treaty to Council Decision 1999/468/EC with regard to the regulatory procedure with scrutiny. Official Journal of the European Union, 11.03.2009, L 87/109 (n.d.-q)

Foreign & Offshore Compliance Division (CG-CVC2), Port State Control (n.d.) http://www.uscg.mil/hq/cgcvc/cvc2/psc/. Accessed 8 June 2016

Gavouneli M (2007) Functional jurisdiction in the law of the sea. Martinus Nijhoff Publishers, Leiden

Gavrilov VV (2015) Legal status of the Northern Sea Route and legislation of the Russian Federation: a note. Ocean Dev Int Law 46:256–263

Gwin P (2014) The ship-breakers [Electronic version]. Natl Geogr, May 2014. http://ngm.nationalgeographic.com/2014/05/shipbreakers/gwin-text. Retrieved 2 June 2016

Hayes M (2011) The law of the sea: the role of the Irish Delegation at the Third UN Conference. Royal Irish Academy, Dublin

Huttington HP, Raychelle D, Hartsig A, Harun K, Heiman M, Meehan R, Noongwook G, Pearson L, Prior-Parks M, Robards M, Stetson G (2015) Vessels, risks, and rules: planning for safe shipping in Bering Strait. Mar Policy 51:119–127

Insurers' alarm on crew quality: Report raises concerns over manning levels and 'mixed' training standards. Nautilus International Telegraph 48(5), 48 (2015)

International Chamber of Shipping: Shipping industry flag State performance table 2015–2016. ICS Publications, London

International Maritime Organisation (n.d.) Ballast water management. http://www.imo.org/en/OurWork/Environment/BallastWaterManagement/Pages/Default.aspx. Accessed 13 June 2016

International Maritime Organisation. Structure of IMO (n.d.) http://www.imo.org/en/About/Pages/Structure.aspx. Accessed 2 June 2016

International Maritime Organisation: Assembly Resolution A774 (18) on Guidelines for preventing the introduction of unwanted organisms and pathogens from Ships' ballast waters and sediment discharges, 4 November 1993

International Maritime Organisation: Assembly Resolution 1097(29) of 25 November 2015, Strategic Plan for the Organisation (For the Six-Year Period 2016–2021)

International Maritime Organisation: Assembly Resolution A868 (20) on Guidelines for the Control and Management of Ships' Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens of 27 November 1997

International Maritime Organisation: Legal Committee LEG/MISC.7 of 19 January 2012, Implications of the United Nations Convention on the Law of the Sea for the International Maritime Organization (n.d.)

International Maritime Organisation: Marine Environmental Protection Committee Resolution 50(31) on the International Guidelines for preventing the Introduction of Unwanted Aquatic Organisms and Pathogens from Ships' Ballast Water and Sediment Discharges, 1–5 July 1991

International Oil Pollution Compensation Funds: Annual Report 2015. http://www.iopcfunds.org/uploads/tx_iopcpublications/IOPC_Funds_Annual_Review_2015_ENGLISH_WEB.pdf. Accessed 10 June 2016

Karim KS (2015) Prevention of pollution of the marine environment from vessels: the potential and limits of the International Maritime Organisation. Springer Publishing, Heidelberg

Keselj T (1999) Port State jurisdiction in respect of pollution from ships: the 1982 United Nations convention on the law of the sea and the memoranda of understanding. Ocean Dev Int Law 30:127–160

Khee-Jin TA (2006) Vessel-source marine pollution. Cambridge University Press, Cambridge

Liying Z (2010) A comparative study of 'Hong Kong flag' ship registration. Asia Pacific Law Rev 18:197–212

Mandaraka Sheppard A (2007) Modern maritime law. Routledge-Cavendish, Oxford

McDorman T (2000) Regional Port State control agreements: some issues of international law. Ocean Coastal Law J 5:209–212

Military and Paramilitary Activities in and against Nicaragua (Nicaragua v. United States of America). I.C.J. Rep, 14 (1986)

Molenaar EJ (2007) Port State jurisdiction: towards comprehensive, mandatory and global coverage. Ocean Dev Int Law 38:225–257

Molenaar EJ (2015) Port and Coastal States. In: Rothwell DR, Oude Elferink A, Scott K, Stephens T (eds) The Oxford handbook of the law of the sea. Oxford University Press, Oxford, pp 280–303

Mouawad J (2016, February 16) Ballast water management: Belgium to ratify. The Maritime Executive. www.maritime-executive.com/blog/ballast-water-management-belgium-to-ratify. Accessed 13 June 2016

Nengye L, Maes F (2010) The European Union and the International Maritime Organization: EU's external influence on the prevention of vessel-source pollution. J Maritime Law Commerce 41:581–894

Owen J (2003) Eat the invading alien crabs, Urge U.K. Scientists [Electronic version]. National Geographic, November 2013. http://news.nationalgeographic.com/news/2003/11/1113_031113_mittencrabs.html. Accessed 13 June 2016

Pearce F (2013, March 13) Aliens aboard. New Scientist. https://www.newscientist.com/article/mg21729106-000-ships-must-kill-off-the-beasties-in-the-ballast-water. Accessed 13 June 2016

Power V (2014) European union shipping law. Tulane Maritime Law J 38:311–362

Sage-Fuller B (2016) The greening of ports. In: Markus T (ed) Marine environmental handbook. Springerlink Publishers, New York. (complete reference)

Sage-Fuller B (2013) The precautionary principle in marine environmental law, with special reference to high risk vessels. Routledge, London

Shaw M (2003) International law. Cambridge University Press, Cambridge

Tsimplis M (2014) Marine pollution from shipping activities. In: Baatz Y (ed) Maritime law. Informa law from Routledge, Oxon, pp 368–427

United Nations Conference on Environment and Development (1992) Agenda 21, Rio Declaration, Protection of the Oceans, All kinds of Seas, Including Enclosed and Semi-Enclosed Seas and Coastal Areas and the Protection, Rational Use and Development of their Living Resources. New York: United Nations. Para. 17.22(a), 17.30(a)(i), (iii), (viii), 17.31

United Nations Conference on Trade and Development (UNCTAD) (2015a) Cooperation, Training And Development: Review of Maritime Transport 2015. United Nations Publications, New York, p 22

United Nations Conference on Trade and Development (UNCTAD) (2015b) Cooperation, Training And Development: Review of Maritime Transport 2015. United Nations Publications, New York, p 41

United Nations Environment Programme (UNEP): Land-Based Sources of Pollution (n.d.) http://www.unep.org/regionalseas/issues/landactivities/default.asp. Accessed 2 June 2016

Vorbach J (2001) The vital role of non-flag state actors in the pursuit of safer shipping. Ocean Dev Int Law 32:27–42
Wan Z, Zhu M, Chen S, Sperling D (2016) Pollution: three steps to a green shipping industry [Electronic version]. Nature 530:275–277
World Wildlife Fund (n.d.) Shipping Problems: Alien invaders. http://wwf.panda.org/about_our_earth/blue_planet/problems/shipping/alien_invaders. Accessed 13 June 2016
Young M (2016) Then and now: reappraising freedom of the seas in modern law of the sea. Ocean Dev Int Law 47:165–185
Zhu L, Dong B, Li KX (2013) China's 2012 regime for compensation for vessel source oil pollution: a comparative study. Ocean Dev Int Law 44:270–286
1966 International Convention on Load Lines (LL), 640 UNTS 133 (n.d.)
1969 International Convention on Civil Liability for Oil Pollution Damage (1969 CLC), 973 UNTS 3
1969 International Convention on Tonnage Measurement of Ships (Tonnage), 1291 UNTS 3 (1969)
1972 Convention on the International Regulations for Preventing Collisions at Sea (COLREG), 1050 UNTS 16 (1972)
1973 International Convention for the Prevention of Pollution from Ships (MARPOL), 1340 UNTS 184 and 1978 Protocol relating to the International Convention for the Prevention of Pollution from Ships, 1340 UNTS 61. Annex I (Oil) Regulation 38. Annex II (Noxious liquid substances in bulk) Regulation 18, Annex IV (Sewage) Regulation 12, Annex V (Garbage) Regulation 7 and Annex VI (Air pollution) Regulation 17 (n.d.)
1974 International Convention for the Safety of Life at Sea (SOLAS), 1184 UNTS 278, as amended by the 1978 Protocol relating to the International Convention for the Safety of Life at Sea, 1226 UNTS 237 and the 1988 Protocol relating to the International Convention for the Safety of Life at Sea, IMO Doc.: HSSC/CONF/11 (1974)
1976 ILO Convention No. 147 Concerning Minimum Standards on Merchant Ships (ILO 147), 1259 UNTS 335 (n.d.)
1978 International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), 1361 UNTS 2; as amended by the 1995 Protocol (Amendments to the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers 1978) 2052 UNTS 94) and the Manila Amendments (Amendments to the annex to the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978) STCW/CONF.2/33
1979 International Convention on Maritime Search and Rescue (SAR), 1405 UNTS 97 (1979)
1982 Memorandum of Understanding on Port State Control in Implementing Agreements on Maritime Safety and Protection of the Marine Environment (Paris MOU), 21 I.L.M. 1 (1982)
1982 United Nations Convention on the Law of the Sea (UNCLOS), 1833 UNTS 3 (1982)
1992 Protocol to amend the International Convention on Civil Liability for Oil Pollution Damage of 29 November 1969 (CLC PROT 1992), 1956 UNTS 255
1996 International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea (HNS), 35 I.L.M. 1415 (1996); as amended by the 2010 Protocol to the International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea, IMO Doc. LEG/CONF.17/10
2001 International Convention on the Control of Harmful Anti-Fouling Systems on Ships (Anti-Fouling Convention), [2008] ATS 15/AFS/CONF/26
2004 International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWC), IMO Doc. BWM/CONF/36 (2004)
2006 Maritime Labour Convention (MLC), 45 I.L.M. 792 (2006)

Chapter 37
Management of Hazardous Substances in the Marine Environment

Mikael Karlsson and Michael Gilek

Abstract While modern society is highly dependent on chemicals, numerous substances also turn out to be hazardous and many give rise to severe risks and problems in the marine environment. In response, national, regional and global chemical policies, often focusing on the land-based sources to marine pollution, have been developed, as outlined in the article. As a result, the levels of some pollutants have decreased, but the vast majority of substances are not controlled in line with the internationally stated objectives of sound management of chemicals. An environment-oriented development of present policies, implementing the precautionary principle, is considered needed in order to improve the situation, and the question is raised in the article whether the present main international chemicals agreements would not also gain from being merged into a global framework convention.

Keywords Marine pollution • Chemicals policy • Stockholm convention • HELCOM • SAICM • REACH • TSCA

37.1 Introduction

Chemicals are indispensable in modern life and contribute to welfare in a number of areas, from agriculture to medicine and engineering. However, there is another side of the coin as well, in terms of chemicals that cause problems for human health and the environment. Regarding the marine environment, there is broad international agreement that the oceans of the world must be protected against hazardous chemicals. This is reflected in numerous national, regional and global policies relating to

M. Karlsson (✉)
Royal Institute of Technology, Stockholm, Sweden
e-mail: mikaelka@kth.se

M. Gilek
Södertörn University, Stockholm, Sweden

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_37

chemicals management and marine environmental protection. An early regional example is the binding Helsinki Convention (1974), a more recent illustration with global significance is the political declaration from the 2012 Rio Conference (UN 2012). Despite these strategies and measures, the chemical pollution levels in many ocean basins are high and in some cases increasing. There are thus commonly clear gaps between the state of the environment and stated objectives, i.e., problems and risks are not managed in the way desired.

In this chapter we describe the situation and the drivers behind the problems and risks, and in particular provide a broad overview of the main present public chemicals policies from the national to international level, with their respective objectives, approaches and tools. Based on an analysis of these instruments, in which we consider their scope, orientation and underlying principles, we also discuss how chemicals management potentially can be improved regarding both present and emerging risks. Our conclusions will also be related to a wider governance perspective, since marine risks and management in one area are closely linked to other marine activities and policy fields. Without such a holistic governance approach, the gap between objectives and the state of the environment will be difficult to bridge. Moreover, this chapter focuses on public management of a set of chemicals pollutants from land-based sources, as far as relevant for the marine environment where these substances commonly eventually end up. Pollution from maritime activities as such, e.g., shipping and extraction of oil and minerals will not be covered (Simcock et al., Chap. 6; Patin, Chap. 8). Moreover, we centre on industrial chemicals rather than on speciality chemicals, for example, pharmaceuticals, for which the legal set-up usually is stricter.[1]

37.2 Chemical Risks and Management Approaches Over Time

The broader understanding of marine chemical pollution emerged in the 1960s. Following studies on effects of pesticides, such as DDT in agriculture, and the debate linked to the publication of the seminal *Silent Spring* (Carson 1962), scientists investigated the consequences of toxic substances from agriculture and industry reaching the marine environment. In the Baltic Sea Region, effects on seals and white-tailed eagles were revealed and PCBs were eventually identified as the main cause (Jensen 1966; Karlsson and Gilek 2016). In the coming decades, numerous other substances came in focus and politics responded with policies and legislation.

[1] For more comprehensive overviews of chemicals policy, see e.g., Wexler, P., van der Kolk, J., Mohapatra, A. & Agarwal, R. (Eds.) Chemicals, environment, health: a global management perspective. Boca Raton: CRC Press; and Eriksson, J., Gilek, M. & Rudén, C. (Eds.) (2010). Regulating Chemical Risks: European and Global Challenges. Dordrecht: Springer.

The principal basis in chemicals policy for the analysis and management of risks is the understanding that "the dose makes the poison," which originally stems from the medieval physician Paracelsus. The related "conventional risk paradigm" differentiates between risk assessment and risk management. Risk is regarded as the product of inherent hazardous properties and the probability for exposure. Assessment is ideally conducted by purportedly objective scientists, and management is to be done by value-driven politicians. Among policy tools in use in industrialised countries, classification and labelling emerged in various countries already in the 1960s, whereas general rules of consideration, like substitution, and notification requirements often came later. Permits for the use of substances are generally not required, unless substances are explicitly designed for having biological effects, as in the cases of pesticides and pharmaceuticals. The number of restrictions is limited in most countries. A key reason is that the starting point for decision-making is the polluter's situation, in the sense that any mitigating measures are balanced against market-related economic parameters in one way or another. This polluter-oriented conventional risk paradigm places a high burden of proof on the regulator in two ways; first to show the existence of problems or unacceptable risks, and second, to ideally show that measures are cost-effective and motivated from a cost-benefit point of view (Karlsson et al. 2011; Karlsson 2005).

For a number of substances present in the marine environment, the referred conventional approach has led to decreasing pollution levels over time (Karlsson and Gilek 2016). An important reason is that these early problems were often caused by high-volumes of known highly hazardous substances that caused effects in ecosystems that became quite obvious and severe, as in the referred case of PCBs (Broeg et al., Chap. 20).

While such problems still exist, not least in developing countries to which chemicals industry is increasingly translocating, the challenges today are more complex (UNEP 2013). Emission sources are nowadays multiple and the volumes and numbers of substances have grown substantially over time. From an earlier domination of industrial point sources and dispersal of agricultural pesticides, the present risk challenge is also closely linked to consumer products. Today's situation with tens of thousands of substances used in billions of globally traded, e.g., electronic goods, textiles, vehicles and toys poses a quite different management challenge than when industrial policies and pesticide control emerged in the 1960s. Little is known today about the properties for the vast majority of substances on the market and exposure conditions are also incompletely described (Gilbert 2011; Karlsson 2005). The risks related to, for example, the multitude of endocrine disrupting substances in plastic products that children are continuously exposed to are thus largely unknown. How the substance mixture that ends up in marine environments affects biodiversity is even more difficult to assess (Kortenkamp et al. 2009). In addition, new types of risks, such as those following engineered nanoparticles, add on top of the above outlined uncertainties and other complexities (e.g., Wu et al. 2015).

Considering the huge uncertainties, it is hardly surprising that the polluter-oriented approach has been insufficient in terms of enabling goal achievement in chemicals policy (Karlsson and Gilek 2016). In response, an environment-oriented perspective has developed in policy over time (Karlsson et al. 2011). Here, environment-based parameters play a central role, for instance as expressed by environmental quality standards, which can be seen in US and EU law. The idea is that if a standard is violated, stricter mitigating measures may be taken. Closely linked to this, an ecosystem approach to management (EAM) has also emerged. In the marine environment, the EAM is of relevance for not only chemicals, but also for fish stocks, eutrophication and other types of problems and risks, and the EAM has been formulated jointly in two regional marine conventions (HELCOM and OSPAR 2003):

> '"the comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of marine ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity." The application of the precautionary principle is equally a central part of the ecosystem approach.'

In parallel, chemicals policy has also gradually developed in some instances in response to the increasingly obvious problems and the resulting partial acknowledgement of a mismatch between a multifaceted reality and an inappropriate risk paradigm. A clear illustration of this, with relevance for the marine environment, is the "Sintra Statement" in the OSPAR Commission in 1998, were the Parties[2] agreed (OSPAR 1998):

> "to prevent pollution of the maritime area by continuously reducing discharges, emissions and losses of hazardous substances (i.e., substances which are toxic, persistent and bioaccumulative or which give rise to an equivalent level of concern), with the ultimate aim of achieving concentrations in the environment near background values for naturally occurring substances and close to zero for man-made synthetic substances."

In brief, the common demand to prove exposure before taking decisions on mitigation is not made here. In some countries, such as Sweden, as well as in the European Union to some extent, one further step has been taken in the sense that proof of toxicity is not always considered to be needed in policy-making, before decisions on, e.g., restrictions can be made. This reflects the precautionary understanding that, on the one hand, persistent and bioaccumulative substances eventually often cause problems, and, on the other, that chronic toxicity may be difficult to prove and that chronic toxicity data is missing or is being deficient for most substances on the market (Karlsson 2005; Gilbert 2011). In addition, this development has often gone hand in hand with an emerging understanding that a stricter chemicals policy would not automatically be negative from a competitiveness point of view, as has been claimed previously; on the contrary, progressive policies may stimulate innovation, growth and employment (Karlsson 2006). Furthermore, in some countries, the dominating command-and-control style of policy, has increasingly been complemented with measures such as extended producer responsibility and sometimes also environmental taxes on chemicals (Söderholm 2009).

---

[2] Parties to an international agreement can be nation states but also international institutions and other bodies, such as the European Union.

In addition, decisions taken by governments are nowadays often complemented by voluntary measures from businesses, civil society, local agencies and other stakeholders, to an extent not seen previously. It is therefore relevant to talk about governance of chemicals, from the local and national, to supra-regional and international level. We will now look into how these approaches and tools are applied in some present national, regional and international policies, presented chronologically.

37.3 National and Regional Policies: From Forerunners to Laggards

Some of the fundaments in present chemicals policy go back long in history. Management measures such as knowledge requirements, listing of toxic substances, and precautionary group classification can actually be found in for example Swedish law already from the eighteenth century and onwards (Karlsson 2006). Modern chemicals policy, however, emerged in response to the development of products from chemicals industry, with the referred common division between permit requirements for e.g., agricultural pesticides and mere notification provisions for industrial chemicals in general. Again though, Sweden and some other Nordic countries, as well as Germany, took a position as policy forerunners by recognising, albeit to a different extent, the need for precautionary measures, and in some cases also the need to aim for a non-toxic environment (Karlsson 2006). This strand in chemicals policy developed in the shadow of the conventional risk paradigm but has over time received gradually increasing recognition, for instance in the European Union. In the following, we will take a look at the three larger economic areas of the EU, US and China, as well as on the forerunning regional cooperation around the Baltic Sea and in the UN ECE, presented in a chronological order.

37.3.1 The European Union

EU chemicals legislation dates back to the 1960s, when the first fundaments of the conventional risk paradigm were put in place. Due to data and management gaps, attempts were made from the 1980s and onwards to improve the system, partly by differentiating between existing substances to deal with step-wise, and new substances, for which more comprehensive data demands were stipulated. Continued shortcomings led over to a contested regulatory reform, though, resulting in the REACH regulation (EC 2006), which has been considered the most ambitious chemicals law in the world (Chemicals Agency 2015).

The regulation covers huge numbers of industrial chemicals and includes the blocks: registration, evaluation, authorisation and restrictions of substances. The registration requirements are implemented stepwise until 2018 and differ with respect to substances' market volumes and properties. For high volume or toxic (i.e., carcinogenic, mutagenic and toxic to reproduction) substances, registration was demanded comparatively early, whereas low volume substances were to be phased in later. Based on registered data, national agencies and the European Chemicals Agency (ECHA), where the registration is made, may conduct an evaluation of risks, which may trigger further measures. One option is to list substances meeting specific requirements, such as criteria for PBT (persistent, bioaccumulative and toxic) or vPvB (very persistent and very bioaccumulative), on a Candidate List for potential authorisation, for which particular provisions apply, e.g., regarding information along supply chains. If also prioritised by the ECHA, a substance can subsequently be decided as a target for authorisation. Another option is to more or less restrict a substance, even though that seldom happens due to high burden of proof requirements placed on the regulator. With relevance for the marine environment, REACH has for example led to authorisation processes for the phthalate DEHP and the brominated flame retardant HBCD (both e.g., very toxic to aquatic life) and to restrictions of e.g., nonylphenolethoxylates and the phthalate DBP, all being, e.g., toxic to aquatic life.

While REACH is comparatively progressive, a number of shortcomings have been revealed. These include that many substances are not targeted by REACH, that data demands are too weak to allow evidence-based decision making, that substitution is not regularly required, that a substance group-based approach is missing, that the authorisation process is burdensome and slow, and that the high burden of proof prevents that, sometimes even well-known, hazardous and risky substances are restricted (Karlsson 2010). Moreover, the regulation only insufficiently targets the nano-dimension of materials, the potential combination effects of various substances, and the exposure of children to hazardous substances in consumer goods (Chemicals Agency 2015).

Besides REACH, a number of other laws relevant for chemicals management in the marine environment apply in the EU, for example the Water Framework Directive (EC 2000) the Priority Substance Directive (EC 2008a) and the Marine Strategy Framework Directive (EC 2008b). These are primarily based on an environment-oriented approach and are supposed to trigger regulatory measures and action plans once a targeted non-desired substance is found in the environmental compartment in question. The linkages with the REACH regulation are, however, all but optimal (Karlsson et al. 2011). A closer integration of the different policy fields is needed to enhance goal achievement.

37.3.2 The Baltic Sea Region and HELCOM

In the Baltic Sea Region, the first regional international treaty with relevance for the marine environment came quite early, the Helsinki Convention (1974) for the protection of the Baltic Sea. The cooperation under the convention included the coastal states and was in practice carried out with the Helsinki Commission (HELCOM) as the operative body. Chemical pollutants were included already from start, but following the finding of significant levels of numerous hazardous substances in the marine environment in the 1980s, a 1988 Ministerial Declaration set a more concrete target to reduce the total discharges of the most harmful substances by around 50% by 1995 (HELCOM 1988), a target that later was proven difficult to reach in general, but which was also followed by new action-oriented recommendations (Karlsson and Gilek 2016).

After the fall of the Iron Curtain, more countries joined the cooperation and the Helsinki Convention was revised and broadened in 1992, including a requirement for the Parties to prevent and eliminate marine pollution by harmful chemicals from all sources, not least by banning a set of listed specific substances such as PCBs (Helsinki Convention 1992). The precautionary principle was explicitly included and some phase-out requirements concerned also substances not fully scientifically proven to be problematic (Karlsson and Gilek 2016). In 1998, for example, another recommendation on hazardous substances required continuous reduction of discharges, emissions and losses of hazardous substances into the environment toward the target of their cessation by 2020, in order to reach background values for naturally occurring substances and close to zero concentrations for man-made substances (HELCOM 1998).

The presently dominating strategy under the convention is the Baltic Sea Action Plan (BSAP) (HELCOM 2007). For chemicals, the plan aims at a life in the Baltic Sea "undisturbed by hazardous substances," and it underlines the ecosystem approach to management and sets four 'ecological objectives' for hazardous substances, including to keep concentrations close to natural levels. The more detailed implementation of the plan rests with the Parties of the collaboration, but the plan has also been updated and made more concrete in recent years (e.g., HELCOM 2013).

The number of targeted hazardous substances differs between different recommendations over time and for a number of these, including several pesticides, PCBs and brominated flame retardants, progress in terms of decreased levels in the marine environment has been measured, albeit not yet in line with the close to zero objective (Karlsson and Gilek 2016). Increasingly, the achievements are due to linkages and a positive interplay between the convention and various EU measures, with the former body often setting the agenda and the latter having stronger regulatory power (Karlsson and Gilek 2016).

37.3.3 The USA

In the US, chemicals policy in a broader sense emerged a few years after the basic building blocks were put in place in the EU around 1970, and as in the EU, a number of laws exist in parallel today. The main legislation for industrial substances is the Toxic Substances Control Act (TSCA 1976), which has remained more or less the same since then.

The key elements in TSCA (1976) concern testing, pre-manufacturing clearance and regulation of hazardous substances and the act still differentiates between existing and new chemicals, as EU did in the past. TSCA obliges the US Environmental Protection Agency to require testing if needed for enabling, e.g., the determination of whether or not a substance may present an unreasonable risk. Such a process commonly takes many years to complete and the burden of proof placed on the EPA is high before a process can be initiated. TSCA also requires a pre-manufacture notification before a new substance is produced or before an existing substance is used in new ways. Depending on the level of risk considered to be at hand, the EPA can either limit the use of a substance pending more information, or more permanently restrict it. Finally, the EPA may regulate single substances, in the least burdensome way, if there is reasonable basis to conclude that problems will probably occur (Karlsson 2010).

Considering practice, TSCA has not been implemented with the intended results (GAO 2013, Karlsson 2010). Only a small share of the substances on the market has been managed effectively. Testing has been limited, data requirements hardly reach much further than granting access to already available information, and only a handful of substances have been banned or restricted, including some CFCs, PCBs, and dioxin in a specific case. This is mainly due to the strong burden of proof placed on the EPA and clearly illustrates the drawbacks of the conventional risk paradigm (Karlsson 2010). For these reasons, the EPA has rather tried to work on basis of voluntary agreements and the mere threat of potential legal action has led to quite a number of substance withdrawals. Several of the EPA-initiated voluntary agreements have led to risk management measures, e.g., on some fluorinated substances, such as PFOA, detergents and certain brominated flame retardants. Moreover, after numerous reform attempts over the years, in June 2016, President Obama signed the bipartisan Frank R. Lautenberg Chemical Safety for the twenty-first Century Act, which aims to strengthen the role of the EPA and lower the burden of proof requirements for regulatory measures (HR 2016; US EPA 2016). All in all, however, the regulatory set-up is still conventional and despite the reform aspirations, precautionary elements hardly exist and the polluter-oriented approach is strong.

37.3.4 Regional Air Pollution Convention: The Aarhus Protocol on Persistent Organic Pollutants[3]

The 1979 Long Range Transboundary Air Pollution Convention entered into force in 1983 for the area covered by the UN ECE region (which includes over 50 states across the Northern hemisphere), with the aim to reduce the damage on health and

[3] See http://www.unece.org/env/lrtap/pops_h1.html.

the environment from air pollutants. Over the years, a number of protocols on various air pollutants have been attached to the convention, for example regarding nitrogen and sulphur emissions. In 1998, the Aarhus Protocol on Persistent Organic Pollutants (POPs) was adopted. The protocol contains a list of 11 pesticides, 2 industrial substances, e.g., PCB, and 3 unintended by-products, e.g., dioxins. In order to eliminate discharges, emissions and losses of these substances, eight of them were banned directly, while others became targets for emission reductions or other measures at a later stage; limit values for incineration were for instance stipulated. About a decade later, the protocol became instrumental for the development of the Stockholm Convention on Persistent Organic Pollutants, which has a much broader, global, outreach (Selin 2013). However, the POP protocol as such also developed, when it was broadened in 2009 to include 7 new substances, including some brominated and fluorinated organic chemicals, being problematic in for example the marine environment. At the same time, some provisions for the earlier included substances were revised, including time-wise flexibilities for Parties with economies in transition. Since then, a set of more technical amendments have been adopted but not entered into force. In summary, the protocol has been instrumental for furthering international chemicals management (Sliggers 2012), but the coverage is very limited in relation to the number of substances on the market.

37.3.5 China

Although chemical and environmental laws and regulations were developed much later in China than in, for example, Europe and North America, the Chinese regulatory system for chemicals management has today been viewed as comparatively comprehensive (Lau et al. 2012). For example, the enactment (2003) and later amendment (2010) of the 'Measures on the Environmental Management of New Chemical Substances' has resulted in a REACH-like system for notification and registration of chemical substances to potentially allow proactive identification and control of harmful new substances (Wang et al. 2012). Along the same line, China has or is in the process of implementing international conventions and agreements in chemicals management such as the Rotterdam, Basel and Stockholm Conventions and the Globally Harmonized System for Classification and Labelling. In respect to marine chemical pollution, this regulatory development has enabled that several severe marine pollutants, such as tributyltin paint on vessel hulls and toxic pesticides such as DDT, have been banned, and that various standards and specifications for managing POPs have been issued (Lau et al. 2012).

Still, despite this development, contamination by chemicals remains severe in China, not the least in coastal marine environments and estuaries (Zhang et al. 2014). To some extent this seems to reflect both the burden of the past and the fundamentally challenging situation of attempting to manage the continuously increasing numbers and volumes of chemical substances in the wake of ongoing growth of Chinese chemical industry. However, several challenges more directly linked to Chinese chemicals policy and in particular its implementation can also be identified.

First, China's system for chemical management is very complex and fragmented between various governmental ministries for health, environment, public security etc. and lack of coordination among these has been argued to be a major bottleneck in China's management of chemicals (Park 2012). Second, since comprehensive risk-based chemical management was initiated almost 30 years later in China than in for example Europe, there are significant gaps in professional and technical capabilities and capacities to perform the required testing and risk assessments, as well as to support monitoring and enforcement (Wang et al. 2012). Third, harmonized methods and capacities to monitor, for example, environmental concentrations and specific pollution sources are in need of substantial development. Similarly, assessment of policy implementation, which frequently is mentioned as a major problem, and compliance to support enforcement is in need of more focussed action (Park 2012). Finally, several commentators have argued that substantial efforts are needed in China to improve and develop stakeholder participation and public risk communication to reduce conflicts and improve implementation in chemical management (Park 2012), as well as to raise public awareness on environmental values and risks (Lau et al. 2012).

37.4 Global Frameworks on Hazardous Chemicals

Over the years, national and regional chemicals policy initiatives have often been considered insufficient in order to control substances in globally traded goods, and consequently a number of international declarations, conventions and other agreements concerning the environment, chemical substances and the oceans have been developed in order to share information and to take common mitigating initiatives. Some of these reflect political commitments, whereas others are also legally binding treaties for the ratifying Parties, once an agreement has entered into force. We will now focus on some key illustrative examples of such international agreements and as for the national and regional level, we consider policies covering land-based activities of central importance for the marine environment.[4]

[4] In addition to our selection, the 1985 Vienna Convention on Protection of the Ozone Layer as well as the 2013 Minamata Convention on Mercury, which has not entered into force at the time of writing (2016), are clearly central for chemicals policy, the latter one not least with respect to the marine environment, but due to limited space here, we refer to http://ozone.unep.org/en/treaties-and-decisions/vienna-convention-protection-ozone-layer and http://www.mercuryconvention.org/.

37.4.1 The Broader Frame: The UN Conferences

Among the institutions, the United Nations has played the central role in the environmental field over the years, starting with the Stockholm Conference in 1972 and resulting more recently in the 2016 UNEA resolution on chemicals. The 1972 Stockholm Conference produced a Declaration, containing a set of important principles for international environmental governance, an Action Plan, which recommended the development of an international registry for data on chemicals in the environment, and a recommendation to set up the United Nations Environment Programme. From a broader point of view, it can easily be concluded that the conference became the starting point for accelerated international environmental governance (Engfeldt 2012). However, the 20 years later follow-up, the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, became much more precise in terms of management principles and other fundaments of chemicals policy (UNCED 1993). The Rio Declaration refers explicitly to the precautionary principle and the polluter pays principle, both being central for marine chemicals control, and the adopted Agenda 21 contains an entire chapter on "environmentally sound management of toxic chemicals," which is permeated by the conventional risk paradigm, but which at the same time paved the way for enhanced international collaboration on the issue. Moreover, UNCED became groundbreaking for the perspective of sustainable consumption and thus helped to broaden the environmental policy area.

The subsequent 2002 UN World Summit on Sustainable Development (WSSD), adopted the more precise objective to achieve by 2020 "sound management" throughout the lifecycle of chemical substances, and called on countries and organisations to carry out the more precise Johannesburg Plan of Action, which in the field of chemicals calls for several measures, including to implement a global system for harmonisation of chemicals classification and labelling, and to further develop a strategic approach to chemicals management (UN 2002).

The 2012 Rio+20 Conference on Sustainable Development reaffirmed all Rio principles and addressed chemicals and oceans in two sections (UN 2012). In the section on oceans, a commitment is made to protect and restore the marine environment, and the ecosystem approach to management is held forward. Marine pollution, including persistent organic pollutants and heavy metals, is noted with concern and the value of marine resources is emphasised. For chemicals, the WSSD 2020 objective was confirmed, and calls were made on countries and organisations to implement the Strategic Approach to International Chemicals Management and to help in particular developing countries, where resources are often missing, to improve chemicals management. Research, public information, extended producer responsibility and sustainable design were among other measures encouraged. The need for enhanced cooperation and coordination between the Stockholm, Rotterdam and Basel conventions was also underlined.

The most recent UN document in this family at the time of writing (2016), is the Resolution adopted by the UN Environment Assembly in May 2016 (UNEA

2016), which for the first time aims longer than 2020 and links chemicals to the UN Agenda 2030 for Sustainable Development, which is the framework for the Sustainable Development Goals that now are supposed to be implemented around the world in the coming decades. On the one hand, this signals that the 2020 objective might not be met, but that is on the other hand not very surprising and it is logical and effective to link the UN chemicals agenda to the broader UN work on sustainable development. In addition, the resolution highlights a number of emerging topics like "sustainable chemistry".

37.4.2 A Non-binding Central Tool: The Strategic Approach to International Chemicals Management (SAICM)[5]

Another tool is the SAICM, the Strategic Approach to International Chemicals Management. Resulting from a multi-year long process, it was adopted in 2006 by the International Conference on Chemicals Management as a policy framework, broadly endorsed by governments, international institutions and various stakeholders, coordinated by a secretariat placed at the UNEP (Shubber 2012). The agreement is not legally binding but signals political obligations and aims to guide the "sound management" of hazardous substances throughout their lifecycles by 2020, i.e., to promote the goal adopted at the WSSD. While the concept of "sound" is far from precise, but more or less meaning "safe" from a human health and biodiversity point of view, SAICM is comprehensive in scope. It recognises the importance of applying a life cycle perspective and is not restricted to, for example, specific substances or individual sectors in society. Five themes are central in the agreement; risk reduction, knowledge and information, governance, capacity-building and technical cooperation, and illegal international traffic. In terms of texts, the SAICM consists of the Dubai Declaration on International Chemicals Management, an Overarching Policy Strategy, and a Global Plan of Action, the latter intended to be a working tool that helps to guide the implementation. Both the policy strategy and the action plan are quite detailed. Marine issues are hardly expressed explicitly in the documents, but since chemicals pollution reaching the oceans is often initiated on land, SAICM is clearly instrumental for marine chemicals management. More concretely, SAICM has come to function as an instrument stimulating exchange of information and experience, national policy development and capacity building, not least in developing countries, to some extent thus functioning principally as the Helsinki Convention does regionally. An issue continuously discussed though, concerns the need for improved financial mechanisms, which are considered key for a well-functioning implementation of SAICM (Shubber 2012).

[5] See further at http://www.saicm.org.

37.4.3 Communicating Hazards: The Globally Harmonized System of Classification and Labelling of Chemicals[6]

Following a mandate at the 1992 UN Rio Conference on Environment and Development, the first version of the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) was adopted in 2002. Although global GHS implementation is still underway and varies greatly between countries, the key importance of GHS as a tool for chemicals management, including the management of marine pollution, is increasingly being recognised by countries and stakeholders alike (Chang 2012). The GHS is a system for identification of inherent hazards of chemical substances and mixtures, and for communicating these hazards to professional and non-professional users and other target audiences. The scope is restricted to classification and labelling of all types of chemicals, by using existing data. Hence, GHS does not in itself require additional testing or prescribe methods for such data generation. In line with the overall objectives of GHS to provide an internationally harmonized system for hazard communication it: (1) defines criteria for classification of physical, health and environmental hazards of chemicals, (2) makes requirements on how identified chemical hazards should be communicated through labels with associated hazard and precautionary statements, and through so-called Safety Data Sheets (SDS) (Chang 2012).

37.4.4 An Early Agreement: The Basel Convention[7]

In reaction to the shipping of hazardous waste from industrialised to developing countries, which started to grow rapidly in the 1970s, the 1989 Basel convention on the Control of Transboundary Movement of Hazardous Wastes and their Disposal was adopted in 1989. It entered into force in 1992 and today (2016), there are over 180 Parties to the treaty. Considering leaking waste deposits and for example pollution from ship dismantling, the convention is of clear relevance to the marine environment.

The convention aims to protect health and the environment from adverse effects of various kinds of hazardous waste, as defined in the agreement, by reducing waste generation and promoting sound waste management. Two types of provisions are central for promoting environmentally sound management of waste, prevention and collaboration respectively. A cornerstone is a set of various general restrictions on transboundary movement of hazardous waste. Export of hazardous waste to Antarctica and to states not being part of the convention or that have prohibited such import is prevented, unless specific circumstances

[6] See http://www.unece.org/trans/danger/publi/ghs/ghs_welcome_e.html.

[7] See http://www.basel.int.

apply. In response to criticism that the convention in practise legitimised waste export under the pretext of recycling, the so-called “Ban Amendment” was adopted in 1995, in short prohibiting hazardous waste export for all purposes, to developing countries. The amendment has been ratified by some 85 Parties, which, however, is not sufficient for it to enter into force. Last but not least, the collaborative part of the convention is of importance. It concerns exchange of information and technical assistance, as well as the setting up of a series of regional centres for training, capacity building and transfer of technology. Linked to this, a number of non-binding elements and technical guidelines within the frames of the cooperation have played a key role for waste management. Moreover, the European Union has implemented legislation in line with the Ban amendment (EC 1997). While being a part of waste policy rather than chemicals policy, the impact of the convention has clearly been decreased emissions of hazardous substances in for example marine environments around developing countries (Portas 2012).

37.4.5 Hazardous Chemicals under Increasing Control: The Rotterdam Convention[8]

The 1998 Rotterdam Convention on the “Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade” entered into force in 2004. It has the objective to promote shared responsibility, cooperation and sound use of chemicals in international trade with certain hazardous substances, foremost pesticides, in order to protect public health and the environment, which is of clear relevance for the marine environment, a well-known recipient for many pesticides. As in the Basel Convention, exchange of information, and the concept of prior informed consent (PIC) are central elements of the agreement. The key focus is placed on pesticides and industrial substances that have been nationally restricted, and that after notification may be targets for a so-called a “PIC procedure,” in which Parties have the possibility to take a stance on the future trade of the substance in question. Regarding information, the convention promotes, for instance, exchange of data and contains provisions on labelling requirements. At present, over 170 Parties (mostly countries but also the European Union and UN institutions) participate under the convention. It has been considered clear that the work under the convention has proved useful for information exchange and awareness raising on some hazardous substances (Mashimba 2012), but no direct bans follow the cooperation and the number of targeted substances is limited.

[8] See http://www.pic.int.

37.4.6 *Restricting the Worst: The Stockholm Convention*[9]

The 2001 Stockholm Convention on Persistent Organic Pollutants with 180 Parties is the perhaps most central international treaty on polluting chemical substances in general. It entered into force in 2004 and requires the parities to, mindful of the precautionary approach, protect human health and the environment from persistent organic pollutants (POPs). The intended means include taking measures that eliminate, restrict or reduce the production, use and release of substances, as specified in various annexes to the convention.

The initial focus in the convention was placed on 12 notorious POPs—sometimes called “the dirty dozen”—in the three categories pesticides, industrial compounds and unintended by-products, all being present in the marine environment. Among these, the substances and groups DDT, aldrin, PCBs and dioxins were included, which all have severe effects in nature, including in marine ecosystems. With a few exceptions, the production and use, or the unintentional release, of these substances are to be eliminated, restricted or reduced. Over time, additional POPs have been added to the list of the convention, including some brominated flame retardants and perfluorinated substances, amounting to around 30 substances or groups today (2016), mostly being targets for elimination, albeit with some exemptions here as well. More recently, four additional POPs have been proposed for listing and are now pending review (deca-BDE, dicofol, short-chained chlorinated paraffins, and a group of perfluorinated substances). Clearly, the convention has been useful in globally restricting the use and emissions of the so far most problematic chemicals known, but the coverage is still limited and as for other treaties, financial challenges related to implementation have turned up (Kohler and Ashton 2012).

37.5 Discussion—Closing the Gap

In this chapter, we have shown that a number of national, regional and international binding and non-binding policies, laws and agreements aim to manage chemicals in order to reduce risks and sometimes also hazardousness, and by doing so, separate the chemicals’ wheat from the problematic chaff. It is clear from the overview that some well-known chemical risks have been mitigated in some environmental compartments due to such policies, but also that most objectives in place are generally not reached, whether it is the global target of sound chemicals management, or more ambitious national ones concerning, e.g., a non-toxic environment. This depends on that policies target too few substances and too few types of effects, with too weak demands, and with too strong burden of proof requirements placed on the public side. The number of chemicals in common use today is unknown, but the somewhat

[9] See http://chm.pops.int.

150,000 industrial substances pre-registered in the EU illustrates that what is restricted internationally is around two to three orders of magnitude below what potentially can be found on the market. In addition, the uncertainties at hand are only seldom met with strategies focusing on management based on inherent properties, which are easier to test, or by taking a group-based approach. Moreover, there is an obvious lack of environment-oriented approaches, which for example could depart from sensitive groups such as children, or from sensitive ecosystems, like many marine environments. To improve management, these and similar precautionary tools are much needed in chemicals policy as such, from the national to international level, in order to close the gap between policy objectives and the impaired state of the environment.

Furthermore, it is important to put chemicals policy in a broader context, in line with the ecosystem approach to management. This is of particular importance in the marine context, since there are obvious interactions between various environmental risks. In a larger study on marine risk governance in the Baltic Sea, seven functions were identified as vital for promoting sustainable governance, besides precaution—coordination, integration, interdisciplinarity, deliberation, communication and adaptability (Gilek and Karlsson 2016). Here, we want to emphasise in particular the need for coordination of policies, foremost on the international level.

The three binding Basel, Stockholm, and Rotterdam conventions each cover a relatively small part of the many substances on the market, and have different focus, partly overlapping, partly leaving gaps in between. The SAICM, on the other hand, is based on a comprehensive set-up, but is not binding. While a more far-reaching cooperation between the conventions have emerged over time, including joint head and secretariat functions, it seems clear that a Global Framework Convention on Chemicals (as exists for e.g., biodiversity and climate) would constitute a more rational organisation of these policies. Gaps and overlaps would easier be avoided and the institutional and practical arrangement, the generation and exchange of knowledge, as well as the development and implementation of measures, would most likely be more effective in relation to both goals and costs, with one framework. Without developing this idea further here,[10] one option would be to transform SAICM into a framework convention, to which the existing binding treaties could more or less be attached as protocols. Alternatively, the existing conventions could be fused together into one framework (compare the OSPAR convention), but that might be a more demanding exercise. Irrespective of the exact route, we consider it of utmost importance to establish a more harmonised global regulatory framework on chemicals. That will obviously be of importance for human health and the terrestrial environment, but to a large extent also for the marine environment, where many substances still end up, a problem it is high time to put a stop to.

[10] See however, SSNC and CIEL (2013), as well as Perrez and Karlaganis (2012), on these issues.

References

Carson R (1962) Silent Spring. Fawcett Publications, Greenwich, Connecticut

Chang C (2012) The globally harmonized system of classification and labelling of chemicals: the system, its history and context, and the future of implementation. In: Wexler P, Van der Kolk J, Mohapatra A, Agarwal R (eds) Chemicals, environment, health: a global management perspective. CRC Press, Boca Raton

Chemicals Agency (2015) Developing REACH and improving its efficiency—an action plan. Report 2/2015. Swedish Chemicals Agency, Sundbyberg

EC (1997) Council decision 97/640/EC on the amendment to the Basle convention, as laid down in decision III/1 of the conference of the parties. Official Journal L 272:45–46

EC (2000) Water framework directive, 2000/60/EC. Official Journal L 327:1–72

EC (2006) Regulation 1907/2006/EC (REACH). Official Journal L 396:1–849

EC (2008a) Priority substance directive, 2008/105/EC. Official Journal L 348:84–97

EC (2008b) Marine strategy framework directive, 2008/56/EC. Official Journal L 164:19–40

Engfeldt LG (2012) Stockholm 1972: conference on the human environment. In: Wexler P, van der Kolk J, Mohapatra A, Agarwal R (eds) Chemicals, environment, health: a global management perspective. CRC Press, Boca Raton, pp 17–26

GAO (2013) Toxic Substances. US Government Accountability Office 13-249. GAO, Washington D.C.

Gilbert N (2011) Data gaps threaten chemicals safety law. Nature 475:150–151

Gilek M, Karlsson M (2016) Seeking pathways towards improved environmental governance of the Baltic Sea. In: Gilek M, Karlsson M, Linke S, Smolarz K (eds) Environmental governance of the Baltic Sea. Springer, Dordrecht

HELCOM (1988) Declaration on the Protection of the Environment of the Baltic Sea. Helsinki, 15 February 1988

HELCOM (1998) Recommendation 19/5. HELCOM objective with regard to hazardous substances

HELCOM (2007) Baltic Sea action plan. Adopted at HELCOM Ministerial meeting, Krakow, Poland 15 November 2007

HELCOM (2013) HELCOM Copenhagen Ministerial Declaration. Taking further action to implement the BSAP—Reaching good environmental status for a healthy Baltic Sea. 3 October 2013, Copenhagen, Denmark

HELCOM & OSPAR (2003) Statement on the ecosystem approach to the management of human activities. First joint Ministerial meeting of the Helsinki and OSPAR commissions, Bremen, 25–26/6/03

Helsinki Convention (1974) Convention on the protection of the marine environment of the Baltic Sea Area

Helsinki Convention (1992) Convention on the protection of the marine environment of the Baltic Sea Area

HR (2016) The Frank R. Lautenberg chemical safety for the 21st century act. U.S. house of representatives, 114th Congress, 2D Session, H. R. 2576

Jensen S (1966) Report of a new chemical hazard. New Scientist, 32, 612

Karlsson M (2005) Managing complex environmental risks for sustainable development: policies for hazardous chemicals and genetically modified organisms. Doctoral Thesis. Karlstad University Studies 2005:34. Karlstad: Karlstad University

Karlsson M (2006) The precautionary principle, Swedish chemicals policy and sustainable development. J Risk Res 9:337–360

Karlsson M (2010) The precautionary principle in EU and US chemicals policy: a comparison of industrial chemicals legislation. In: Eriksson J, Gilek M, Rudén C (eds) Regulating chemical risks: European and global challenges. Springer, Dordrecht

Karlsson M, Gilek M (2016) Chemicals governance in the Baltic Sea region: a study of three generations of hazardous substances. In: Gilek M, Karlsson M, Linke S, Smolarz K (eds) Environmental governance of the Baltic Sea. Springer, Dordrecht

Karlsson M, Gilek M, Udovyk O (2011) Governance of complex socio-environmental risks: the case of hazardous chemicals in the Baltic Sea. AMBIO 40:144–157
Kohler PM, Ashton M (2012) Implementing the Sotckholm convention, an increasingly expensive challenge. In: Wexler P, Van der Kolk J, Mohapatra A, Agarwal R (eds) Chemicals, environment, health: a global management perspective. CRC Press, Boca Raton
Kortenkamp A, Backhaus T, Faust M (2009) State of the art report on mixture toxicity. Final report of a project on mixture toxicology and ecotoxicology commissioned by the European Commission. DG Environment, European Commission, Brussels
Lau MHY, Leung KMY, Wong SWY, Wang H, Yan ZG (2012) Environmental policy, legislation and management of persistent organic pollutants (POPs) in China. Environ Pollut 165:182–192
Mashimba E (2012) The Rotterdam convention. In: Wexler P, Van der Kolk J, Mohapatra A, Agarwal R (eds) Chemicals, environment, health: a global management perspective. CRC Press, Boca Raton
OSPAR (1998) The Sintra Statement, final declaration of the Ministerial meeting of the OSPAR Commission, Sintra 22–23 July 1998, OSPAR 98/14/1
Park D-Y (2012) Chemical management system in China. In: Wexler P, van der Kolk J, Mohapatra A, Agarwal R (eds) Chemicals, environment, health: a global management perspective. CRC Press, Boca Raton, pp 503–515
Perrez F, Karlaganis G (2012) Emerging issues in global chemical policy. In: Wexler P, Van der Kolk J, Mohapatra A, Agarwal R (eds) Chemicals, environment, health: a global management perspective. CRC Press, Boca Raton
Portas P (2012) The Basel convention—a promising future. In: Wexler P, Van der Kolk J, Mohapatra A, Agarwal R (eds) Chemicals, environment, health: a global management perspective. CRC Press, Boca Raton
Selin H (2013) Global chemicals politics and policy. In: Falkner R (ed) The handbook of global climate and environment policy. John Wiley & Sons, Hoboken
Shubber H (2012) Strategic approach to international chemicals management. Development and opportunities. In: Wexler P, Van der Kolk J, Mohapatra A, Agarwal R (eds) Chemicals, environment, health: a global management perspective. CRC Press, Boca Raton
Sliggers J (2012) Convention on long range transboundary air pollution. In: Wexler P, Van der Kolk J, Mohapatra A, Agarwal R (eds) Chemicals, environment, health: a global management perspective. CRC Press, Boca Raton
Söderholm P (2009) Economic instruments in chemicals policy. Past experiences and future use. TemaNord 2009:565. Copenhagen: Council of Nordic Ministers
SSNC and CIEL (2013) Paths to global chemicals safety: the 2020 goal and beyond. SSNC, Stockholm
TSCA (1976) Toxic substances control act. 15 United States code §§ 2601-2692
UN (2002) World summit on sustainable development (WSSD), Johannesburg, South Africa
UN (2012) The future we want. Rio +20. Outcome of the conference. UN. A/CONF.216/L.1
UNEA (2016) Resolution 2/7. Sound management of chemicals and waste. UNEP, Nairobi
UNCED (1993) Report of the conference of the United Nations on environment and development (UNCED), Rio de Janeiro, 3–14 June 1992, vol 1-3. United Nations, New York
UNEP (2013) Global chemicals outlook. UNEP, Nairobi
US EPA (2016) The Frank R. Lautenberg chemical safety for the 21st century act: frequent questions. Available: https://www.epa.gov/sites/production/files/2016-06/documents/the_frank_r._lautenberg_chemical_safety_for_the_21st_century_act_frequent_questions.pdf. Accessed 30 June 2016
Wang H, Yan Z-G, Li H, Yang N-Y, Leung KMY, Wang Y-Z, Yu R-Z, Zhang L, Wang W-H, Jiao C-Y, Liu Z-T (2012) Progress of environmental management and risk assessment of industrial chemicals in China. Environ Pollut 165:174–181
Wu B, Torres-Duarte C, Cole BJ, Cherr GN (2015) Copper oxide and zinc oxide nanomaterials act as inhibitors of multidrug resistance transport in sea urchin embryos: their role as chemosensitizers. Environ Sci Technol 49:5760–5770
Zhang Z-W, Xu X-R, Sun Y-X, Yu S, Chen Y-S, Peng J-X (2014) Heavy metal and organic contaminants in mangrove ecosystems of China: a review. Environ Sci Pollut Res 21:11938–11950

Chapter 38
Origin and Management of Radioactive Substances in the Marine Environment

Hartmut Nies

Abstract Artificial radioactive substances have been introduced into the marine environment by various human activities since the beginning of the nuclear age in the 1940ties. Sources are atmospheric nuclear weapon tests, dumping of radioactive wastes, authorised discharges from the nuclear industry, as well as accidental releases, such as the Windscale fire in 1957, the accident at Chernobyl in 1986, and Fukushima Daiichi in 2011. Military activities and losses of nuclear submarines are also an important input of radioactive material to the marine environment. The following chapter will give a short introduction to some of the most relevant sources and discuss the radiological consequences to biota and man. It will also give a brief overview of pertinent management measures.

Keywords Radioactivity • Military activities • Nuclear fuel cycle • Radioactive discharges • Nuclear accidents • Nuclear weapon tests • Radioactive wastes • Chernobyl • Fukushima Daiichi • Nuclear submarine accidents

38.1 Radioactive Substances as Pollution in the Marine Environment

The first introduction of radioactive substances into the marine environment was related to the development of nuclear weapons at the end of World War II. Particularly atmospheric and under water tests from 1945 to 1963 with massive releases to the atmosphere resulted in subsequent contamination of earth's surface soil and ocean water. In addition, the nuclear fuel cycle produced huge amounts of nuclear wastes and the first solution to get rid of these products were the idea to dump it in coastal

H. Nies
Bundesamt für Seeschifffahrt und Hydrographie (BSH), Hamburg, Germany

International Atomic Energy Agency (IAEA), Monaco, Monaco
e-mail: Hartmut.nies@gmx.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_38

areas and later into the deep oceans. The idea behind this proposal was to reduce the actual toxicity to lower levels due to the enormous dilution capability of the world ocean. In addition, deep sea areas were considered to be almost completely separated from the (human) biosphere. However, these considerations were completely put into doubt after more intensive research in abyssal oceans. In the meantime the *London Convention 1972* expressed a total ban of any dumping of nuclear wastes into the oceans or even coastal seas. But there exist old legacies of nuclear wastes and releases in the world oceans from past activities. A number of nuclear accidents like Chernobyl and Fukushima had the consequence of wide spread release of radionuclides both into the atmosphere and water sheds as well directly into coastal waters. In principal, only long lived radionuclides with half-lives of more than 1 year are relevant for the radioecology in the marine environment. The huge dilution capacity of the oceans and the radiation shielding property of water keeps the impact to living organisms in most cases limited. However, accumulation within the marine food chain can lead to significant levels in marine food close to nuclear input release areas. Aarkrog (2003) has provided an excellent review about different sources, type of artificial radionuclides and geographical distribution in the world ocean. The following part cannot cover all aspects of marine radioactivity, but will explain the most dominant input sources of artificial radioactivity in the oceans and regional seas and will show potential managerial actions to reduce potential harm to man and nature.

38.1.1 Sources of Marine Radioactivity

38.1.1.1 Nuclear Weapon Tests

One of the initial sources of nuclear material into the earth's surface were the intensive atmospheric and underwater tests primarily by the United States and the former Soviet Union. The two bombs on Hiroshima and Nagasaki during Second World War II were relative small explosions, but nevertheless with catastrophic human consequences in Japan. The real tests series commenced in 1946 on the Marshall Islands at the small Bikini Atoll. A comprehensive list of nuclear tests is provided by Yang et al. (2000). One of the first huge tests was an underwater test called "Baker Shot" of the Crossroad operation in July 1946 on the Bikini atoll. Figure 38.1 provides an impression of the devastating impact of a nuclear underwater test at the Bikini Atoll in 1946.

These tests in particular on the Marshall Islands caused massive contamination of the Bikini Atoll and the Northern Pacific Ocean, which finally had the consequence that the local population could not return to their home island until today. The soil of the Atoll is still highly contaminated with Cs-137 and Plutonium isotopes, which are accumulated in the coconut trees to such high levels that the coconuts cannot be used for human consumption. One of the measures to reduce the accumulation of radiocesium[1] in palm trees was the dispersion of potassium salts on atoll soils to favour the enrichment of potassium instead of radioactive Cesium.

[1]The term *radiocesium* means mostly Cs-134 and Cs-137 with half lives of 2 and 30 years,

Fig. 38.1 Picture of the 23 kt underwater nuclear weapons effects test, known as Operation CROSSROADS (Event Baker), conducted at Bikini Atoll (July 1946). The series was to study the effects of nuclear weapons on ships, equipment, and material. A fleet of more than 90 vessels was assembled in Bikini Lagoon as a target. Source: Defense Threat Reduction Agency, http://www.dtra.mil/Home/Nuclear-Test-Personnel-Review/US-Atmospheric-Nuclear-Test-History-Documents/ DNA 6032F, Operation Crossroads: 1946.

The Soviet Union soon undertook their atmospheric and underwater tests at Novaja Semlja and at the Semipalatinsk test site. These tests have led to huge atmospheric and subsequent soil and ocean contamination, which finally resulted in the "*Partial Nuclear Test Ban Treaty*" (PNTB). The PNTB makes it illegal to detonate nuclear explosions anywhere except underground. Most countries have signed and ratified the *Partial Nuclear Test Ban* which went into effect in October 1963. Other important test sites used by the USA were Enewetak and Johnston atolls in the North Pacific, Christmas Island in the Indian Ocean, Lop Nor in China, and Mururoa and Fangataufa atolls in the South Pacific used by France.

Due to the location of most of these test sites on the northern hemisphere, the major part of radioactive fallout was deposited on the northern hemisphere environment. Figure 38.2 shows the areal deposition of Sr-90 on the surface of the globe in relation to the geographical latitude. Some long-lived radionuclides such as tritium (H3), Cs-137, Sr-90 and Pu-238, Pu-239 and Pu-240, and Am-241 are still detectable in ocean seawater up today. The average concentration of Cs-137 in surface seawater of the oceans is currently about 1 Bq/m^3 and about 0.6 Bq/m^3 for Sr-90.

respectively.

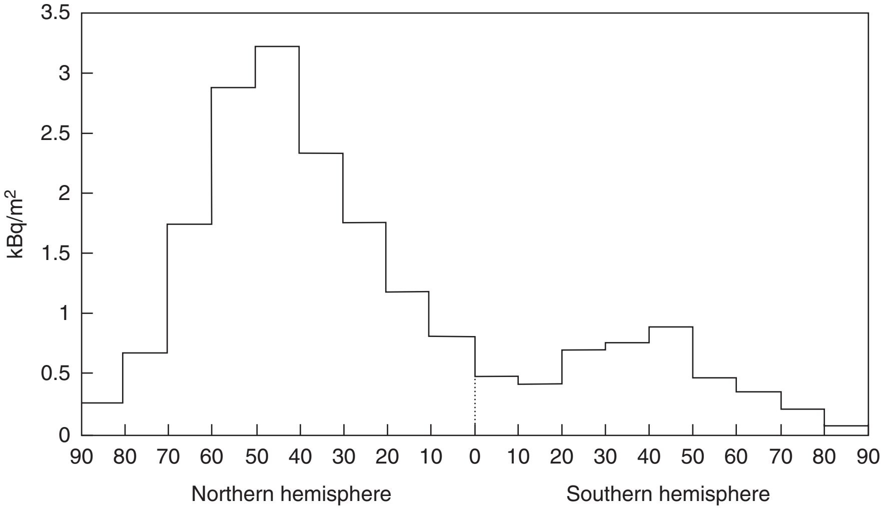


Fig. 38.2 Integrated deposition of Sr-90 [kBq/m^2] on the surface of the earth integrated to the year 2000. (UNSCEAR 2000; Aarkrog 2003; IAEA 2005)

The typical nuclear fallout shows an activity ratio between Cs-137 and Sr-90 of about 1.5 (UNSCEAR 2000; Aarkrog 2003; Aoyama 2012).

Due to the good solubility of tritium, Sr-90, and Cs-137 most of the deposited fallout activity is still detected in the water column and transported with ocean currents over long distances. Cs-137 and Pu-isotopes have been also incorporated into particles and deposited in sediments. This process leads to an *effective half-live* of Cs-137 in the world ocean of about 15 years, i.d. Cs-137 is removed faster from the water column than the physical half-live or about twice the period of one physical half-live of 30 years. In coastal waters with higher suspended particulate matter the removal or residence time of Cs-137 in the water column is much shorter with higher sediment deposition rates.

38.1.1.2 Dumping of Radioactive Wastes and Other Nuclear Material

The nuclear fuel cycle produces also enormous amounts of nuclear wastes. In the early days of the nuclear age it was believed that an easy way of elimination would be dumping of these wastes into the ocean. In the 1950s, drums with low-level nuclear inventory were even dumped in the Channel between France and England by UK authorities, however, when some of these drums were found in fisher nets, it was decided to dump this waste in the deep ocean in the Atlantic at depths of more than 4000 m. The same was done by US authorities in the western Atlantic Ocean and the eastern Pacific. The positions and inventories at the time of dumping are displayed in Fig. 38.3. Dumping was one option of disposal of radioactive wastes and carried out between 1946 and 1993. The last reported dumping activity was in 1993, when the Russian Federation released low level liquid radioactive waste into the Sea of Japan. In total, 14 countries have used more than 80 locations to dispose of about 85 PBq of radioactive waste (IAEA 2015). The recently updated report by the IAEA about the historical inventory provides all details about the type of dumping, periods and amounts.

Dumped materials include all types of radioactive wastes. About 50% of the dumped wastes were low level wastes and dumped under the guidance of the OECD/NEA in the eastern Atlantic at depths of more than 4000 m. However, the USA and Russia have also dumped parts of nuclear reactors from nuclear submarines and the ice breaker "Lenin." The former USSR used the arctic area of the Kara Sea at depths of only 40–300 m including some bays of Novaya Semlya (Fig. 38.4).

There were several international campaigns to study the potential impact from these dumping activities in the Kara and Barents Seas (e.g., Gwynn et al. 2016). These investigations were mostly initiated by Norway due to the vicinity of the dumping areas to Norwegian fishing grounds. These dumping activities were partly carried out on emergency situations, because military had serious problems with the repairing of the reactors, which turned out to be too dangerous. In 1992, it became public that the USSR has dumped high level wastes in the Kara Sea violating international regulations based on the *London Convention 1972*. The water depths were not according to the agreed rules and the levels of radioactivity was too high. Based on international public pressure, the Russian Federation issued a detailed report about the amount and types of wastes dumped in the Kara and Barents Seas. This report was called "White Book" (Yablokov et al. 1993) and reported the knowledge of available documents about past dumping operations. The total radioactive inventory of dumping was estimated to about 90 PBq[2] (90×10^{15} Bq) at the time of dumping, which decayed to less than 40 PBq at present. The IAEA initiated the *International Arctic Seas Assessment Project* (IASAP) in 1993 and concluded in 1996 to address concerns over the potential health and environmental impacts of high level radioactive waste dumped in the shallow waters of the Arctic Seas. The IASAP report was published in 1998 (IAEA 1998) and concluded that relatively low releases have been detected from these dumped materials, but recommended to keep these sea areas under continuous monitoring control. Potential remediation measures were also examined, but up to now no operations were initiated to remove these wastes or reactor vessels from the shallow bays of Novaya Semlya. It can be expected that removing and disposing of these objects in the Kara Sea and fjords of Novaya Semlya will be under discussion again in the future. The final decision in this regards is likely to depend also very much on financial support from international sources. The current situation, however, is not in accordance with international rules and cannot be accepted by the international communities.

38.1.1.3 Discharges to the Marine Environment

All nuclear installations release some radioactive material to the environment. The amounts depend very much on the technical details of the facility. Generally, it can be stated that research facilities and nuclear power stations only release small amounts

[2] Peta-Becquerel = 10^{15} Bq.

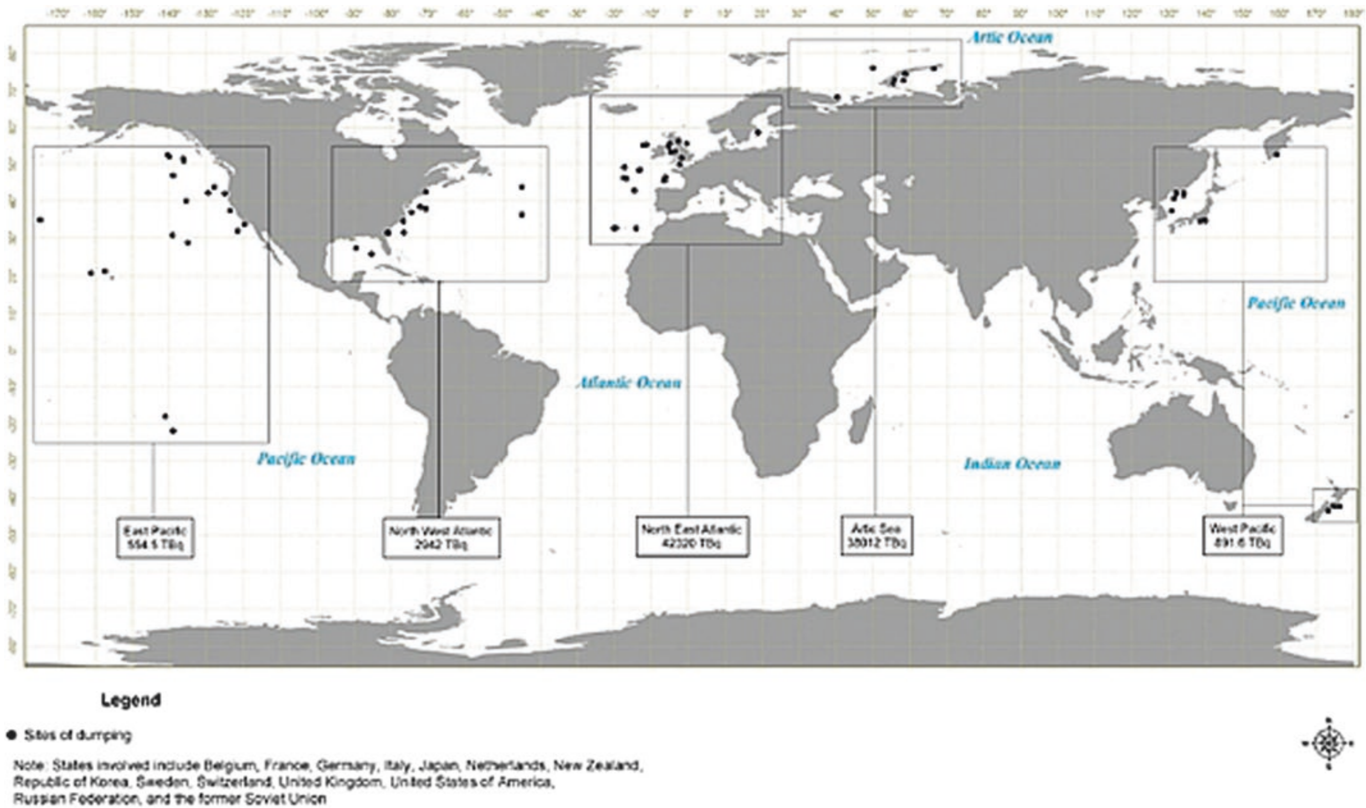


Fig. 38.3 Worldwide dumping sites with activity inventory (TBq) and countries of origin of the wastes. The activity is calculated for the time of dumping (IAEA 2015)

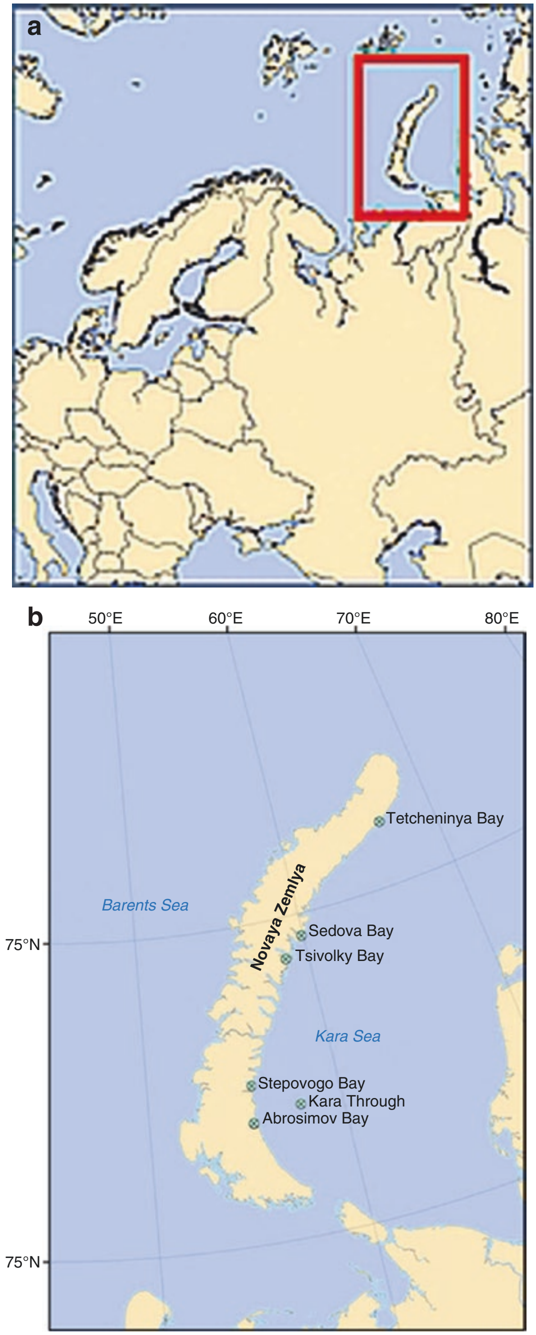


Fig. 38.4 Location of dumping areas used by the former Soviet Union and the Russian Federation between 1966 and 1988. Type of materials and time of dumping is given in Table 38.1 (Gwynn et al. 2016)

Table 38.1 Location, type and time of dumping of party high level radioactive wastes carried out in the Kara Sea and bays of Novaya Semlya (IAEA 2015)

Dumping location	Type of waste, time of dumping and remarks
Tetcheninya Bay	• Two reactors of the nuclear submarine K-22 (N538) (dumped in 1988), without spent nuclear fuel (SNF)
Sedova Bay	• Reactor compartment of the atomic icebreaker Lenin (1967), without SNF
Tsivolky Bay	• 237 containers with RW (radioactive waste)
	• Shielding assembly of the atomic icebreaker Lenin (1967), with SNF
Stepovogo Bay	• Nuclear submarine K27 (1981), two reactors with SNF
	• Four reactor lids
Kara Trough	• Reactor of the nuclear submarine K-140 (N421) (1972), with SNF
Abrosimov Bay	• Two reactors of the nuclear submarine K-3 (N254) (1988)
	• Reactor compartment of nuclear submarine K-5 (N260) (1967), with SNF
	• Reactor compartments of the nuclear submarines K-11 (N285) (1966) and NS K 19 (N901) (1965), with SNF

to the environment during regular operations, thus having an extreme low environmental and radiological impact. Accidental releases however, may lead to catastrophic impact to life with long lasting radiological and economic consequences as can be seen at the cases of Chernobyl and Fukushima Daiichi nuclear power stations.

With regard to the marine environment, aqueous discharges are primarily relevant, if radionuclides with half-lives of more than 1 year are released. Again the most important radionuclides are Sr-90 and Cs-137, but also tritium is one candidate to consider, but with—in most cases—negligible radiological consequences. On a short term the Iodine radionuclides are of higher importance, but only during the first few weeks of the accident due to the short half-live of 8 days.

As one example, the discharges over many years into the maritime area of the Northeast Atlantic are considered here. There are a number of nuclear power stations, research facilities, and two major reprocessing plants, i.e., BNFL Ltd. at Sellafield (UK), COGEMA at Cap de la Hague (F). The OSPAR Commission has collected the annual discharge data from all nuclear installations, which discharge their effluents into rivers or coastal areas of the OSPAR maritime area. Figure 38.5 shows the annual discharges from different types of aqueous releases between 1990 and 2013. The main contributor for most of the radionuclides was the nuclear reprocessing plant Sellafield discharging into the Irish Sea. The highest discharges occurred in the seventies with about 5.2 PBq of Cs-137 in 1975 (Nies et al. 2000). The ocean residual currents transported this material around Scottish waters into the North Sea and further along the Norwegian coastal current to the Arctic Ocean. It was possible to follow this contamination track of Cs-137 and other radionuclides like Sr-90 and Tc-99 for many years into Artic waters. The time of transfer from the discharge pipe line in the Irish Sea into the North Sea is about 2 years, to the entrance of the Baltic Sea about 4 years, and to northern Norway about 4–5 years and into the Arctic Ocean, and the southern part of Greenland about 8–9 years. A review of these transfers and contaminations by different radionuclides in the Northeast Atlantic Ocean can be found at Kershaw (2010). The discharges from the reprocessing plant at Cap de la Hague were generally much lower than those from Sellafield and with a different nuclide pattern; e.g., the activity ratio between Cs-137 and Sr-90 were significantly different in the 1980ies with the consequence that the contamination of seawater in the North Sea gave a typical nuclide pattern with higher Sr-90 levels in

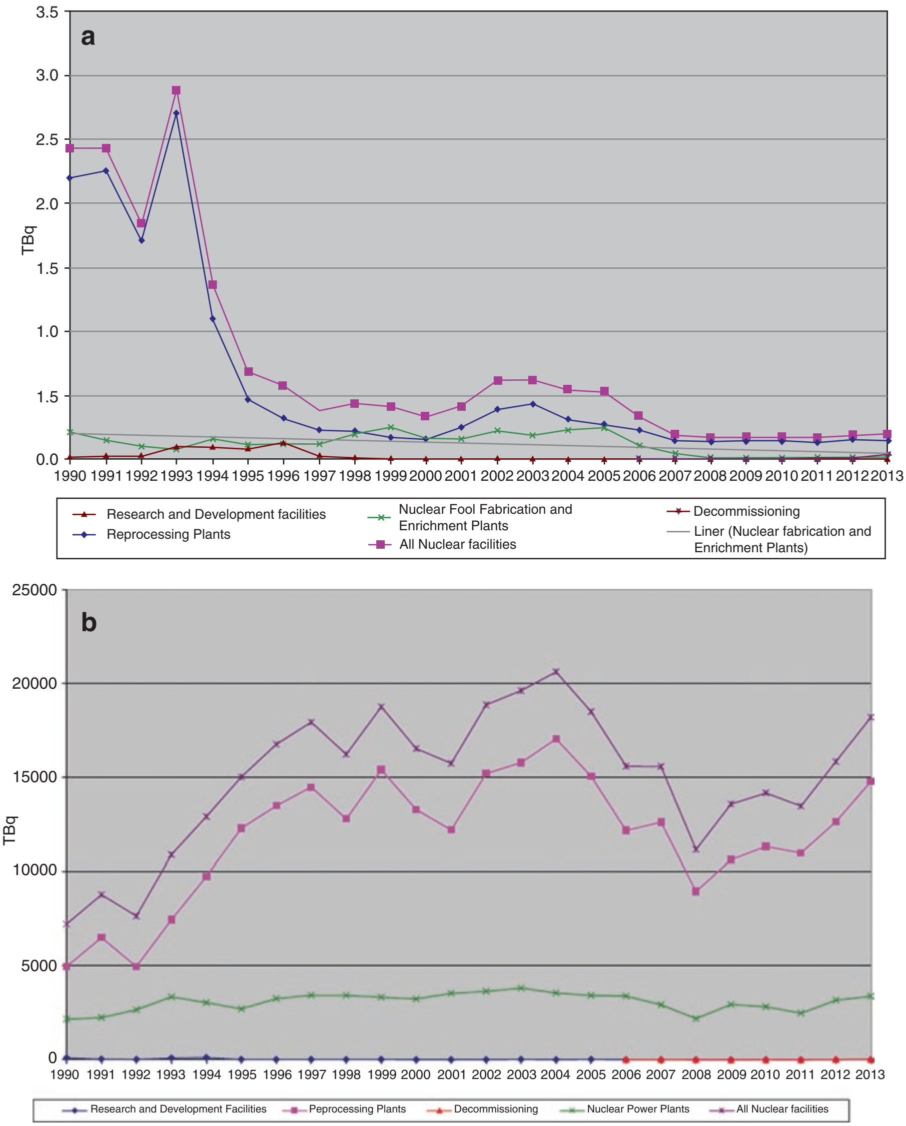


Fig. 38.5 Annual liquid discharges from different nuclear installations into the OSPAR maritime area between 1990 and 2013. (**a**) Alpha-activity; (**b**) Tritium activity; (**c**) Beta-activity (except tritium) OSPAR Commission (2015)

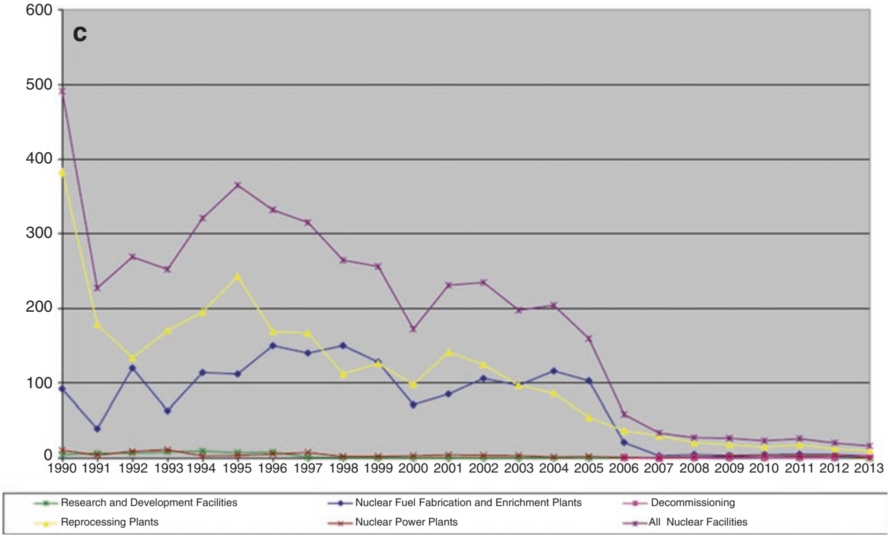


Fig. 38.5 (continued)

the southern North Sea (La Hague derived) in comparison to the central or north-western North Sea influenced mainly by the dominating discharges of Cs-137 from Sellafield (Nies et al. 2000).

It became obvious that the discharges from the plant at Sellafield were too high in the 1970ties and the UK authorities got under national and international political pressure—in particular from Ireland—to reduce the authorized discharge limits for Sellafield significantly. The result can be seen in time series of discharges of Figs. 38.5, because the effluents from the reprocessing plants are the dominating source compared to other types of installations. The discharge levels from all sources are currently extremely low with only insignificant radiological impact to man or living organisms in the marine environment. The radiation exposure from natural sources, e.g., from the natural radionuclide Po-210 accumulated in marine food is about three to four orders of magnitude higher.

In the 1950s, the discharges from the Russian nuclear complex near Chelyabinsk into the Ob and Yenisei river system has been very high with radiological impact to the Russian population living along these river systems, however, the documentation of this problem is rather limited. Traces from these activities are still detectable in Kara Sea sediments. This was documented in the IASAP project initiated by the International Atomic Energy Agency in 1993 (Trapeznikov et al. 1993; IAEA 1998).

38.1.1.4 Marine Contamination by the Accident at Chernobyl in April 1986

On April 26, 1986, a devastating accident occurred at the Chernobyl Nuclear Power Plant, then located in the Ukrainian Soviet Socialist Republic of the former Soviet Union (USSR). The accident was the consequence of an experiment which got out

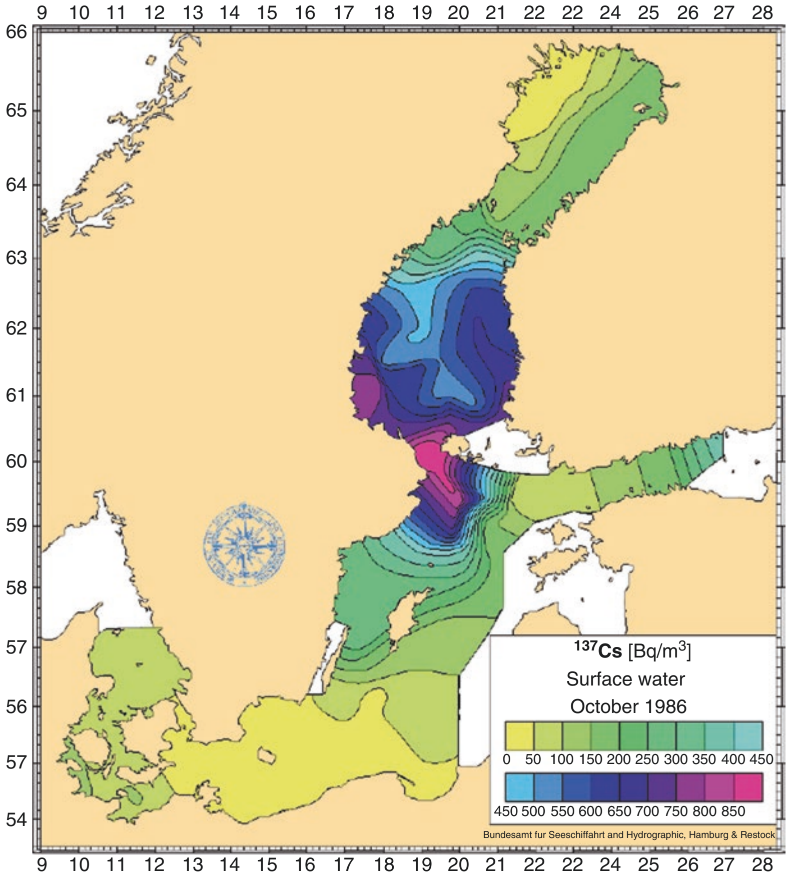


Fig. 38.6 Smoothed surface Cs-137 contamination pattern after the fallout from the Chernobyl disaster investigated in October 1986 (HELCOM 1989; Ribbe et al. 1991)

of control. It resulted in the explosion of the reactor and the reactor building, as well as in a fire of the graphite moderator, which released large quantities of radioactive particles into the atmosphere, spreading over much of the western USSR and Europe. One of the first wind directions transported huge contaminated air masses into northern direction and deposited large quantities of radioactivity over the Baltic Sea and the riparian areas in Sweden and Finland. The contamination was very patchy, but the main fallout from this event was the central Baltic Sea and the southern Bothnian Sea. The typical nuclide pattern of this accident had an activity ratio of Cs-134/Cs-137 of 0.54, which provided the opportunity to discriminate this fallout from other sources. It was possible to follow the spreading of the marine contamination by the sea water currents over many years. Still now, the contamination level of Cs-137 has not yet reached the levels prior to 1986. The contamination distribution of the surface water of the Baltic Sea can be seen in Fig. 38.6.

Ocean currents and dilution in seawater have reduced and dispersed the initial contamination level and pattern as it also occurred for the dispersion from the discharges from the nuclear reprocessing plants at Sellafield and La Hague. Figures 38.7a–d show the evolution of the surface contamination of the North Sea, the Baltic Sea and the Norwegian and Barents Seas between the years 1976 and 1995. Picture (a) demonstrates the dominating input from the reprocessing plant at Sellafield with the highest contamination levels in the Irish Sea and its influence to the North Sea due to residual water transport by the prevailing ocean currents. Decrease of discharges from Sellafield after 1975 is reflected by decreasing concentrations in seawater during the following years. The fallout by the accident at Chernobyl can be clearly identified in the Baltic Sea with the hot spot in the southern Gulf of Bothnia. Even the run-off from highly contaminated land masses in Finland can be seen in this figure. Further reduction of Sellafield discharges lead also to lower concentrations in the Irish Sea and central North Sea. The last picture in part (d) shows the levels at the beginning of the 1990s with significantly reduced Cs-137 concentrations in European Seas. In the meantime, the levels in the North Sea are about the background level from the nuclear atmospheric tests in the sixties. The major source of Cs-137 contamination is historical levels in the sediments of the Irish Sea from the seventies.

There were some studies about other radionuclides like Tc-99 ($T_{1/2}$ = 210,000 years) and I-129 (16×10^6 years), i.e., two extremely long-lived radionuclides (Nies et al. 2010; Michel et al. 2012; Daraoui et al. 2016). These were mainly studied as water tracers for long distances. The radiological consequences are extremely low due to the low activity due to the extreme long half-lives.

The temporal evolution in seawater and the corresponding concentration of CS-137 in marine fish in the different regions of the Baltic Sea are given in Fig. 38.8 during the years 1984 to 2010. These data were compiled by HELCOM based on the monitoring data in the riparian states. In addition, a so called “target value” is given, which is based on the pre-Chernobyl values in the Baltic Sea. It can be expected that the levels will reach this value not before the year 2020. The residence time of water in the Baltic Sea is in the order of 25–30 years, which will finally decrease the initial concentrations quite slowly. Although the levels in seawater

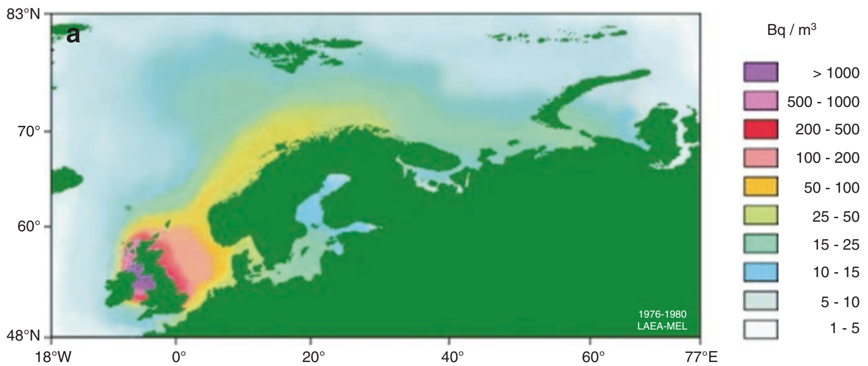


Fig. 38.7 Regional distribution of Cs-137 in surface water of the Irish, North and Baltic, Norwegian, and Barents Seas and its temporal evolution. (**a**) Compiled data 1976–1980; (**b**) Data 1981–1985; (**c**) Data 1986–1990; (**d**) Data 1991–1995 (Povinec et al. 2003; IAEA 2005).

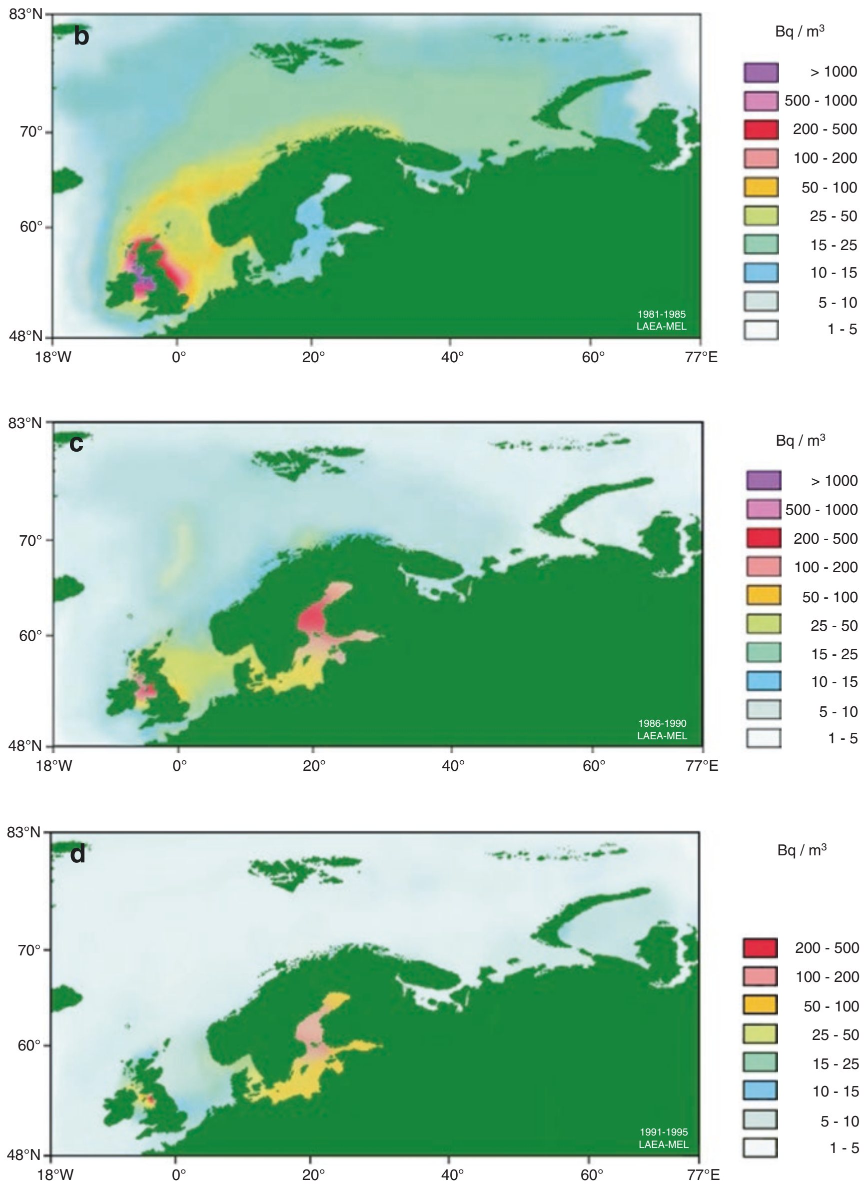


Fig. 38.7 (continued)

were relatively high with maximum surface concentrations of about 1000 Bq/m^3 during the first year, the levels in fish were rather moderate and mostly significantly below 100 Bq/kg fresh weight. For comparison, the residence time of water in the North Sea is in the order of 3 years, i.d. pollutants are much faster removed from water masses of the North Sea.

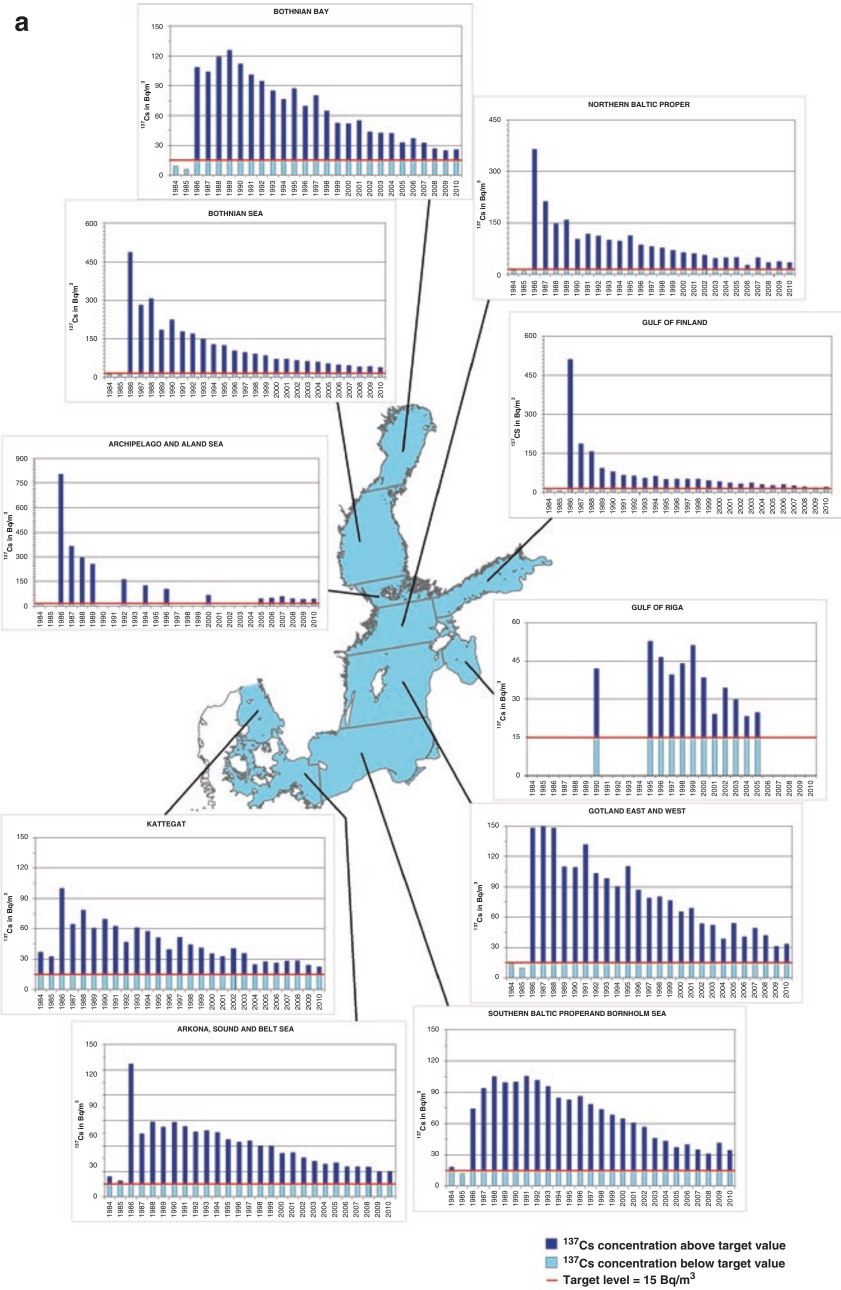


Fig. 38.8 *Left*: ^{137}Cs concentrations (Bq/m^3) in surface water (sampling depth < =10 m) in 1984–2010, as annual mean values by basin. Target values (15 Bq/m^3) have been calculated as the average of pre-Chernobyl (1984–1985) concentrations. *Right*: Annual average ^{137}Cs concentrations (Bq/kg wet weight) in herring muscle (fillets) in 1984–2010. Uncertainty has been indicated as bar lines. The target value (2.5 Bq/kg wet weight) has been calculated as average of the pre-Chernobyl (1984–1985) activity concentrations (HELCOM 2013).

Fig. 38.8 (continued)

The impact from the Chernobyl disaster in the Black Sea is lower compared to the Baltic Sea by the radionuclide Cs-137, because the initial deposition was relatively low. In contrast, the contamination by Sr-90 is higher, because this radionuclide was transported by the river system from the Dnepr into the Black Sea during the years after the accident. Compared to Cs-137, Sr-90 is by far less fixed to clay mineral particles on land with the consequence of higher river run-off of Cs-137 from the highly contaminated drainage area.

38.1.1.5 Contamination of the Pacific Ocean by the Fukushima Daiichi Nuclear Power Stations Accident in March 2011

Due to a catastrophic tsunami on 11 March 2011 as a consequence from a severe earthquake with the magnitude of 9.0 located about 130 km east of the Pacific Coast of the Japanese Island Honshu, about 16,000 people were killed and about 4000 people are stilling missing. The tsunami caused huge damage of the infrastructure and destruction of houses and property at the Japanese east coast. In addition, the reactors number 1–4 of the Nuclear Power Plant Fukushima Daiichi (FNPP 1) were heavily damaged due to total loss of electricity connection and black out. A catastrophic explosion of hydrogene and destruction of the buildings of reactors 1, 3 and 4 occurred during the following days. The reactors 5 and 6 of this site were not in operation during the tsunami and were not damaged. The crippled reactors 1–4 released large quantities of radioactive substances, both into the atmosphere and directly into coastal waters (Kobayashi et al. 2013). The marine environment was widely contaminated via the atmosphere and by direct discharge into coastal waters over a very long period. The airborne contamination was even detectable in North America and Europe. There are indications that releases into the atmosphere are still occurring in 2015 (Steinhauser et al. 2015).

There were a number of calculations about the total aqueous discharge from FDNPP 1 and the total inventory in the Pacific Ocean. The data varies between 3.5 and 27 PBq (=10^{15} Bq) for the discharge of Cs-137 and 15–16 Pb for the inventory in the Pacific Ocean both, from discharges between March 2011 and summer 2015 and atmospheric deposition from the aerial contamination during the first few weeks (Buesseler et al. 2017). The most reliable value for the discharges is estimated between 4 and 5 Pb for Cs-137. The activity ratio between Cs-134 and Cs-137 was about 1.0 in the initial phase, but the short half-life of Cs-134 of only 2 years leads to rapid decrease of the Cs-134 contribution.

For the marine environment, only the longer lived radionuclides Cs-134 and Cs-137 are of radiological importance. According to the prevailing ocean currents, the radiocesium was transported along the Kuroshio extension into eastern direction and was detected after about 4 years in Canadian and US waters, however, with extremely low concentration (Hirose 2016; Buesseler 2015; Smith et al. 2015; Aoyama 2015a, 2015b; Yu et al. 2015). Part of this contamination was also bound to suspended particulate matter and fixed into the sediments (Otosaka and Kato 2014), where it can easily been taken up by bottom dwelling organisms and accumulated in the food chain. This part is under continuous monitoring control from Japanese authorities in order to avoid any transfer to man and to exclude any border crossing exports of contaminated food including marine products. The contamination of marine food was intensively monitored, both in the vicinity of the prefecture Fukushima and Iwaki as well in remote areas far away from the source (Nakata and Sugisaki 2015).

38.1.2 Management Measures to Reduce the Potential Impact from Marine Radioactive Sources to the Population

The previous sections showed that there exists a wide range of radioactive sources in the world oceans. They are present as a result of authorized discharges, dumping, as well as from accidental releases. Management measures must aim at the reduction of potential harm to man and nature. With regards to dumping, a ban was established in 1993 within the framework of the *London Convention 1972*. Since then, radioactive wastes must be safely stored on land in deep geological disposal sites. Sub-Seabed disposal in the deep ocean sediment was once considered as one possible option in the 1980ties, but never implemented.

In the cases of all dumped highly radioactive material in the Kara Sea, lifting and recovery should be considered as an option, but funding of this partly risky and extremely expensive measure might be a major problem. Political pressure is also needed to initiate this process. However, regular monitoring is needed to ensure safe food production and fishery in the vicinity of the Barents Sea. Norway continuously pressures Russia politically to get as much information as possible and to be able to carry out independent monitoring and analyses of samples close to the objects.

Regular monitoring programmes are generally necessary at all locations and for all compartments, where radioactive contamination is likely to occur. This monitoring must cover seawater, sediments and biota. As one example, the results of the temporal trend of the contamination with Cs-137 in fish taken from the monitoring programme of Japan near the coast to Fukushima prefecture are shown in Fig. 38.9. Fishery activity for seafood production was immediately prohibited within a sector of 20 km around the Fukushima Daiichi site and all food was extremely carefully checked on any contamination from this accident. Of course, this extremely intensive monitoring activity in Japan covers all food produced in Japan and also any export is under strict control to ensure that no contaminated food will be found on the market and consumed by humans. It was interesting that the previous limit for food contamination of 600 Bq/kg Cs-137 or other beta emitting radionuclides was reduced by the Japanese government to only 100 Bq/kg Cs-134 + Cs-137 after the accident. This limit will ensure that no individual person will receive any dose which might be above the annual limit for the public of 0.1 mSv. These limits were derived from calculations based on consumption of food by a so called reference *person* with *average* consumption habits. However, the *average* consumption can be considered as relatively high values with the conse-

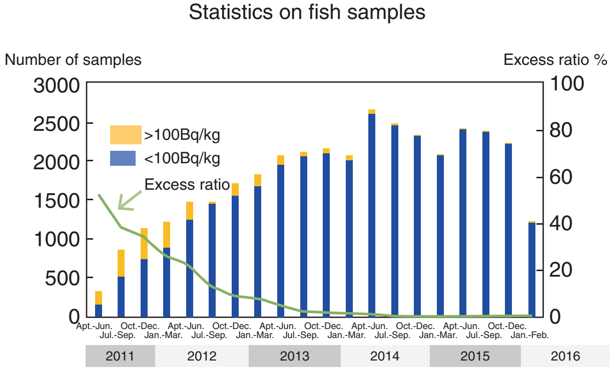


Fig. 38.9 Statistic on fish contamination since 2011 at the coast of Fukushima and Ibaraki. The rate of contamination beyond the given limit for consumption in Japan of 100 Bq/kg (fresh weight) Cs-134 + Cs-137 in fish decreased significantly over time (Fisheries Agency of Japan 2015; Nakata and Sugisaki 2015)

quence that the calculated dose tends to be mostly likely above the real radiation exposure. This is considered to be on the safe side or a conservative calculation. These limits are based on recommendations given by the International Commission on Radiological Protection (ICRP) and implemented by national laws and regulations. The legal contamination limit of 600 Bq/kg of Cs-134 + Cs-137 for food prior to the Fukushima Daiichi accident would even be on a safe side, but political pressure and the need to regain trust into political decisions have lead to this lower limit for food contamination.

38.2 Conclusions

Radioactive materials were introduced into the marine environment by a number of activities and accidents. For any kind of political or scientific management it is important to ensure that the food for human consumption must be controlled by regular and continuous monitoring programmes. In cases of higher contamination food must be removed from the market and limits for food contamination introduced. These limits are normally established in laws or regulations like the EURATOM Treaty of the European Union. However, in special cases, these limits could even be lowered due to political pressure or to regain trust from the population as it was decided by the Government in Japan after the Fukushima Daiichi nuclear catastrophe in March 2011.

The Northeast Atlantic Ocean with its shallow marginal seas (Irish Sea, North Sea, Baltic Sea, Barents Sea, and Kara Sea) can be considered to have received most of fallout and discharges from nuclear installations and lead to the most contaminated part of the World Ocean as far as Cs-137 is concerned. This input stems from all three major sources: global fallout, reprocessing, and Chernobyl accident in 1986.

Reductions of authorized discharges from the reprocessing plants at Sellafield and La Hague are responsible for very low levels of artificial radionuclides in these marine regions today. All these industrial activities show that the best option for reducing the marine pathway dose is the reduction of discharges into the marine environment.

The accident at Chernobyl has led to a significant increase of Cs-137 and Cs-134 levels primarily in the Baltic Sea, but any restrictions to fishery activities and consumption of seafood was never necessary. The concentrations in food were always within the authorized levels. The radiation exposure of the general population via food consumption due to the discharges or the Chernobyl fallout were significantly below 0.1 mSv per year and even critical groups like fisherman with high seafood consumption were within safe limits.

The accident at Fukushima has caused only partly levels of radioactivity in seafood which were not sufficiently safe for human consumption. An immediate ban on fishing activities in the vicinity of the prefecture Fukushima and Ibaraki was initiated in order to avoid any contaminated fish or other seafood for consumption. In addition, a strict control of potential food contamination by intensive monitoring programmes on all relevant radionuclides will ensure the safe limit for any food consumption to be below any harmful contamination. In any case of potential contamination, a carefully designed monitoring programme initiated by competent authorities is absolutely necessary to be. However, this is a demand by most national or international regulations, e.g., in the EURATOM treaty of the European Union. These regulations are based on the recommendations given by the International Commission on Radiological Protection (ICRP), which develops the basic principles for radiological protection for man and the environment.

References

Aarkrog A (2003) Input of anthropogenic radionuclides into the World Ocean. Deep Sea Res II 50:2597–2606

Aoyama M (2012) Oceans and seas. In: Atwood DA (ed) Radionuclides in the environment. Wiley & Sons, Ltd., Chichester, pp 339–345

Aoyama M (2015a) ^{134}Cs and ^{137}Cs in the North Pacific Ocean derived from the March 2011 TEPCO Fukushima Dai-ichi nuclear power plant accident, Japan. Part one: surface pathway and vertical distributions. J Oceanogr 72:53. doi:10.1007/s10872-015-0335-z

Aoyama M (2015b) ^{134}Cs and ^{137}Cs in the North Pacific Ocean derived from the March 2011 TEPCO Fukushima Dai-ichi nuclear power plant accident, Japan. Part two: estimation of ^{134}Cs and ^{137}Cs inventories in the North Pacific Ocean. J Oceanogr 72(1):67–76. doi:10.1007/s10872-015-0332-2

Buesseler K (2015) Tracking the fate of particle associated Fukushima Dai-ichi Caesium in the ocean off Japan. Environ Sci Technol 49:9807–9816

Buesseler K, Dai M, Aoyama M, Benitez-Nelson C, Charmasson S, Higley K, Maderich V, Masqué P, Oughton D, Smith JN (2017) Fukushima Daiichi–derived radionuclides in the ocean: transport, fate, and impacts. Ann Rev Mar Sci 9:173–203

Daraoui A, Tosch L, Gorny M, Michel R, Goroncy I, Herrmann J, Nies H, Synal H-A, Alfimov V, Walther C (2016) Iodine-129, Iodine-127 and cesium-137 in seawater from the North Sea and the Baltic Sea. J Environ Radioact 162-163:289–299

Fisheries Agency of Japan (2015) Report on the monitoring of radionuclides in fishery products (March 2011–January 2015). www.jfa.maff.go.jp/e/inspection/pdf/report_on_the_monitoring_of_radionuclides_in_fishery_products.pdf. Accessed 26 Oct 2016

Gwynn JP, Nikitin A, Shershakov V, Heldal HE, Lind B, Teien H-C, Lind OC, Sidhu RS, Bakke G, Kazennov A, Grishin D, Fedorova A, Blinova O, Sværen I, Liebig PL, Salbu B, Wendell CC, Strålberg E, Valetova N, Petrenko G, Katrich I, Logoyda I, Osvath I, Levy I, Bartocci J, Khanh Pham M, Sam A, Nies H, Rudjord AL (2016) Main results of the 2012 joint Norwegiane Russian expedition to the dumping sites of the nuclear submarine K-27 and solid radioactive waste in Stepovogo Fjord, Novaya Zemlya. J Environ Radioact 151:417–426

HELCOM (1989) Three years observations of the levels of some radionuclides in the Baltic Sea after the Chernobyl accident. Baltic Sea environment proceedings, No. 31. Helsinki: Baltic environment protection commission – Helsinki commission

HELCOM (2013) Thematic assessment of long-term changes in radioactivity in the Baltic Sea, 2007-2010. Baltic Sea environment proceedings, No. 135. Helsinki: Baltic environment protection commission – Helsinki commission

Hirose K (2016) Current trends of ^{137}Cs concentrations in coastal waters near the Fukushima Daiichi NPP. J Radioanal Nucl Chem 307:1699–1702. doi:10.1007/s10967-015-4537-z

IAEA (1998) Radiological conditions of the Western Kara Sea: Assessment of the radiological impact of the dumping of radioactive waste in the Arctic Seas. In: Report in the international artic seas assessment project (IASAP). International Atomic Energy Agency, Vienna

IAEA (2005) Worldwide marine radioactivity studies (WOMARS): radionuclide levels in oceans and seas. IAEA, Vienna

IAEA (2015) Inventory of radioactive material resulting from historical dumping, accidents and losses at sea: for the purposes of the London convention 1972 and London protocol 1996, IAEA-TECDOC-1776. IAEA, Vienna

Kershaw P (2010) Atlantic ocean. In: Atwood DA (ed) Radionuclides in the environment. Wiley & Sons, Ltd., Chichester, pp 361–373

Kobayashi T, Nagai H, Chino M, Kawamura H (2013) Source term estimation of atmospheric release due to the Fukushima Dai-ichi nuclear power plant accident by atmospheric and oceanic dispersion simulations. J Nucl Sci Technol 50:255–264

Michel R, Daraoui A, Gorny M, Jakob D, Sachse R, Tosch L, Nies H (2012) ^{129}I and ^{127}I in European seawaters and in precipitation from Northern Germany. Sci Total Environ 419:151–169

Nakata K, Sugisaki H (eds) (2015) Impacts of the Fukushima nuclear accident on fish and fishing grounds. Springer, Tokyo

Nies H, Obrikat D, Herrmann J (2000) Recent radionuclide concentrations in the North Sea as a result of discharges from nuclear installations. Kerntechnik 65:195–200

Nies H, Goroncy I, Hermann J, Michel R, Daraoui A et al. (2010) Kartierung von 99Tc, 129I und 127I im Oberflächenwasser der Nordsee: Abschlussbericht zum Forschungsvorhaben StSch 4881. Schriftenreihe Reaktorsicherheit und Strahlenschutz

OSPAR Commission (2015) Liquid discharges from nuclear installations, 2013. OSPAR Commission, London

Otosaka S, Kato Y (2014) Radiocesium derived from the Fukushima Daiichi nuclear power plant accident in seabed sediments: initial deposition and inventories. Environ Sci Process Impacts 16:978–990

Povinec PP, Bailly du Bois P, Kershaw PJ, Nies H, Scotto P (2003) Temporal and spatial trends in the distribution of ^{137}Cs in surface waters of Northern European Seas: a record of 40 years of investigations. Deep Sea Res II 50:2785–2801

Ribbe J, Müller-Navarra SH, Nies H (1991) A one-dimensional dispersion model for radionuclides in the marine environment applied to the Chernobyl fallout over the Northern Baltic Sea. J Environ Radioact 14:55–72. doi:10.1016/0265-931X(91)90015-8

Smith JN, Brown RM, Williams WJ, Robert M, Nelson R, Moran SB (2015) Arrival of the Fukushima radioactivity plume in North American continental waters. Proc Natl Acad Sci U S A 112:1310–1315

Steinhauser G, Niisoe T, Harada KH, Shozugawa K, Schneider S, Synal H-A, Walther C, Christl M, Nanba K, Ishikawa H, Koizumi A (2015) Post-accident sporadic releases of airborne radionuclides from the Fukushima Daiichi nuclear power plant site. Environ Sci Technol 49:14028–14035

Trapeznikov AV, Pozolotina VN, Chebotina MY, Chukanov VN, Trapeznikova VN, Kulikov NV, Nielsen SP, Aarkrog A (1993) Radioactive contamination of the Techa River, the Urals. Health Phys 65:481–488

UNSCEAR (2000) United Nations scientific committee on the effects of ionizing radiation: sources and effects of ionizing radiation. UN, New York

Yablokov AV, Karasev BK, Rumyantsev VM, Kokeyev ME, Petrov OI, Lystsov BN, Yemelyanenkov AF, Rubtsov PM (1993) "White book". Facts and problems related to radioactive waste disposal in seas adjacent to the territory of the Russian Federation on, Office of the President of the Russian Federation. Small World Publisher, Moscow

Yang X, North R, Romney C, Richards PG (2000) Worldwide nuclear explosions. CMR technical report, CMR-00/16, third revision 2000

Yu W, He J, Lin W, Li Y, Men W, Wang F, Huang J (2015) Distribution and risk assessment of radionuclides released by Fukushima nuclear accident at the northwest Pacific. J Environ Radioact 142:54–61

Chapter 39
Waste/Litter and Sewage Management

Aleke Stöfen-O'Brien and Stefanie Werner

Abstract Marine litter is seen as one of the most threatening types of pollution to our marine ecosystems. Recently, this issue has been gaining increasing recognition in international and regional fora, as exemplified by the resolution on marine debris adopted by the first United Nations Environmental Assembly in 2014. The reasons for this are the persistence of marine litter that might last for centuries in the oceans as well as its potential to cause harm to the marine environment, marine animals, society at large and potentially also human health. Whereas the potential impacts of marine litter are broadly identified, the management approaches to address this issue have been almost exclusively targeted towards specific sources of marine litter. The different approaches towards land or sea-based sources of marine litter have their limitations with regard to interconnected and cumulative character of marine litter or unknown or as of yet underestimated sources of marine litter. In order to provide comprehensive and coordinated approaches to overcome these challenges, regional actions plans on marine litter have been developed. These constitute a paradigm shift in marine litter management as they propose actions targeted at diverse sources of marine litter and address knowledge gaps with regard to these sources and the impacts of litter while being framed by common principles and approaches. The challenge remains to use the current political momentum to effectively implement and develop the envisaged measures on a national and regional basis.

Keywords Marine litter management • Regional action plans on marine litter • Solutions to marine pollution • Sea-based sources of marine litter • Land-based sources of marine litter • Diffuse sources of marine litter

A. Stöfen-O'Brien (✉) • S. Werner
German Environment Agency, Dessau-Roßlau, Germany
e-mail: Aleke.stoefenobrien@uba.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_39

39.1 Introduction

Marine litter is currently ranked as one of the largest threats to marine ecosystems. This stems from its longevity and also its impact on the marine environment and potentially also human health. Even though knowledge of the exact amount of marine litter entering our oceans is incomplete, it is recognized as a problem by the international community, which has recently started to act to undertake actions to address this issue. The dedication of the first United Nations Environmental Assembly resolution in 2014 to marine litter as well as recent efforts on a global, regional and national level stand testimony to the urgency of this issue. However, as the impacts of marine litter have been known and monitored for several decades, these endeavours do not stand in isolation, but are complementary to existing institutional and regulatory work that addresses various aspects of the problem. Due to the many potential sources of marine litter, both from land as well from the sea, these measures need to involve governments and a broad range of stakeholders, including international and regional organisations, industry, non-governmental organisations (NGOs), as well as the general public. In the following, various regulatory and policy measures relating both to land as well as sea-based sources are presented with a view to illustrate and evaluate the current management approaches and the specific involvement of stakeholders. The chapter attempts to identify the limitations and challenges of these approaches as well as foresee future developments.

39.2 Marine Litter: Facts and Management Requirements

It has been estimated that in 2010 alone, 4.8–12.7 million metric tons of marine litter entered the oceans (Jambeck et al. 2015). The sources of marine litter are manifold and some not yet entirely known. Globally, it is estimated that the dominant sources of marine litter are land-based. Nevertheless, sources vary greatly, e.g., for Europe depending on the region (see also Chap. 23). Known land-based sources of marine litter include inadequate waste and sewage management systems, tourism and urban littering combined with land run-off after floods or severe weather conditions.

Various uses of the oceans may intentionally or unintentionally lead to the introduction of marine litter. These include, inter alia, shipping, dumping, industrial activities such as oil and gas production, and also recreational activities. Fisheries and aquaculture are, in some regions, major sources of marine litter and contribute to litter pollution by accidental loss or intentional dumping of fishing gear, loss of ancillary items (such as gloves, fish boxes etc.), galley waste and release of fibres (UNEP 2016).

However, the specific role and knowledge of the potential to cause marine litter pollution from these sources differs immensely from region to region and impacts from certain potential sources, such as dumping or offshore activities, are only marginally studied or understood.

Another key reason for the extent of the problem and therefore the necessity to act, is the extreme longevity of especially plastic litter in the oceans: once marine litter has been introduced in the marine environment, it takes centuries to disintegrate, due to the specific material characteristics of plastic (see Chap. 23).

Besides its aesthetic impact, it is also known to cause harm to marine organisms, the environment and also potentially human beings (Thompson et al. 2009, for further reference Chap. 23). Marine litter is taken up by marine organisms that often cannot excrete the pieces of litter they have swallowed. Marine organisms also become entangled in lost, abandoned or discarded fishing gear, also widely referred to as "ghost nets," and other litter items, e.g., originating from packaging that in many cases lead to severe injuries or death of the marine organisms.

Both the diverse impacts and persistence of marine litter make it an intra- and inter-generational issue. The plastic that has already entered and is currently entering our oceans will impact generations to come.

Knowledge about the input vectors and sources of marine litter is an essential prerequisite for taking adequate and effective management measures. With a view to the adverse consequences of marine litter in the marine environment, an effective management regime needs first and foremost to address the prevention of marine litter pollution at source. However, taking effective management measures of marine litter is impeded by incomplete knowledge on the multiple potential sources and activities that may lead to its introduction. This makes the application of precautionary and integrated approaches to the issues essential.

Marine litter management efforts can broadly be categorised into measures addressing either land- or sea-based sources. This distinction is also justified by the existence of different jurisdictional regimes including rights and obligations applicable to marine litter sources from land-based and sea-based pollution. Addressing solutions to marine litter sector by sector alone, i.e., without understanding their contexts, does not adequately reflect the complex causal relationship between the many different and diffuse sources (known and unknown). In addition, in an assessment of management approaches, factors beyond the geographical categorisation need to be considered. These include aspects such as weather conditions, (waste management) infrastructure and also the awareness and behaviour of individuals (Ryan et al. 2009). Moreover, the management approaches with regards to marine litter need to integrate a broad range of actors including governments, international and regional organisations, industry and NGOs as well as citizens, who all play an important part in addressing the issue.

Due to its persistency and the further disintegration process within the marine environment, marine litter as such is not an acute environmental catastrophe. Rather it is a long-term and latent problem that has the potential to become acute if we do not act to prevent its introduction. Therefore, an effective protection regime addressing its introduction into the sea does not necessarily address specific singular incidences or processes, but must, in a comprehensive way, address the different relevant stakeholders and sources.

The management approach of marine litter is framed by different international and regional agreements and legal frameworks that provide a more or less broad set of rules and obligations for marine litter management. The United Nations Convention of the Law of the Sea (UNCLOS) provides the overall framework of rights and obligations for States. These legal obligations are complemented by internationally agreed targets and policies that will guide and focus the management measures to address marine litter pollution. One central objective is the Sustainable Development Goal 14 on Oceans which was adopted in 2015 by the UN General Assembly. It envisages, in target 14.1., that States should, "by 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution" (UN General Assembly 2015). Even though this target refers mainly to land-based sources of marine litter, it will act as a compass in the development of international, regional and national measures to address this issue in the coming years.

39.3 Sectoral Approaches to Address Different Sources of Marine Litter

Even though the UNCLOS provides an overarching framework with regard to marine pollution, the management strategies relating to marine litter have been almost exclusively limited to sectoral approaches. Whereas these approaches target specific known point sources of marine litter resulting from certain activities, they fail to address diffuse sources or as of yet unknown sources in a comprehensive manner.

Two international agreements indicated a certain level of awareness among decision-makers of the impacts of plastic and waste on the marine environment at an early stage. This relates firstly to the adoption of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and other matter from 1972 under which plastic, may, in principle, not be dumped, and secondly to Annex V of the International Convention for the Prevention of Pollution from Ships from 1973/78. Despite these efforts, it has been very difficult to assess the effectiveness of these measures in preventing the introduction of marine litter to the marine environment. The effectiveness of measures can only be measured through targeted monitoring within the marine environment. However, a wide-scale coherent and systematic monitoring is, to this day, only being developed in the context of the EU's implementation of the Marine Strategy Framework Directive (MSFD) (see for further reference Chap. 23).

39.3.1 Management Strategies to Address Sea-Based Sources of Marine Litter

In the following section, different sectoral management options addressing the issue of marine litter will be presented and their specific approaches highlighted. It aims to reflect upon the specific regulatory techniques that are relevant to specific sources of marine litter and their challenges in preventing its introduction.

39.3.1.1 Shipping

Shipping, as a commercial maritime activity, covers a broad range of functions, such as transport of goods (merchant shipping) or people (ferries or cruise shipping). Pollution from this source could either be accidental, intentional or operational. The central international agreement relating to shipping as a potential source of marine litter is the International Convention for the Prevention of Pollution from Ships, as modified by the Protocol of 1978 (MARPOL) administered by the International Maritime Organisation (IMO). MARPOL aims to prevent the pollution of the marine environment by the discharge of harmful substances or effluents containing such substances (Art. 1 MARPOL). The Convention covers both accidental and operational pollution from vessels and has developed a specific instrument in the remit of its scope that explicitly addresses the issue of marine litter from vessels. This is done in the form of an Annex on pollution by garbage from ships (MARPOL Annex V), which forms an integral part of the Protocol. Even though it is an "optional annex," meaning that States may opt not to be bound by it, it currently has 151 Contracting Parties representing 98.32% of the world tonnage (IMO 2016a). MARPOL Annex V was amended in 2011 and entered into force on 1 January 2013. These amendments are important with regard to marine litter and have improved the protection standard significantly.

MARPOL Annex V's protection standards are developed through four fundamental elements that address the disposal of garbage by ships. These are the discharge standards of garbage by ships, the reception facilities of ship waste in ports, operational obligations such as keeping a garbage record book, and port state control. MARPOL Annex V stipulates a general discharge prohibition that varies depending on the discharge location and type of waste. It thus applies an area-based management approach in which a distinction is made between areas outside of or within so-called Special Areas. Currently, around Europe, the Mediterranean Sea, the Baltic Sea, the North Sea and the Black Sea are Special Areas in accordance with MARPOL Annex V. However, the Special Area requirement has not taken effect in the Black Sea because of lack of notification on the existence of adequate reception facilities (IMO 2016a). In these Special Areas more restrictive discharge standards apply and adequate port reception facilities along the coast for the disposal of the on-board generated waste must be provided. Port reception facilities and the cost recovery system for disposed on-board generated waste are important disincentives for illegal discharge at sea (Sherrington et al. 2016). Even though the provision of port reception facilities plays an important role with regards to enforcing strict discharge standards, the issue has been subject to contentious debates among Contracting Parties of the Protocol. One aspect, among several raised issues, is the concern that the costs for ship operators related with the use of reception facilities may impact the port's competitiveness on a global market (Tan 2006).

The issue of port reception facilities has been addressed under the applicable regional seas convention to the Baltic Sea, i.e., the Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) of 08 April 1992. Contracting Parties are obliged to develop and apply uniform requirements for the provision of reception facilities for ship-generated wastes (Art. 8 (2) Helsinki Convention). The work that has been pursued in this regard has led to the development of a specific cost recovery system for the discharge of waste from vessels with the aim to prevent operational and illegal discharges of waste into the sea. The so-called "no-special-fee-system" establishes an indirect charging system where the cost of reception, handling and disposal of ship-generated waste is included in the harbour fee or otherwise charged to the ship irrespective of whether wastes are delivered to the harbour or not (HELCOM 2007). The fundamental idea of the "no-special-fee-system" is that no additional costs are imposed on the ship using the port reception facilities, thereby removing incentives to illegally discharge on-board generated waste in order to reduce the costs of waste disposal. In order to eliminate competition among ports, the Helsinki Convention regime envisages a harmonised application of cost recovery systems among ports of the Baltic Sea and in the North Sea region (HELCOM 2007). Notwithstanding its legally non-binding nature, the concept of the no-special fee system has found entrance in different other fora, including one on proposals to amend relevant legislation in the European Union.

39.3.1.2 Fisheries and Aquaculture

Fisheries and aquaculture are also sources of marine litter and contribute to the pollution by loss of fishing gear, loss of ancillary items, galley waste and release of fibres (UNEP 2016). Fishing gear may become marine litter through its loss, disposal or abandonment. This so-called abandoned, lost or otherwise discarded fishing gear (ALDFG) is addressed through different management approaches. Since 1991, United Nations General Assembly (UNGA) resolutions have explicitly recognized problems resulting from ADLFG, particular in the context of large-scale pelagic drift-net fishing, and requested States to act on this aspect (UNGA 1991, 2004, 2014). The Code of Conduct for Responsible Fisheries of the Food and Agricultural Organisation (FAO) stipulates a set of obligations that are directly relevant to this issue. It encourages the cooperation among States to develop the application of technologies and materials that aim to reduce the loss of fishing gear (Art. 8.4.6). Furthermore, the relevant provisions under MARPOL Annex V with regard to the disposal and return of used fishing gear, is also highly relevant in this regard. MARPOL Annex V prohibits the disposal into the sea of all types of plastic including fishing gear and lines. Fishing vessel operators are required to report accidentally lost or discharged fishing gear in the Garbage Record Book or Ship's log and to report such loss or discharge to the flag State and where appropriate to the coastal State in whose jurisdiction the loss of fishing gear occurred.[1]

In the regional seas agreements, the aspect of accidentally lost or discharged fishing gear complements the work undertaken on a global level and has also been further substantiated. The Helsinki Convention also includes the return of fishing gear in their "no-special-fee-system," so as to create incentives for their disposal on land.

[1] Regulation 7 in conjunction with Regulation 10 MARPOL Annex V.

Furthermore, Regional Fisheries Management Organisations have been active on this issue. Among others, some have proposed a spatial management scheme at sea to separate fishing activities from other maritime activities so as to avoid conflicts with fishing gear that might lead to their loss. Also, the North East Atlantic Fisheries Commission, for example, has addressed the issue by prohibiting the deployment of gillnets, entangling nets or trammel nets in waters deeper than 200 m (FAO 2009).

39.3.2 Addressing Land-Based Sources of Marine Litter

Addressing land-based sources necessitates a diverse set of measures that differ from those adequate for sea-based sources. In addition, a different set of actors represents the diverse land-based sources that generate marine litter. On a global level, no legally binding agreement exists that comprehensively addresses the issue of land-based pollution of the marine environment (Trouwborst 2011). UNCLOS only provides certain broad obligations and rights of States to prevent marine pollution from land-based sources on a global level (Stöfen-O'Brien 2015). The issue of land-based pollution is further substantiated in regional seas agreements such as, amongst others, the OSPAR Convention, the Helsinki Convention or the European Union.

39.3.2.1 Waste Management

Waste Management relates to waste disposal or recycling measures, which are both boon and bane of the marine litter problem. Waste management of municipal and industrial waste not only plays an important role in addressing the issue of marine litter, it is also an important economic sector which is therefore intertwined with economic interests. As an example, in the European Union, the Waste Framework Directive (Directive, 2008/38/EC, WFD) forms the fundamental framework for all aspects relating to waste management. It establishes a waste hierarchy with an order of preference for prevention, preparing for re-use recycling, energy recovery, and finally disposal (Art. 4 (1) WFD). The understanding of what is meant by waste (Art.3 (1) WFD) in the Waste Framework Directive is broad, which underlines the broad protection standard of this instrument (Stöfen-O'Brien 2015). This is coupled with the ambitious aim of the WFD to protect the environment and also human health from adverse impacts resulting from the generation and management of waste. The WFD forms the fundamental framework against which new initiatives such as a ban of plastic bags or increased recycling targets are to be measured. In a recent judgement, the Court of Justice of the European Union (CJEU) had to judge whether an illegal landfill in a marine park established to protect the loggerhead turtle (*caretta caretta*), a species protected under the EU's Habitat Directive, was infringing the high protection standards established by the Waste Framework Directive and the Habitat Directive. The CJEU ruled that the illegal landfilling, resulting in increased marine litter in the surrounding waters, constitutes a disturbance to the turtle population but was also in breach with the protection standards of the Waste Framework Directive (CJEU 2014). This example illustrates that even though a wide array of measures and fundamental principles are already in place, the lack of their enforcement and implementation also pose a challenge to the effective prevention of marine litter.

The Regional Action Plans on marine litter in the Baltic Sea and North-East Atlantic (see for further reference Sect. 4 of this chapter) encourage, amongst others, the implementation and any future revision of relevant EU Directives and the potential inclusion of marine considerations into National Waste Prevention Plans and Waste Management Plans.

39.3.2.2 Sustainable Production and Consumption

Whereas waste management and subsequent legislation, such as those relating to landfilling activities or waste packaging, are important parameters in regulating ongoing waste disposal activities, it is fundamental to address structural underlying issues as well as their economic, social and environmental costs that may contribute to marine litter. Some of the fundamental structural issues of marine litter are the production and consumption of those materials that might lead to marine litter, which is closely related to resource efficiency and the circular economy. This approach underlines that the resources that are being used to create products or waste could be used in a more sustainable way. Measures to support this are to promote the re-evaluation of plastic waste as a resource and to encourage green engineering principles and frameworks as well as eco-design and eco-labelling. Additionally, to support the circular economy measures need to be put in place to promote the life cycle approach to plastic products, including the application of the extended producer responsibility to cover the entire life-cycle of a product of items that frequently end up in the marine environment. Part of this is to encourage producers to improve the lifespan of products and internalize the environmental and social costs of products (UNEP 2016).

The promotion of life-cycle thinking among producers includes not only the consideration of the intended use of the product, but also its disposal, its re-use, and recycling. Different mechanisms have been or are being developed, these include, amongst others, the use of market mechanisms to reduce waste being disposed. In 2015 the European Commission proposed a circular economy package that aims for a common EU target for recycling 65% of municipal waste by 2030, a common EU target for recycling 75% of packaging waste by 2030 and a ban on landfilling of separately collected waste (European Commission 2015).

However, merely addressing and involving producers is not sufficient in following structural issues of marine litter. In order to strengthen and encourage sustainable consumption and the involvement of consumers, several initiatives have been launched. These not only aim to reduce the potential amount of waste entering the sea, but also aim to raise awareness among the broader public and encourage public participation in addressing the issue of marine litter through personal action, either

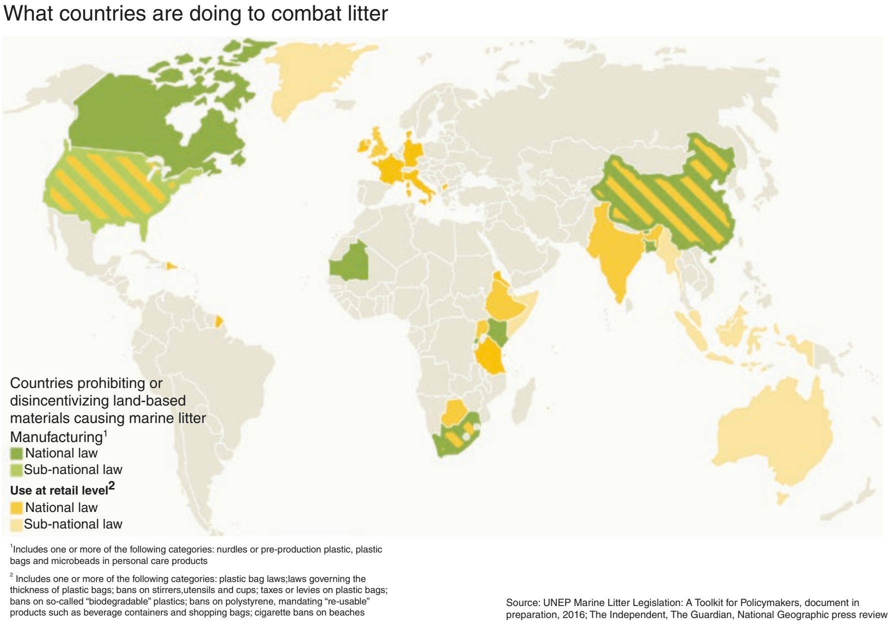


Fig. 39.1 National bans and disincentives to combat marine litter (Source: GRID-Arendal and Maphoto/Riccardo Pravettoni)

through clean-up activities and responsible decisions when consuming and buying products. An example of this is the concept of *citizen science* in which citizens are encouraged to monitor the pollution load on beaches for example and thereby instilling a sense of responsibility for the protection of the marine environment (UNEP 2016). Public awareness and stakeholder participation are fundamental aspects in creating ownership of measures among the broader public and in encouraging stakeholders, including local communities and industries, to integrate marine litter reduction measures into their activities and plans (Fig. 39.1).

39.4 Integrated Approaches to Marine Litter

With regard to the above outlined and briefly discussed management measures, it becomes clear that these mainly relate to sectoral contexts that result in a fragmented understanding and approach to the management of marine litter pollution. Also, the marine litter pollution load has not been significantly reduced following the introduction of sectoral measures and the effectiveness in preventing marine litter from land- and sea-based sources is highly limited, due, for example, to incomplete implementation and enforcement as well as regulatory gaps. Marine litter is a complex scientific and societal challenge that necessitates moving away from traditional and sectoral regulatory schemes in order to encompass its complex sources and impacts. The role of integrated management approaches that cover a diverse range of sources, activities, actors and regulatory levels is a prerequisite. It also serves as a means of cooperation of seemingly unrelated aspects of marine litter sources that, in this way, can be harmonized.

In recent years, Regional Seas Conventions have used their broad competences to protect the marine environment by developing action plans on marine litter which aim to address the issue in a holistic and encompassing way. Even though they have diverging competences and capacity to develop and adopt specific measures aimed to address marine litter, they serve as a common denominator for countries with different socio-economic statuses and political association to develop common marine environmental protection standards (Stöfen-O'Brien 2015).

These action plans are vehicles for the pursuance of integrated approaches in a regional context. They pursue an ecosystem approach and support issues such as public participation and awareness among stakeholders. In their framework, common indicators are being developed that serve as guidance for the prioritization of targeted and specific interventions (see also Chap. 23). Two of these will be presented in the following.

39.4.1 Regional Action Plan on Marine Litter in the Baltic Sea

The Regional Action Plan on Marine Litter for the Baltic Sea (HELCOM RAP ML) was adopted in 2015. It provides regional and national actions, the latter serving as voluntary actions aiming at information exchange between Contracting Parties (HELCOM HOD 2015). Both the regional actions as well as the voluntary national actions are clustered around three approaches: (1) actions addressing land-based sources, (2) actions on sea-based sources and (3) actions addressing education and awareness. Removal actions are treated as an integrated part of the land- and sea-based sources. The Annex outlines regional actions which require a joint approach by Contracting Parties followed by a lead-country approach and are of a large-scale, widespread and transboundary character. The joint approaches to address these actions are not only limited to actors within the Baltic Sea region, but also refer to the cooperation with other organisations such as the European Union or IMO, depending on whether the subject matter in question lies within their competences (e.g., port reception facilities). The collective actions addressing land-based sources of marine litter include measures on generally improved waste prevention and management, measures to tackle "top items" such as microplastics and plastic bags, measures to seek coordination with third parties such as River Basin Commissions[2]

[2] River Basin Commissions provide the institutional framework to promote regional cooperation at a river basin level. The River Basin Commission for the river Elbe, for example, is the International Commission for the Protection of the Elbe River with a Secretariat in Magdeburg, Germany. Similar organisations are established for the rivers Danube, Moselle or Rhine for example.

as well as remediation and removal actions. Some of the measures are based on existing guidance or recommendations that are adopted within HELCOM, and which are to be developed within a specific time frame.[3] A second set of collective measures addresses actions regarding sea-based sources of marine litter, including actions on shipping related waste such as waste delivery in ports and actions on waste resulting from fisheries and aquaculture. Thirdly, the regional measures regarding education and awareness envisage, amongst others, a communication strategy on the HELCOM RAP ML.

The voluntary national actions are actions that can be selected by the Contracting Parties for voluntary implementation. Proposed measures are to promote extended producer responsibility by requiring producers and manufacturers to take responsibility for the entire life cycle of a product or to promote the enforcement of MARPOL Annex V.

The diverse range of actions and specifications exemplifies the ambitious scope of HELCOM RAP ML. The implementation framework of the Action Plan is also strengthened by a reporting format on implemented actions, a reporting format on the effectiveness of the implemented actions, as well as a list of definitions of terms for the purpose of the Recommendation. However, the implementation of the Action Plan including the development of corresponding measures has been delayed because adequate working structures to deal with the issue of marine litter within HELCOM are only now being established.

39.4.2 The OSPAR Regional Action Plan on Marine Litter

The OSPAR Regional Action Plan on Marine Litter for the Northeast-Atlantic (OSPAR RAP ML) was adopted as an Agreement during OSPAR 2014 in Cascais, Portugal, the implementation is coordinated by the OSPAR Intersessional Correspondence Group on Marine Litter (ICG ML). An Agreement is a legally non-binding instrument under the OSPAR Convention. The OSPAR RAP ML is designed as a flexible tool providing a set of actions to address marine litter. The OSPAR RAP ML and its Implementation Plan aim to deliver, amongst others, measures on specific sources of marine litter that are of particular concern in different OSPAR regions or the entire OSPAR maritime region. Once the concrete measures to these actions have been developed in detail through a lead-country approach, they will be adopted as further agreements, recommendations or decision, the latter fully legally binding.

[3] This relates amongst others to produce by 2020 a regional-wide map on landfills and dumpsites including historic ones which may eventually pose a risk to the marine environment. Other measures include to coordinate and share information among HELCOM Contracting Parties on the consumption of plastic bags on an annual basis by 2018 as well as to establish by 2019 a reduction target of plastic bags, taking into account the measures which are implemented nationally.

The OSPAR RAP ML has four sections that comprehensively address the issue of marine litter. Section I addresses the objectives, scope and principles of the Action Plan. One of the main objectives is to prevent and reduce marine litter pollution in the North-East Atlantic and its impacts on marine organisms, habitats, public health and safety. The OSPAR RAP ML is directed by guiding principles, amongst others, the precautionary and polluter-pays-principle, as well as the ecosystem approach. These also highlight the importance of cross-sectoral cooperation. Section II addresses the action items of the OSPAR RAP ML. The OSPAR RAP ML is split into two sections; one defining the actions that require collective activities and implementation and one with national voluntary actions, which solely aim at information exchange. The first category includes issues that also fall under the competence of other international organisations and competent authorities, but require concerted supporting input by OSPAR Contracting Parties. In these, four themes are identified: (1) actions that combat sea-based and (2) land-based sources of marine litter, (3) actions for marine litter removal as well as (4) actions for education and outreach on the topic (for an overview on the action fields addressed in the OSPAR RAP ML see Chap. 23).

Section III addresses monitoring and assessment in which reference is made to the marine litter monitoring scheme that is established under the OSPAR Convention. This section also outlines how marine litter will be integrated in OSPAR's major assessment mechanisms. Section IV stipulates the implementation and reporting mechanisms of the OSPAR RAP ML. The implementation period of the Action Plan is from 2014 to 2021, after which it shall be reviewed and updated. The Implementation Plan of OSPAR RAP ML is outlined in Annex I and Contracting Parties will use the implementation reporting process to update OSPAR on their national implementation progress. Annex I on the OSPAR RAP ML Implementation Plan outlines a differentiated table in which the actions listed in the OSPAR RAP ML are outlined and the specific type of OSPAR measures are or will be described. In this regard, the implementation and substantiation of the action items could lead to legally binding measures in form of decisions. For each measure, it is envisaged to determine a lead party or parties and to agree on a target year for developing the measure or implementing the actions.

The implementation of these Action Plans is ongoing and some actions have already been taken. With regard to shipping, for example, the OSPAR RAP ML stipulates to ensure regional coordination on the implementation of EU Directive 2000/59/EC on port reception facilities for ship-generated waste (PRF-Directive) in relation to MARPOL Annex V. The Intersessional Correspondance Group on Marine Litter (ICG-ML), as part of the OSPAR institutional framework, is supporting the review process of the PRF-Directive with the aim of establishing a cost recovery system which ensures that a maximum amount of onboard generated waste of MARPOL Annex V is delivered to port reception facilities. With a view to fisheries-related actions, so-called green deals are being developed together with the fishing industry and Fishing for Litter schemes are applied widely. Besides the different regulatory measures and actions that are being implemented on the global, regional and national level, there are several private and non-profit initiatives that are being implemented, some of which are also taken up in the framework of regional action plans on marine litter. Through setting up a dialogue with the cosmetics industry, OSPAR strengthened ongoing work by NGOs and some Contracting Parties aiming at the phasing-out of the use of microplastics in cosmetic and personal care products. This was followed by a recommendation issued by Cosmetics Europe to their member companies to eliminate the use of microplastics in personal care products (Cosmetics Europe 2015). This voluntary approach has now to be supported with reliable data on reductions achieved. A report by the German NGO "BUND" came to the conclusion that the use of microplastics in personal care products between 2014 and 2016 has only been in a few cases reduced, despite voluntary reduction targets (Codecheck/BUND 2016). If the recommendation should prove not to be sufficient, OSPAR is prepared to urge the EU and its member states to introduce appropriate measures to achieve a 100% phasing out of microplastic in cosmetic products. In addition, OSPAR has set in place additional evaluation products and processes that serve, among others, to understand how the impact of microplastics on the marine environment may be reduced. Actions on waste management will be carried out, amongst others, in close cooperation with the plastics industry trade associations that jointly call for full implementation of landfill bans throughout Europe by 2020, in line with current efforts in the framework of the European Union.

In general it can be said, that the removal of litter is timely and costly and can only capture small amounts. Therefore the focus of any relevant marine litter measures must be put on prevention. Clean-up activities can only act as complementary measures to raise awareness for the issue, to involve the broader public and to clean up parts of the marine environment. The already mentioned so called Fishing for Litter initiative, for example, not only aims to remove marine litter from the sea, but also aims to create awareness among stakeholders, including the fishermen and the broader public (KIMO 2013). OSPAR is also supporting beach clean-ups that are organized on specific days or on a regular basis and involve local communities or certain stakeholders, such as schools. Other clean-up activities are in their pilot phase and have to be evaluated carefully with regard to their environmental soundness. Several ideas aim on extraction of litter in the open sea environment at the sea surface and water column. With regard to their operationalization, it is of special importance to understand the potential biological impacts they might have, such as the bycatch of marine life.

39.5 Outstanding Issues: The Example of Dumping at Sea as a Potential Additional Source of Marine Litter

Another potential, however less well studied and understood, source of marine litter concerns the role of dumping. It differs from the regime established under MARPOL in that dumping is the deliberate disposal of wastes or other matter at sea and does not include the disposal of waste, for example from vessels, that are incidental to or derived from normal operations (see only Art.1 (5) UNCLOS). Its potential importance comes from its close relationship to efficient waste management policies as well as alternatives to land-based pollution (Frank 2007). The international regime that addresses dumping at sea is established by the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention) from 1972 as well as the Protocol to the Convention from 1996. Both Conventions differ also with regard to their approach on how to prevent the pollution of the marine environment by waste. The London Convention (LC) pursues a "listing-approach" in which a dumping prohibition for all substances listed in its Annex I ("black list") is established, therefore allowing, in principle, the dumping of Annex II-substances after a prior special or general permit has been issued. The London Protocol (LP) on the other hand pursues a "reverse listing approach" which establishes a general dumping prohibition including exemptions for those substances listed in its Annex I.

Both instruments address the issue of marine litter, however, in a somewhat different approach. Among the substances listed in Annex I LC are persistent plastics and other persistent synthetic materials. This means that dumping these substances is prohibited under the London Convention. Notwithstanding this, some Annex I LC substances such as persistent plastics may be dumped if they are rapidly rendered harmless by physical, chemical or biological processes in the sea, and provided that they do not make marine organisms used for human consumption unpalatable or endanger human health. The Convention also stipulates that certain Annex I LC substances, also persistent plastics, may be dumped if these occur in sewage sludge or dredged material. Even though the knowledge about the potential impacts of plastic on the marine environment was limited at the time of adoption, these exemptions and potential loop-holes for the introduction of marine litter through dumping activities constitute a weakness in the regime established by the LC. This relates in particular to the issue of microplastic or small fibres which are presently under discussion with regard to their potential to harm the environment and human health.

The London Protocol on the other hand establishes a much broader environmental protection regime that generally prohibits the dumping of all substances that are not listed in Annex I LP. One possible pathway of microplastics into the marine environment that is permissible under the current LP to dump sewage. The Specific Guidelines for Assessment of Sewage Sludge relate to human sewage sludge, therefore also including residues from municipal sewage treatment plans that could contain microplastics from personal care products or microfibers from textiles. However, the Guidelines for the Assessment of Sewage Sludge contain assessment criteria, such as the availability of alternatives to dumping and characterisation of chemical properties, and they are understood to be "living documents" that can be updated if new scientific knowledge arises (Lexmond 2009).

Even though waste management and waste disposal are closely related to the issue of marine litter, this has not been considered further under the work of the LC or LP (Stöfen-O'Brien 2015). This refers mainly to the close relationship of finding alternatives for waste management on land without opting to revert to offshore waste disposal. However, a recent study undertaken within the framework of the

IMO, concluded that it is currently impossible to make general statements on the litter content of either sewage sludge or dredged materials with regard to litter types, properties and quantities. It was outlined that further studies need to be conducted for assessing mircoplastic contamination in these substances (IMO 2016b).

39.6 Conclusion

The management approaches necessary to address the issue of marine litter are as manifold and complex as the issue itself. Whereas clean-up activities are important factors in raising awareness for this issue, prevention of the introduction of marine litter has to have the highest priority in any marine litter regulatory approach. As has been presented above, the diversity of possible solutions is broad and potentially runs the risk of merely focussing on single sources without looking at cumulative impacts, therefore becoming fragmented and ineffective. What is more, different solutions can be found at different regulatory levels, such as in the international, regional and European Union framework. Even though UNCLOS provides a broad global legal framework in which general rules and obligations are established, the substantiation of concrete and precise measures is done in different fora, with so far limited cooperation. Even though certain challenges arise with regard to understanding the effectiveness of the above presented sectoral instruments, as off yet, it is clear that despite their development, they do not yet have a major effect on reducing the input of marine litter into the marine environment. The reasons for this being their incomplete implementation and enforcement as well as remaining regulatory gaps.

It is clear, that addressing the issue of marine litter in an effective manner necessitates integrated approaches in which measures and general guidelines are developed that follow a holistic framework. The presented regional action plans on marine litter are such vehicles as they cover, depending on the scope of the specific regional seas agreement, the management of different sources of marine litter and provide an overall framework in which these measures are to be adopted. They are not limited to tackling specific measures at their source, but also provide a context for these measures by way of stressing the importance of guiding principles such as the precautionary principle or the application of the ecosystem approach and concrete implementation plans.

Besides structural and economic measures and mechanisms that are quintessential to address the underlying reasons for marine litter pollution, other factors are also important. This in particular relates to public participation and the involvement of industry as well as private and non-profit stakeholders. Participation is an important vehicle to create awareness among a diverse set of actors, which serves several purposes. On the one hand, the actions of individuals through intentional or unintentional littering or the use of non-reusable plastic bags, e.g., when shopping, add in a cumulative way to the waste potentially released into the environment. On the other hand, public participation and awareness helps to guide actions when the pollution load of marine litter becomes inacceptable (for society). This may lead, as a consequence, to the development of higher protection standards through legislation or to the prioritisation of enforcing and implementing existing obligations (UNEP 2016).

The challenge in achieving significant progress to reduce the introduction of marine litter into the marine environment in the next years, possibly decades, is to develop effective prevention measures and to ensure their implementation and enforcement. This not only relates to existing obligations from MARPOL Annex V or the LP, for example, but also to those measures that are developed within the framework of the regional action plans on marine litter in OSPAR and HELCOM as well as to those measures being implemented during the MSFD process. It might be possible that the action plans provide a vehicle for regional best practices and means to ensure enforcement and develop effective measures that can then be scaled up to a broader level. However, the implementation of measures necessitates the provision of sufficient financial means and political will so as to move away from business as usual and to achieve the reduction targets as outlined in different action plans. The current endeavours, especially in the framework of the regional seas have already resulted in a first implementation of measures in the form of national, subregional or regional reduction targets and are a first step in addressing this issue.

References

CJEU (2014) Case C-600/12, European Commission v Hellenic Republic (Fifth Chamber) of 17 July 2014. Reports of case not yet published. Accessed 5 Sept 2016

Codecheck/BUND (2016) Mikroplastikstudie 2016

Cosmetics Europe (2015) Press statement- cosmetics Europe issues a recommendation on solid plastic particles (plastic micro particles). https://www.cosmeticseurope.eu/news-a-events/news/822-cosmetics-europe-issues-a-recommendation-on-solid-plastic-particles-plastic-micro-particles.html. Accessed 12 Sept 2016

European Commission (2015) Press release - closing the loop: Commission adopts ambitious new circular economy package to boost competitiveness, create jobs and generate sustainable growth, IP/15/6203, 02.12.2015

FAO (2009) Abandoned, lost or otherwise discarded fishing gear. FAO Fisheries and Aquaculture Technical Paper 523/UNEP Regional Seas Reports and Studies No 185

Frank V (2007) The European Community and marine environmental protection in the international law of the sea – implementing global obligations at the regional level. Brill/Nijhoff, Boston

HELCOM HOD (2015) Annex 2 36/1 Recommendation on a Regional Action Plan on Marine Litter, http://www.helcom.fi/action-areas/marine-litter-and-noise/marine-litter/marine-litter-action-plan

HELCOM (2007) Recommendation 28E/10 (2007) on the Application of the no-special-fee system for ship-generated wastes and marine litter caught in fishing nets in the Baltic Sea Area

IMO (2016a) Summary of status of conventions, as at 08 July 2016. http://www.imo.org/en/About/Conventions/StatusOfConventions/Pages/Default.aspx. Accessed 5 Sept 2016

IMO 2016b Review of the current state of knowledge regarding marine litter in wastes dumped at sea under the London Convention and Protocol

Jambeck J, Geyer R, Wilcox C et al (2015) Plastic waste inputs from land into the ocean. Science 6223:768–771

KIMO (2013) Fishing for litter. http//:www.kimointernational.org/FishingforLitter.aspx. Accessed 5 Sept 2016
Lexmond S (2009) International law and ocean dumping: steering the precautionary course aboard the 1996 London Protocol, but still an unfinished voyage. In: Chircop A, McDorman T, Rolston S (eds) The future of ocean regime-building. Brill/Nijhoff, Boston, pp 515–571
Ryan PG, Moore CJ, van Franeker JA et al (2009) Monitoring the abundance of plastic debris in the marine environment. Philos Trans R Soc Lond B Biol Sci 364:1999–2012
Sherrington C et al. (2016) Study to support the development of measures to combat a range of marine litter sources. Report for European Commission DG Environment, Eunomia
Stöfen-O'Brien A (2015) The International and European Legal Regime Regulating Marine Litter in the EU. Nomos, Baden-Baden
Tan (2006) Vessels-source marine pollution – the law and politics of international regulation. Cambridge Studies in International and Comparative Law
Thompson RC, Moore CJ, vom Saal FS, Swan SH (2009) Plastics, the environment and human health: current consensus and future trends. Philos Trans R Soc Lond B Biol Sci 364:2153–2166
Trouwborst A (2011) Managing marine litter: exploring the evolving role of international and European law in confronting a persistent environmental problem. Utrecht J Int Eur Law 27(73):4–18
UN General Assembly (2015) A/RES/70/1. Resolution adopted by the general assembly on 25 September 2015 on transforming our world: the 2030 agenda for sustainable development
UNEP (2016) Marine plastic debris and microplastics - global lessons and research to inspire action and guide policy change. United Nations Environment Programme, Nairobi
UNGA (1991) United Nations general assembly resolution a/RES/46/215 large-scale pelagic drift-net fishing and its impact on the living marine resources of the world's oceans and seas. United Nations, New York
UNGA (2004) United Nations general assembly resolution a/RES/59/25 sustainable fisheries, including through the 1995 agreement for the implementation of the provisions of the United Nations convention on the law of the sea of 10 December 1982 relating to the conservation and management of straddling fish stocks and highly migratory fish stocks, and related instruments. United Nations, New York
UNGA (2014) United Nations general assembly resolution 68/71 sustainable fisheries, including through the 1995 agreement for the implementation of the provisions of the United Nations convention on the law of the sea of 10 December 1982 relating to the conservation and management of straddling fish stocks and highly migratory fish stocks, and related instruments. section VIII, fisheries by-catch and discards. United Nations, New York

Chapter 40
Coastal and Ocean Tourism

Stefan Gössling, C. Michael Hall, and Daniel Scott

Abstract Coastal and marine environments attract hundreds of millions of tourists every year, and in regions including the Mediterranean or the Caribbean, tourism is a mainstay of the economy. Given that a considerable share of tourism is 'sun, sand, and sea' focused, the sector is dependent on the integrity of coastal resources such as unpolluted beaches and waters. These resources are increasingly threatened: External and tourism-related pressures on coastal zones include land conversion and industrial developments, water pollution, loss of mangroves, introduction of invasive species, and overuse of resources (e.g., fresh water or marine species used as seafood and souvenirs). Climate change is exacerbating these problems through sea-level rise, changing rainfall patterns, or higher water temperatures linked to coral bleaching and algal blooms, all of which affect the viability of coastal tourism destinations. In this situation, the management of coastal ecosystems for tourism is paramount. Yet, even though a wide range of management tools is theoretically available, there is evidence that coastal governance is limited and hampered by economic interests and unequal power relations. Considerable political effort will be needed for tourism in coastal zones to become more sustainable and to adapt to on-going environmental change.

Keywords Climate change • Coastal zones • Coastlines • Governance • Resource use • Sustainability • Tourism

S. Gössling (✉)
Department of Service Management and Service Studies, Lund University & School of Business and Economics, Linnaeus University, Kalmar, Sweden
e-mail: stefan.gossling@lnu.se

C.M. Hall
Department of Management, Marketing and Entrepreneurship, University of Canterbury, Christchurch, New Zealand

D. Scott
Department of Geography and Environmental Management, University of Waterloo, Waterloo, ON, Canada

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_40

40.1 Introduction

Tourism is one of the most important economic activities in coastal areas, and also one of the fastest growth sectors of the global economy (Hall 2001). International tourist arrivals have almost reached 1.2 billion per year (UNWTO 2016), and about four times this volume in domestic tourism arrivals (UNWTO-UNEP-WMO 2008). A large share of tourism is focused on coastal areas, with the Mediterranean and the Caribbean representing the most popular tourism regions in the world. The Mediterranean attracts almost a third (31%) of all international tourist arrivals (UNEP 2009), corresponding to 300 million tourists in 2008. This number is expected to reach 368 million by 2020, with about half of these visiting coastal zones. Taking into account domestic tourism, coastal zones of Mediterranean countries receive an estimated 250 million visitors every year (UNEP 2009). Coastal tourism is also a key feature of the Caribbean. In 2014, the region received more than 22 million international tourists (UNWTO 2015), most of them searching out the islands for sun, sand and sea related motives.

Tourism is a key source of foreign exchange earnings in 46 out of 50 of the world's least developed countries, most of them small island developing states (SIDS) (UNWTO 2007). Visitor spending as a percentage of GDP exceeds 50% in for instance Anguilla, Palau and the Cook Islands, and 25% in Seychelles, Cape Verde, Maldives, Aruba, Turks & Caicos, Saint Lucia, Antigua and Barbuda, Bahamas, Barbados, and Vanuatu (Gössling et al. 2009). Coastal zones are central features of these islands, and used for a wide range of tourism and leisure activities including fishing, swimming, snorkelling, windsurfing, water skiing, jet skiing, boating and yachting (Hall 2001; Cater and Cater 2007). Scuba diving, as a form of special interest tourism in coastal areas, now involves at least 28 million active divers (Garrod and Gössling 2007; Musa and Dimmock 2013).

Cruise tourism catered to an estimated 23 million tourists in 2015 (Cruise Lines International Association 2015). However, this does not include all inshore and small craft cruising. It has been estimated that although cruise ships comprise less than 1% of the global merchant fleet they account for 25% of the waste (Herz 2002; Butt 2007). Because of the large numbers of people they carry sewage management is inherently a major problem for cruise ships. Butt (2007) estimated that approximately 50 t of sewage per day are produced by an average cruise ship, equating to between 20 and 40 L per person per day. In addition, cruise ships also discharge considerable quantities of grey water, which is other waste water such as from sources such as kitchens, laundries, and showers. Like sewage grey water also contains organic matter which, because of the often coastal nature of much cruise traffic, can have considerable impacts on algal growth and eutrophication (Caric 2011; Andersson et al. 2016; Box 40.1).

Tourists and their transport act as major vectors for species transfer (Hall 2015a). In the coastal environment, cruise and passenger ships are a major focus in the introduction of marine and terrestrial invasives (Molnar et al. 2008), especially in areas that may have only recently been opened up for cruising (Hall 2010). Hull fouling (Drake and Lodge 2007) and ballast water (Endresen et al. 2004) are identified as major sources of alien maritime species.

Box 40.1 MARPOL and sewage—Best practice?

According to the MARPOL regulations 73/78 Annex IV, the discharge of sewage into the sea is allowed if the ship is discharging comminuted and disinfected sewage using an approved system under the local jurisdiction a distance of more than three nautical miles from the nearest land, or sewage which is not comminuted or disinfected at a distance of more than 12 nautical miles from the nearest land. However, such treatment does not reduce the nutrient load. Under the Annex if a ship has a certified sewage treatment plant, discharge of sewage is permitted anywhere. Public awareness of passenger and cruise ship discharges into the Baltic Sea, which has a significant nutrient load problem, led to substantial public disapproval and negative publicity. In response many of the passenger ferry companies began discharging the sewage into the municipal sewer network ashore or into tank trucks and reception facilities for passenger and cruise ships is being upgraded. In 2008 the Port of Helsinki launched a campaign to increase the number of cruise liners that would opt to leave their waste water ashore. In all three harbours of the Port of Helsinki facilities exist to discharge ship sewage directly into the municipal waste-water treatment plant. Additionally, international cruise ships can leave their sewage onshore at the cruise quays. Even though MARPOL and Finnish legislation allows the discharging of sewage into the sea, increasing numbers of ships are leaving the black and grey waste waters to be treated onshore rather than discharge into the Baltic (Hänninen and Sassi 2009).

Coastal environments including reef systems also support tourism more generally, as they are important elements of the scenery attracting travellers, and host a plethora of marine life of relevance for tourism in the form of seafood or biodiversity. Where corals are affected by environmental change, this can have costly implications for tourism (Hall 2011). A considerable share of global tourism is consequently dependent on coastal zones' unique assets, as well as specific environmental features and climatic conditions that make coastal zones attractive and consumable (Craig-Smith et al. 2006; Scott et al. 2012a).

The sheer size of tourism volumes and their concentration in coastal areas suggests that tourism has a considerable impact on coastal areas (Bramwell 2004; Gormsen 1997; Wong 1998). Impacts can be direct or indirect, related to land use change, (over) use of natural resources (fresh water, biodiversity, marine species; Figs. 40.1 and 40.2), introduction of invasive species, and/or sewage and solid waste generation (Apostolopoulos and Gayle 2002; Hunter and Green 1995; Orams 1999). These impacts are often synergistic. For example, disturbance of coastal habitat for tourism development makes it easier for introduced exotic species to become invasive (Hall 2015a). Tourism is also a significant contributor to emissions of greenhouses gases, with climate change being a major factor of coastal change because of sea level rise (Scott et al. 2012a). Where tourism infrastructure is developed, projects can transform entire regions or coastlines, often with little or inadequate planning

Fig. 40.1 Pool landscape, Mauritius. In dry areas, tourism can be a major factor in the abstraction of freshwater. Direct water consumption ranges between 84 L to 2000 L per tourist per day have been reported in the literature

(GFANC 1997; Wong 2003). In tropical destinations, developments often focus on areas that have previously had limited economic value, such as remote beaches, leading to various forms of sociocultural conflict with and within local communities, and potentially detrimental outcomes for coastal zones (Gössling 2003).

Coastal zones consequently face a wide range of environmental impacts and social problems. To illustrate this, in the Mediterranean, population growth has been 46% in the period 1980–2000, and population density in coastal zones is about twice as high as on national average (UNEP 2009). Tourism-related pressures add to this in the form of infrastructure developments for accommodation and associated businesses (retail, activity suppliers), as well as land conversion for gardens, pools, or marinas (Essex et al. 2004; Rico-Amoros et al. 2009). Tourism development also has considerable labour requirements, which will often be recruited from outside the area. Staff bring with them families, and can be a major factor in coastal population growth and accompanying increased pressures on housing (Chhetri et al. 2008). For example, Gormsen (1997) reported that the number of residents in Cancun, Mexico had increased from 426 in 1970 to 177,300 in 1990, largely a result of migration following tourist infrastructure development. Population growth will affect marine life or pressure on specific species that may be targeted by the curio trade or as seafood. A study in Zanzibar, Tanzania found that 39% of tourists had

Fig. 40.2 Trade in marine curio, Zanzibar. In many countries, there is a vivid trade in marine curio, including shark teeth, tortoise shells, molluscs, bivalves, and corals. The photograph shows the stall of a small-scale trader in souvenirs, with marine artefacts including the giant triton shell (*Charonia tritonis*)

collected shells and 7% bought ornamental shells, including various protected species. Tourists also bought shark teeth and other marine curio, and significantly increased the consumption of crustaceans and pelagic fish (Gössling et al. 2004). As the Millenium Assessment (2005: 12) concluded: "the development of coastlines for tourism and activities such as shrimp farming has dramatically altered the meeting point of land and ocean. In just two decades, it is estimated that people have removed more than a third of the world's mangroves." This situation is not necessarily better in developed countries: all around the Mediterranean, tourism is a threat to biodiversity and natural resources as a result of land use conversion (GFANC 1997; Gheskiere et al. 2005).

Given these tourism-related impacts, Harriott (2002), in the context of the Great Barrier Reef, distinguished tourism management needs related to:

- Coastal tourism development (population pressures, construction activities);
- Island-based tourism infrastructure (marinas, sewage discharge, construction);
- Marine-based tourism infrastructure (pontoons, moorings, fish feeding);
- Boat-induced damage (anchoring, ship grounding, litter, waste discharge);
- Water based activities (diving, snorkelling, reef walking, fishing);
- Wildlife interactions (seabirds, turtle-watching, whale-watching).

Fig. 40.3 Torrential rains in the dry season, Barbados. Small island states in particular rely on stable climatic conditions, as their main tourism product is related to sun, sand and sea (3S). With climate change, rainfall frequencies, intensities, and the timing of rainfall periods has disrupted holiday seasons in many destinations

Climate change exacerbates existing problems in coastal zones, as it affects resources of central value to tourism (Scott et al. 2012a). Climate change may have a wide range of negative consequences for tourism, including heat waves, cold spells, spread of diseases and pests, drought, the associated risk of fires, as well as sea level rise leading to coastal erosion. It also affects key resources for tourism, such as coral reefs, which are under severe stress under climate change scenarios due to increases in extreme weather events, increased run-off and sedimentation, sea level rise, salinity and acidity changes (Hoegh-Guldberg et al. 2007). Fresh water stress is simultaneously projected to affect many regions in the world, with for instance water flows in summer being expected to decline by up to 80% in southern Europe, and sea level rise causing an inland migration of beaches and the loss of up to 20% of coastal wetlands in many parts of the Mediterranean (IPCC 2007). In some locations competition for fresh water between tourism and other users, such as the agricultural sector, is already marked (Gössling et al. 2015).

Other climate change related challenges for tourism include beach erosion, marine biodiversity loss, changes in rainfall patterns (Fig. 40.3) and outbreaks of algal blooms or jellyfish (Fig. 40.4; UNWTO-UNEP-WMO 2008). So far, the time-lines over which these impacts will occur are as yet insufficiently understood, and

Fig. 40.4 Algal bloom affecting coastline in Öland, Sweden. Climate change is expected to have a wide range of consequences for marine ecosystems and tourism. Algal blooms rendered impossible marine activities in large parts of Öland, a popular Swedish holiday destination, in 2005. Even though not necessarily a result of climate change, algal growth is supported by higher water temperatures

so are tourist demand responses (Gössling et al. 2012). Climate change can nevertheless be expected to become a growing threat to the management of coastal tourism in many parts of the world. Nineteen SIDS have population shares greater than 39 per cent in the low elevation coastal zone, or the contiguous area along the coast that is less than 10 m above sea level with tourism dependent economies such as the Maldives and the Bahamas among those most at risk (Hall 2015b). The situation for SIDS is further complicated by a high coastline-to-land-area ratio. This means that many settlements and critical infrastructure are increasingly vulnerable to erosion, storms and tidal surges, and saline intrusion (Nunn 2013). As an example, Scott et al. (2012a) found, in a study of 906 major coastal resorts in 19 CARICOM countries that 29% would be partially or fully inundated by a 1 m sea level rise, and more than 80% of the properties would loose a significant share of their beaches (Fig. 40.5). Notably, erosion is an on-going process, and has been observed to lead to beach loss in the order of 0.5 m per year in a range of locations in the Caribbean (Cambers 2009). Another key issue is rainfall, which is one of the greatest threats to sun, sand, and sea destinations (Scott et al. 2012b). Evidence suggests changes in the frequency, intensity and timing of rainfall in many destinations in the world,

Fig. 40.5 Coastal squeeze, Seychelles. Where tourism infrastructure has been placed close to the sea, and where coastal erosion eats the land, the stretch of beach that can be used for tourism purposes diminishes, while the vulnerability of the infrastructure increases

with significant consequences for tourism. Research in Martinique during a period of intense rains in what is normally the dry season of the island found, for instance, that 11% of tourists stated that they would never return (Hübner and Gössling 2012).

40.2 Coastal Tourism Management

As outlined, many of the impacts on coastal ecosystems and coastlines are related to tourism development, or associated with sectors such as fisheries, agriculture or industry. These pressures need to be addressed in order to maintain ecosystem functions and to conserve biodiversity, and integrated coastal zone management approaches have received much attention over the past two decades (Moksness et al. 2009; for tourism and climate change see Jones and Phillips 2011). Management can be based on three governance approaches, i.e., command-and-control (laws and regulation), market-based measures (taxes, permits, rights, subsidies), and soft policies (programmes, labels, certifications, management systems, guidelines, campaigns) that seek to encourage new behaviours (Boxes 40.2, 40.3, and 40.4).

Box 40.2 Coastal erosion

Issue

Beach erosion is a result of sediment change, i.e., the amount of sediment build up and eroded in a given stretch of coastline. This may lead to coastal squeeze and the loss of tourism infrastructure

Management tools

Zoning, with some near-shore areas being excluded from development (Markus et al. 2015). Potentially, this can be built on modelling of sea level rise (Scott et al. 2012b), and monitoring programmes requiring the consideration of longer timeframes (>50 years)

Regulatory frameworks

National development plans, environmental impact assessment, regional planning

Source: Based on Craig-Smith et al. 2006

Box 40.3 Water pollution

Issue

Poor water quality because of contaminated seepage, nutrition loaded runoff, raw sewage ocean discharge, pollution-causing substances (cleaning detergents, etc.)

Management tools

Monitoring programme, including beach cleaning programmes, fertiliser control and management, treatment plants, catchment management, oil spill contingency plans (open sea)

Regulatory frameworks

Legislation regulating discharge and water treatment, water quality standards, product red lists (see also Oenema 2016, Chap. 14; Schloen, Chap. 35.)

Source: Craig-Smith et al. 2006; Gössling et al. 2015

Box 40.4 Marine-based activities

Issue

Habitat change, including coastal ecosystems, reefs, mangroves, seagrass beds, all leading to pressure on marine species

Management tools

Awareness programmes, codes of conduct, training programmes (e.g., diving, snorkelling, sailing, fishing), zoning (e.g., MPAs), integrated coastal zone management, monitoring, fisheries restrictions

Regulatory frameworks

Fisheries regulation, implementation of (marine) protected areas

Source: Craig-Smith et al. 2006

40.2.1 General Management Approaches

Irrespective of regulatory approach, coastal management will generally follow a similar procedure, i.e., identification of the issues, definition of stakeholders, introduction of management tools, and design of measures, followed by monitoring (Craig-Smith et al. 2006). This process can be embedded in regulatory frameworks adjusted to the specific issue at hand, which may require command-and-control, market-based, soft policy approaches, or any combination of these. Examples as presented in Boxes 40.2, 40.3, and 40.4 illustrate such approaches. Coastal erosion (Box 40.2) may be a result of natural processes including sea-level rise, but it can also be caused or exacerbated by poor coastline management. Management tools can be developed within national development plans, rely on environmental impact assessments, and be integrated in wider regional planning activities. To reduce erosion, management measures may focus on zoning as a command-and-control approach, with sensible areas being excluded from development and infrastructure being located in areas sufficiently far removed from the shore to account for sea-level rise. Other examples include water pollution (Box 40.3), which may be addressed through beach-cleaning campaigns, fertilizer control, the introduction of treatment plants, and contingency plans for oil spills. Habitat change (Box 40.4) can involve various ecosystems (coastal, reefs, mangroves and seagrass beds), and may be addressed through zoning, codes of conduct and tailored legislation (e.g., dive operators, marine life observation, fisheries, shipping), and/or awareness programmes. For example, substantial cruise ship biosecurity protocols have been put in place in the Antarctic and sub-Antarctic regions by national governments as well as industry associations such as the International Association of Antarctic Tour Operators. Ideally, best practice measures involve a combination of all three governance approaches including national biosecurity regulation, behavioural interventions, educational measures and voluntary codes of conduct (Hall et al. 2010).

40.2.2 Climate Change Related Strategies

Dealing with climate change can be more complex than dealing with on-site impacts. This is because the understanding of tourist perceptions of climate change and demand responses is still in its infancy (Gössling et al. 2012), and adaptation to many changes is difficult, as these are largely unpredictable in terms of occurrences or because adaptive response options are limited. For instance, in sun, sand, and sea destinations, there may be limited scope for alternative activities, particularly when beach-related activities become impossible because of prolonged rains. Tourists are likely to have chosen such destinations specifically because of their climate (Rutty and Scott 2013, 2015), and the impossibility of engaging in marine activities or sunbathing is very likely to have significant negative repercussions for tourist experiences. To design indoor-activities is often costly and these may often only be attractive in 'bad weather' periods. However, even with regard to climate change, regulation and planning are of great importance, and can take the form of an adaptive process that deals with uncertainties. Nevertheless, difficulties have been noted in implementing planning-time scales for climate change impacts due to the long-term nature of the planning cycles involved (Hall et al. 2016). Nevertheless, frameworks for climate change adaptation processes have, for instance, been developed by Scott et al. (2012a), and depend on situational context, stakeholders involved, as well as the kind of impact that needs to be addressed. Key elements of such a climate change adaptation process include six steps (Scott et al. 2012a: 284–286), and are relevant to the wider coastal zone management processes:

40.2.2.1 Step 1—Getting the Right People Involved in a Participatory Process

A vital aspect in determining the eventual success of the adaptation process is to get the right people involved and to involve them in a participatory process. The purpose of multi-stakeholder processes is to promote better decision making through an inclusive and transparent process that creates trust and a sense of ownership among stakeholders. Tourism is a highly diverse economic sector and the perspectives of many local, national and, where applicable, international stakeholders should be sought, both those directly involved in the tourism sector or whose livelihoods are affected by tourism (government ministries, local government, tourism industry representatives, tourism labour representatives, local businesses and communities), and those in other sectors that might be affected by tourism adaptations (e.g., transportation, energy or agriculture), whose adaptations might affect tourism (e.g., insurance industry, health sector), or that have other relevant expertise (e.g., universities, non-governmental organizations).

40.2.2.2 Step 2—Screening for Vulnerability: Identifying Current and Potential Risks

The next step is to understand how climate change may affect a region and what risks this would pose for the tourism sector. Understanding climate impacts is an essential early step and the assessment should include examination of physical risks to tourism resources (e.g., biodiversity, water supply) and infrastructure (e.g., coastal resorts), business and regulatory risks (e.g., changes in insurance coverage), or market risks (e.g., changes in international competitiveness through transportation costs). Assessments should include both current (e.g., extreme climatic events—both sudden and slow onset) and potential future risks (e.g., changing climate means and variability). Synthesizing information from existing national or regional climate change assessments may prove valuable at this stage to understand recent and projected climate changes and the implications for natural and human systems that are highly relevant to tourism. Risk management strategies need to be flexible and allow stakeholder participation over “long time horizons" (Jones 2010). Because tourism has not been adequately considered in many previous climate change assessments, a scoping assessment of the range of tourism specific risks may also be needed to supplement existing information and to ensure knowledge gaps are addressed. Where little information is available, interviewing stakeholders about how recent climatic extremes have affected aspects of tourism operations (e.g., warmer tourism seasons, prolonged dry period, extreme events which can serve as analogues for conditions expected under climate change) is a good place to begin. What do these analogue experiences reveal about existing climate sensitivities and what analyses have been undertaken to better cope with future incidences?

40.2.2.3 Step 3—Identifying Adaptation Options

Work with tourism stakeholders to compile a list of alternative technologies, management practices or policies, and behavioural changes that may enable them to better cope with the anticipated impacts of climate change (e.g., economic diversification). This adaptation portfolio building stage should include both preparatory and participatory activities. Preparatory activities should begin by identifying current adaptation strategies and policies in place to address current climate related risks. Reviewing recent climate change reports from other communities and regions expected to face similar risks may be valuable for identifying additional adaptations utilized successfully in other tourism destinations (Kaján and Saarinen 2013. Participatory activities may include holding workshops or smaller focus group meetings with stakeholders. Where it is difficult or overly costly to bring a wide range of stakeholders to a workshops field interviews with stakeholders by an adaptation team or Delphi techniques with key stakeholders and potential implementing partners can also be used to identify adaptation options. National and international experts in climate change risk assessment and adaptation should also be consulted to share information and experience from other nations and to help identify any potential gaps in the stakeholder generated adaptation portfolio.

40.2.2.4 Step 4—Evaluate Adaptation Options and Select Course of Action

The adaptation portfolio building stage is likely to identify a long list of potential adaptations that may be difficult to fully analyse with limited timeframes and budgets. It is recommended that a second round of stakeholder consultation be done to present the full initial list of stakeholder identified adaptations, and determine criteria by which to evaluate adaptations and refine the portfolio of adaptations to be considered for implementation. A range of criteria can be used to evaluate adaptation strategies: net economic benefit, timing of benefits, distribution of benefits, consistency with development objectives, consistency with other government policies, cost, environmental impacts, spill-over effects, capacity to implement, and social-economic-technological barriers. Some criteria may require the additional detailed analysis be undertaken of each adaptation.

40.2.2.5 Step 5—Implementation

Implementation of the adaptation options selected in step four requires that the roles of implementing stakeholders, resource requirements, and timelines be specifically defined. Implementation plans may include the following components: strategic plan outlining actions and timelines of involved stakeholders; capacity building needs assessment and training plan; financial/business plan covering expenditure needs and revenue sources; communication plan; sustainability plan; plan for monitoring the performance of adaptations. Adaptation plans cannot stand alone and must relate to other existing planning processes and policies (i.e., 'mainstreaming' adaptation).

40.2.2.6 Step 6—Monitor and Evaluation Adaptations

Climate change adaptation represents a long-term investment of human and financial resources. To ensure the optimal realization of this on-going investment, the final step in this process is to continuously evaluate the effectiveness of the implemented adaptations. Again, several evaluation criteria are possible (e.g., cost, ease of implementation, delivered intended benefits, adverse impacts). The evaluation criteria and related indicators should be selected by stakeholders in step five as part of the monitoring and performance plan, especially as this also encourages stakeholder adoption. Complete evaluation may prove difficult for some time however, as the long-term risks posed by climate change that required the adaptation may not be realized for many years (even decades). As evaluation of the implemented adaptation strategies becomes possible, this continues the iterative process of adaptation by informing how the initial strategy will need to be refined.

Notwithstanding the significant progress that has been made in identifying measures to preserve, maintain or improve the integrity of coastal environments and legislative opportunities to implement such measures, progress on coastal zone management related to tourism development has often been limited (Bramwell 2004; Gössling 2003; Jones and Phillips 2011). Depending on country and local context, the reasons for this may be complex, virtually always involving political disinterest, unequal power relationships and diverging economic interests. Where tourism development is seen as an opportunity to generate income, taxes and employment opportunities, governments and investors may become interested in environmentally pristine areas that have often existed outside the larger economy. Specifically in poor developing countries, local socioeconomic systems in such areas can rapidly become enmeshed in capitalist modes of production, which are likely to disrupt social structures and traditional resource use systems (Gössling 2003; Sharpley and Telfer 2014). However, even in developed countries tourism is often given priority over ecosystem conservation, while even more environmentally conscious tourism operators have been found to contribute indirectly to ecosystem degradation in coastal zones as a result of unsustainable supply chains (Gössling et al. 2011; Millenium Assessment 2005; Roberts 2002). While there is no lack of calls to change this situation, it appears that governments struggle with the design and implementation of policies (Klein and Ferrari 2015), and institutional constraints have consequently been identified as a major barrier to the sustainable development of tourism in coastal areas (Mycoo 2014) (Box 40.5).

Box 40.5 Best practice example water conservation

Fresh water is scarce in many coastal areas, and specifically in arid regions, there is a risk of overuse. Tourism can be a key factor in fresh water abstraction, potentially at the expense of local populations. In order to save water, Swiss tour operator Kuoni (2013) developed a "skills map", based on a stepwise approach to water reduction. The map sets out with planning for water management, assigning roles and responsibilities from the board of directors to the heads of housekeeping, kitchen and grounds keeping. This is followed by data collection to understand where water is used, and where it can be saved ('water audit'). A cost-benefit analysis will then reveal which measures are cost-efficient, as many have payback periods of less than 3 years. Through action plans, key priorities for management are developed, ideally combining water with energy management. Benchmarks can help to identify acceptable use levels. Monitoring is needed to assess savings, and to understand the overall trend in water use. Staff training and the creation of customer awareness contribute to continuous water savings, reveal water leakage, and can be positively framed in terms of pro-environmental action taken by the hotel. As shown by the Kuoni water champion awards, which are awarded to "outstanding water management practices of hotels" (Kuoni 2013: 11), savings of up to 38% were possible, mostly related to leakages from plumbing. Overall water use remained high in the award-winning hotel, however: The resort and spa in Kenya continued to use more than 1100 L of freshwater per bed night, i.e., almost three times the estimated global average direct water use in hotels (Gössling et al. 2015).

40.3 Conclusion

Coastal zones are under threat, often because of tourism. Population growth and industrialization jeopardize the integrity of ecosystems and the services they provide; processes often exacerbated by climate change. Even though tourism also contributes to ecosystem change in its consumption 'hinterlands'—for example for food production, direct pressures in coastal zones are related to infrastructure construction (marinas, jetties, moorings, hotels), waste and sewage, resource use (fresh water, seafood), and wildlife interactions. In many areas, these impacts compound each other, to a degree where tourism systems are no longer viable or have to be maintained with considerable financial effort or at low profit margins. Coastal tourism consequently requires to be managed in sustainable ways, considering interrelationships between local and non-local resource use, ecosystem change, and climate change. Craig-Smith et al. (2006) concluded that coastal management would have to address a range of issues, including spatial planning with short- and long-term perspectives, in which ecosystem functioning is of central relevance.

Such plans need to assess which developments can be integrated with the overall goal of ecosystem service conservation, which will often require implementation of protected areas. This requires co-ordination between involved authorities and business stakeholders, and the introduction of legislation demanding environmental impact assessments and the collection of data on natural resources and biodiversity. Where developments are accepted, monitoring of change is central in understanding how ecosystems are affected, also because of social change induced by tourism, which may be particularly relevant in remote areas in developing countries. Education and awareness raising programmes can help to create an understanding for restrictions, while increasing the interest in preserving the environment. Benefits from tourism also need to accrue to local communities, though distributional aspects and implications of tourism for socioeconomic change need to be considered. Yet, tourism systems in coastal zones often remain unsustainable, as they require vast tracts of land and significant amounts of water, energy and food, which are often produced in ways that are environmentally harmful and specifically problematic for coastal zones. To develop sustainable coastal tourism will consequently require major political efforts and new approaches to tourism management. Given the lack of national politics in properly addressing these issues, specifically in many developing countries, as well as the disregard paid to these issues by supranational organizations such as UNWTO, there is currently very limited evidence that the situation will improve in the short-term future.

References

Andersson K, Brynolf S, Lindgren J, Wilewska-Bien M (eds) (2016) Shipping and the environment: improving environmental performance in marine transportation. Springer, Berlin

Apostolopoulos Y, Gayle DJ (eds) (2002) Island tourism and sustainable development: Caribbean, Pacific, and Mediterranean experiences. Praeger Publishers, Westport

Bramwell B (ed) (2004) Coastal mass tourism: diversification and sustainable development in Southern Europe. Channel View Publications, Clevedon

Butt N (2007) The impact of cruise ship generated waste on home ports and ports of call: a study of Southampton. Mar Policy 31:591–598

Cambers G (2009) Caribbean beach changes and climate change adaptation. Aquat Ecosyst Health Manage 12(2):168–176

Caric H (2011) Cruising tourism environmental impacts: case study of Dubrovnik, Croatia. J Coast Res Spec Issue 61(Winter):104–113

Cater C, Cater E (2007) Marine ecotourism: between the devil and the deep blue sea. CABI, Wallingford

Chhetri P, Corcoran R, Hall CM (2008) Modelling the patterns and drivers of tourism related employment for South East Queensland, Australia—a spatial econometric approach. Tourism Recreation Res 33(1):25–38

Craig-Smith SJ, Tapper R, Font X (2006) The coastal and marine environment. In: Gössling S, Hall CM (eds) Tourism and global environmental change: ecological, economic, social and political interrelationships. Routledge, London, pp 107–127

Cruise Lines International Association (2015) 2015 CLIA state of the industry. CLIA, Arlington

Drake JM, Lodge DM (2007) Hull fouling is a risk factor for intercontinental species exchange in aquatic ecosystems. Aquat Invasions 2:121–131

Endresen O, Behrens HL, Brynestad S, Anderson AB, Skjong R (2004) Challenges in global ballast water management. Mar Pollut Bull 48:615–623

Essex S, Kent M, Newnham R (2004) Tourism development in Mallorca. Is water supply a constraint? J Sustain Tour 12(1):4–28

Garrod B, Gössling S (eds) (2007) New frontiers in marine tourism: diving experiences, management and sustainability. Elsevier, Amsterdam

GFANC (German Federal Agency for Nature Conservation) (1997) Biodiversity and tourism. Conflicts on the world's seacoasts and strategies for their solution. Springer, Berlin

Gheskiere T, Vincx M, Weslawski JM, Scapini F, Degraer S (2005) Meiofauna as descriptor of tourism-induced changes at sandy beaches. Mar Environ Res 60(2):245–265

Gormsen E (1997) The impact of tourism on coastal areas. GeoJournal 42(1):39–54

Gössling S (ed) (2003) Tourism and development in tropical islands: political ecology perspectives. Edward Elgar, Cheltenham

Gössling S, Kunkel T, Schumacher K, Zilger M (2004) Use of molluscs, fish, and other marine taxa by tourism in Zanzibar, Tanzania. Biodivers Conserv 13(14):2623–2639

Gössling S, Hall CM, Scott D (2009) The challenges of tourism as a development strategy in an era of global climate change. In: Palosou E (ed) Rethinking development in a carbon-constrained world. Development cooperation and climate change. Ministry of Foreign Affairs, Helsinki, pp 100–109

Gössling S, Garrod B, Aall C, Hille J, Peeters P (2011) Food management in tourism: reducing tourism's carbon 'foodprint'. Tour Manag 32(3):534–543

Gössling S, Peeters P, Hall CM, Dubois G, Ceron JP, Lehmann L, Scott D (2012) Tourism and water use: supply, demand, and security. An international review. Tour Manag 33(1):1–15

Gössling S, Hall CM, Scott D (2015) Tourism and water. Channel View Publications, Clevedon

Hall CM (2001) Trends in ocean and coastal tourism: the end of the last frontier? Ocean Coastal Manage 44:601–618

Hall CM (2010) Tourism and environmental change in polar regions: impacts, climate change and biological invasion. In: Hall CM, Saarinen J (eds) Tourism and change in polar regions: climate, environments and experiences. Routledge, Abingdon, pp 42–70

Hall CM (2011) Climate change and its impact on tourism: regional assessments, knowledge gaps and issues. In: Jones A, Phillips M (eds) Disappearing destinations. Climate change and future challenges for coastal tourism. CAB International, Wallingford, pp 10–29

Hall CM (2015a) Tourism and biological exchange and invasions: a missing dimension in sustainable tourism? Tour Recreat Res 40(1):81–94

Hall CM (2015b) Global change, islands and sustainable development: Islands of sustainability or analogues of the challenge of sustainable development? In: Redclift M, Springett D (eds) Routledge international handbook of sustainable development. Routledge, Abingdon, pp 55–73

Hall CM, James M, Wilson S (2010) Biodiversity, biosecurity, and cruising in the Arctic and sub-Arctic. J Heritage Tourism 5(4):351–364

Hall CM, Baird T, James M, Ram Y (2016) Climate change and cultural heritage: conservation and heritage tourism in the Anthropocene. J Heritage Tourism 11(1):10–24

Hänninen S, Sassi J (2009) Estimated nutrient load from waste waters originating from ships in the Baltic Sea area –Updated 2009. Report commissioned by the Finnish maritime administration. Espo: VTT Technical Research Centre of Finland

Harriott VJ (2002) Marine tourism impacts and their management on the great barrier reef. CRC Reef Research Centre Technical Report No. 46. Available: http://crcreef.jcu.edu.au/publications/techreport/pdf/Harriott46.pdf. Accessed 18 June 2013

Herz M (2002) Cruise control. A report on how cruise ships affect the marine environment. The Ocean Conservancy, Washington

Hoegh-Guldberg O, Mumby PJ, Hooten AJ, Steneck RS, Greenfield P, Gomez E, Harvell CD, Sale PF, Edwards AJ, Caldeira K, Knowlton N, Eakin CM, Iglesias-Prieto R, Muthiga N, Bradbury RH, Dubi A, Hatziolos ME (2007) Coral reefs under rapid climate change and ocean acidification. Science 318:1737–1742

Hübner A, Gössling S (2012) Tourist perceptions of extreme weather events in Martinique. J Dest Mark Manage 1:47–55

Hunter C, Green H (1995) Tourism and the environment: a sustainable relationship? Routledge, London
IPCC (2007) Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge
Jones R (2010) A risk management approach to climate change adaptation. In: Nottage R, Wratt D, Bornman J, Jones K (eds) Climate change adaptation in New Zealand: future scenarios and some sectoral perspectives. New Zealand Climate Change Centre, Wellington, pp 10–25
Jones AL, Phillips MR (eds) (2011) Disappearing destinations: climate change and future challenges for coastal tourism. CABI, Wallingford
Kaján E, Saarinen J (2013) Tourism, climate change and adaptation: a review. Curr Issue Tour 16(2):167–195
Klein CJ, Ferrari R (2015) Walk the talk, don't eat it: a call for sustainable seafood leadership from marine scientists. Environ Conserv 42(02):102–103
Kuoni (2013) Kuoni water management manual for hotels. http://www.kuoni.com/docs/kuoni_wmp_manual_0.pdf. Accessed 20 Nov 2013
Markus T, Huhn K, Bischof K (2015) The quest for sea-floor integrity. Nat Geosci 8:163–164
Millenium Assessment (2005) Living beyond our means: natural assets and human well-being. Available: http://www.millenniumassessment.org/documents/document.429.aspx.pdf. Accessed 20 Mar 2016
Moksness E, Dahl E, Støttrup J (2009) Integrated coastal zone management. John Wiley & Sons, Chichester
Molnar JL, Gamboa RL, Revenga C, Spalding MD (2008) Assessing the global threat of invasive species to marine biodiversity. Front Ecol Environ 6:485–492
Musa G, Dimmock K (eds) (2013) Scuba diving tourism. Routledge, Abingdon
Mycoo M (2014) Sustainable tourism, climate change and sea level rise adaptation policies in Barbados. Nat Res Forum 38(1):47–57
Nunn PD (2013) The end of the Pacific? Effects of sea level rise on Pacific Island livelihoods. Singapore J Trop Geogr 34:143–171
Orams M (1999) Marine tourism: development, impacts and management. Routledge, London
Rico-Amoros AM, Olcina-Cantos J, Sauri D (2009) Tourist land use patterns and water demand: evidence from the Western Mediterranean. Land Use Policy 26(2):493–501
Roberts CM (2002) Deep impact: the rising toll of fishing in the deep sea. Trends Ecol Evol 17(5):242–245
Rutty M, Scott D (2013) Differential climate preferences of international beach tourists. Climate Res 57(3):259–269
Rutty M, Scott D (2015) Bioclimatic comfort and the thermal perceptions and preferences of beach tourists. Int J Biometeorol 59(1):37–45
Scott D, Hall CM, Gössling S (2012a) Tourism and climate change: impacts, adaptation and mitigation. Routledge, London
Scott D, Simpson MC, Sim R (2012b) The vulnerability of Caribbean coastal tourism to scenarios of climate change related sea level rise. J Sustain Tour 20(6):883–898
Sharpley R, Telfer DJ (eds) (2014) Tourism and development: concepts and issues. Channel View Publications, Bristol
UNEP (2009) Report on the seminar "Coastal tourism in the mediterranean: adapting to climate change". Cagliari (Sardinia), Italy, 8–10 June 2009. United Nations Environment Programme (UNEP), République Française – Ministère de l'Écologie, du Développement et de l'Aménagement durables, United Nations World Tourism Organization (UNWTO), Priority Actions Programme, Paris
UNWTO (2007) Compendium of tourism statistics. World Tourism Organisation, Madrid
UNWTO (2015) Tourism highlights. Available: http://www.e-unwto.org/doi/pdf/10.18111/9789284416899. Accessed 16 Mar 2016
UNWTO (2016) International tourist arrivals up 4% reach a record 1.2 billion in 2015. Available: http://Media.unwto.Org/Press-release/2016-01-18/international-tourist-arrivals-4-reach-record-12-billion-2015. Accessed 16 Mar 2016

UNWTO-UNEP-WMO (2008) Climate change and tourism: responding to global challenges. United Nations World Tourism Organization (UNWTO), United Nations Environment Programme (UNEP) and World Meteorological Organization (WMO), UNWTO, Madrid

Wong PP (1998) Coastal tourism development in Southeast Asia: relevance and lessons for coastal zone management. Ocean Coastal Manage 38:89–109

Wong PP (2003) Tourism development and the coastal environment on Bintan Island. In: Gössling S (ed) Tourism and development in Tropical Islands: political ecology perspectives. Edward Elgar, Cheltenham, pp 263–282

Part VIII
Emerging Management Topics

Chapter 41
The Greening of Ports

Bénédicte Sage-Fuller

Abstract Ports are key players to implement the global policy of sustainable development. Indeed, ports are critical assets in the global economy, because they are essential to shipping and in turn, shipping is essential to trade. As such ports are not only required to "green" themselves, but they are also helping "greening" the planet. In Europe, the overwhelming majority of ports are actively engaged with environmental policy and legislation. They routinely monitor environmental issues on their grounds such as waste, energy consumption, water and air quality. Despite the very broad spectrum of types of ports (types of cargo, location, size, structure, etc.), and the financial challenge raised by the sustainable development agenda, ports are at the junction of global environmental policy and of the international legal framework of shipping and marine and coastal protection. Globally and locally, they have an enormous responsibility in the protection of the marine environment from potentially environmentally harmful activities such as shipping, marine and atmospheric pollution, IUU fishing and climate change. Examples of the role of ports in combating environmental degradation include Port State Control, which allows the operation worldwide of a harmonised system of control of international standards of safety of life, environmental protection and security. Another important role for ports relates to land use, and how they carry out development and expansion works, particularly when land reclamation, dredging and impact on protected nature reserves are involved. Other issues include climate change, Non Indigenous Aquatic Species and reception facilities in ports.

Keywords Ports • Sustainable development goals • Ecosystems—jurisdiction • Land use • Climate change • Non indigenous aquatic species • Pollution

B. Sage-Fuller
School of Law, University College Cork, Cork, Ireland
e-mail: b.Sage@ucc.ie

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_41

41.1 Introduction

Shipping represents about 80% of the total volume of goods transported worldwide, or 70% in value. It has sustained growth for the last 40 years, managing to even maintain high volumes of global shipments even through the 2008 financial crisis and its aftermath (UNCTAD 2015: 5). In this context, it is clear that ports are key assets in the global economy. Shipping underpins global trade, and ports underpin shipping. It is critical to maintain their competitiveness and their efficiency so that maritime transport can continue to carry world trade. Efforts to maintain efficiency also encompass environmental protection. Broad expansion, the development of infrastructures and superstructures, road and rail connections with hinterlands, the diversification of different types of trades (bulk, break bulk, containers, passengers, oil, gas, LNG, etc.) and the increasing size of ships calling in ports are challenges to the environmental status of ports. Ports affect their water, soil, air and land environment through daily operations and long-term developments and expansions. They are faced with issues of operational and accidental marine pollution in harbours, habitats and wetland conservation, seabed modification by dredging, land use in general, air pollution, wildlife protection. Ports host a nexus of operations on land and at sea and in this respect they come under a framework of legal obligations on environmental protection.

41.2 The Environmental Challenge in Ports

41.2.1 Environmental Management

A recent review by the European Sea Ports Organisation (ESPO) and EcoPorts on the engagement of ports with environmental protection shows that 92% of the 91 European ports surveyed have implemented an Environmental Policy, 90% maintain an inventory of relevant environmental legislation, and 89% keep an inventory of significant environmental aspects for their activities (ESPO and EcoPorts 2016: 3–4). ESPO and EcoPorts have also devised an Environmental Management Index (EMI), to measure the environmental engagement of ports with regard to several factors, each weighed according to its relative importance. There are ten such factors, including the criteria mentioned above, but also whether ports have a certified Environmental Management System, whether they have an environmental training programme for their employees, and whether they have outlined their environmental responsibilities for their key employees. The index was first calculated in 2013 and was 7.25, and in 2016 it measured 7.72, therefore indicating a significantly increased environmental awareness and engagement by ports (ESPO and EcoPorts 2016: 4). Further, the report shows which environmental issues are monitored by European ports, and their importance in terms of priority. Waste, energy consumption, water quality and air quality are the four most monitored issues. Air quality remains the top priority since 2013, and into 2016, and this is very much in line with recent EU legislative action in this area (ESPO and EcoPorts 2016: 7–8; EU Carbon Dioxide Monitoring Regulation 2015/757). Interestingly, the relationship of the port with its local community ranks high in the priorities of European ports: fourth in 2016, up from 6th in 2009 and 2013, whereas it did not appear in the top ten priorities before 2009. In parallel, the development of the port both on land and water and dredging have featured in the top ten priorities since the review by ESPO of the top environmental priorities in 1996. This could be seen as an increased awareness by ports of their role in environmental protection, and the necessity to engage with the local community as a key stakeholder. The report also highlights that ports can also "green" their activities by providing environmental friendly services to ships, notably through Onshore Power Supply (OPS), Liquefied Natural Gas (LNG) bunkering and by applying differentiated port charges to encourage ships to reach better environmental efficiency. In North America, similar awareness is noted (Walker 2016), as it is in Asia (Lam Jasmine and Notteboom 2014) and other parts of the world (UNCTAD 2015: 73).

41.2.2 Challenges and Difficulties

The review abovementioned is very useful to gauge European ports' level of engagement in environmental management. However it must be noted that many small ports rarely have the financial means to respond in a structured and continuous way to the relevant policy and legal requirements of environmental protection. For example, while the largest UK commercial ports have implemented one or other type of environmental management systems (ISO 14001 or the EcoPorts tools methodology), this concerns only ten ports in total: Port of London Authority, Port of Felixstowe, Harbour of Rye, Dover Harbour Board, Belfast Harbour Commissioners, Peterhead, Milford Haven and Shoreham port authorities. An estimated 700 smaller ports do not have ready access to existing environmental management programmes for financial reasons (Kuznetsov et al. 2015: 60). There is indeed a wide diversity of ports, according to, *inter alia*, their size, type of operations, infrastructure, type of ownership, geographic location, traffic volume. Large ports are vital to their national and regional economies for obvious reasons of trade, but smaller ports equally play a critical role in terms of tourism and fishing (Fenton 2015; Kotrikla et al. 2017; Puig et al. 2015).

41.3 Ports in the Global Context of Marine Environmental Protection

The efforts displayed by ports to engage with environmental protection and management must be understood in the global context of international environmental policy, and within the applicable legal framework. Indeed, while ports, in their different sizes and shapes, play a critical economic, societal and environmental role, they are all embedded in a global move to achieve better levels of environmental protection and sustainable development. Ports are at the junction between a global environmental policy, which embraces the principles of sustainable development and ecosystem approach, and the traditional framework of national boundaries on land and at sea.

41.3.1 Global Environmental Policy: Ecosystem Approach and Sustainable Development

Recent policy legal instruments at international and European levels have emphasised the ecosystem approach in the fight against environmental degradation. Goal 14 of the Sustainable Development Goals, adopted in September 2015 by the UN General Assembly, is "To conserve and sustainably use the oceans, seas and marine resources." More specifically, the second target of Goal 14 is to "sustainably manage and protect coastal and marine ecosystems." The United Nations policy document "The Future We Want" adopted in 2012 at the United Nations Conference on Sustainable Development in Rio de Janeiro (Rio+20) shows a commitment by the international community to "effectively apply an ecosystem approach and the precautionary approach in the management, in accordance with international law, of activities having an impact on the marine environment, to deliver on all three dimensions of sustainable development." (UNGA 2012: 158).[1] This call is reiterated in the last target of Sustainable Development Goal 14, which reminds us that UNCLOS and international law "provide the legal framework for the sustainable use of the oceans and their resources" (UNGA 2015: 23). Ports are directly concerned by this global policy, as they are key actors in the activity of maritime transport, which has an obvious direct impact on the marine environment. The 2012 UN policy further identifies specific issues affecting "Oceans and seas," and which are of immediate relevance to ports. Marine pollution by "marine debris, especially plastic, persistent organic pollutants, heavy metals and nitrogen-based compounds, from a number of marine and land-based sources, including shipping and land-run off" (UNGA 2012: 163) is seen as one such issues, which places ports at its core. Alien invasive species are also identified as a severe threat to the integrity of the coastal and marine environment (UNGA 2012: 164). There is a general commitment to implement the measures adopted by the International Maritime Organisation (IMO), and to develop those devised under the Global Programme of Action for the protection of the Marine Environment from Land-Based Activities. Added to this, the 2012 Rio+20 policy stresses without ambiguity the devastating effects of illegal, unreported and unregulated fishing (IUU fishing) for the marine environment and for coastal communities, and declares that the international community "recommit[s]" to "implementing, in accordance with international law, effective and coordinated

[1] See also the call for "area-based conservation measures, including marine protected areas, consistent with international law and based on best available scientific information," p. 177.

measures by coastal States, flag States, port States, chartering nations and the States of nationality of the beneficial owners and other who support or engage in illegal, unreported and unregulated fishing by identifying vessels engaged in such fishing and by depriving offenders of the benefits accruing from it." (UNGA 2012: 170).[2] Here again, ports are at the centre of the enforcement nexus of fishing regulations.

At European level, there are synergies between the EU's marine and water policies and laws, which also show the important role played by ports. The 2008 Marine Strategy Framework Directive (MSFD) aims at the establishment of the ecosystem approach to protect and preserve the marine environment:

"By applying an ecosystem-based approach to the management of human activities while enabling a sustainable use of marine goods and services, priority should be given to achieving or maintaining good environmental status, to continuing its protection and preservation, and to preventing subsequent deterioration" (EU Marine Strategy Framework Directive 2008/56/EC [MSFD], preamble: 8).

The preamble to the Directive refers to the objectives of other existing international instruments (Convention on Biological Diversity, HELCOM Convention, OSPAR Convention, Convention for the Protection of the Marine Environment and the Coastal regions of the Mediterranean, etc.) seen as essential to ensure a coordinated and harmonious approach to the management of the marine environment in Europe (MSFD, preamble: 19). Earlier in the decade, the EU's Water Framework Directive (WFD) had already been structured around the Ecosystem Approach, albeit without explicitly naming it. Article 1(a) explains that one of the objectives of the Directive is to "establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater, which: (a) prevents further deterioration and protects and enhances the status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystem" (EU Water Framework Directive 2000/60/EC). It was noted that the Water Framework Directive narrowly focused on the biological factors relating to ecosystems as they are influenced by natural and human-induced variations (De Jonge et al. 2012: 171; Hartnett et al. 2011: 812). Ports are at the heart of the implementation of both the MSFD and the WFD, as they are at the interface of the coastal and the marine environment. Port activities directly impact on the ecosystems of this environment, while at the same time being vital for their local, regional and national communities. The "greening of ports" is therefore inscribed in the overall philosophy of Sustainable Development which seeks to on the one hand to protect the environment from irreversible deterioration, and on the other facilitate economic and social development (Raakjaer et al. 2014; Brennan et al. 2014).

It is important to understand the legal and institutional setting of ports to measure their importance in this global environmental policy. Indeed, the principle of ecosystem approach poses challenges in terms legal jurisdictions, as typically an ecosystem knows no borders and encroaches across several national boundaries. In this context, ports are a central nexus.

---

[2] There is also a call to ratify the FAO Agreement on Port State Measures to Prevent, deter and Eliminate Illegal, Unreported and Unregulated Fishing, p. 171.

41.3.2 The National and International Legal Framework

Port authorities may take various forms and operate under various types of ownership. Despite this, they remain entrusted with regulatory functions that are determined at State level. Generally, they will have the powers to regulate all aspects of port activities, such as navigation, the prevention of pollution and protection of the environment, the processes of loading and unloading of goods and embarkation of passengers, the health and safety of workers and persons present on port grounds, the movement and handling of hazardous substances, the levy of port dues, and certain aspects of port developments. A port may be a State-owned port authority, a government department, an agency or even a public trust. It may also be a company operating under the same rules as any other limited liability company. For example, the Maritime and Port Authority of Singapore is a typical State-owned statutory body which operates the port of Singapore through the PSA Corporation, a State-owned company. The port of Dover is under the authority of the Dover Harbour Board, which is a public trust under British Common Law. The Port of San Francisco comes under the Board of Commissioners, who are appointed directly by the Mayor and confirmed by the City's Board of Supervisors. Dublin Port and Port of Cork, in Ireland, and Sydney Ports Corporation in Australia take the shape of State-owned companies. In Australia, the Port of Brisbane Pty Ltd. manages and operates the Port of Brisbane under a 99-year lease from the Queensland government. Port of Brisbane Pty Ltd. is itself owned by a consortium of four shareholders: the *Caisse de dépôt et placement du Québec*, Melbourne-based IFM Investors, the Queensland Investment Corporation, owned by the Queensland Government, and the Abu Dhabi Investment Authority, wholly owned by the Government of the UEA (Port of Brisbane n.d.). This example shows that the ownership structure can also be very complex. Generally, ownership of the land remains with State authorities, which then organise different types of leases or concession agreements as regards the superstructure, the infrastructure and the provision of services (Farrell 2012).

The regulation of navigation in harbours is an integral part of the environmental protection role of ports. Ports have generally full control over ships calling at their berths, as they are located within the internal waters of a State. This is called the territorial sovereignty of the port State, and it is usually exercised through the role of the harbour master. The harbour master has a general duty to regulate navigation in the port, for example in the UK this is done under Sect. 52 of the 1847 Harbours, Docks and Piers Clauses Act. Specific statutory duties and powers enable the harbour master to enforce the standards of key international conventions relating to navigation and pollution control, such as MARPOL 73/78 Annexes I, II, IV and V (MARPOL 73/78) on the handling and discharge of waste from ships, the Oil Pollution Response and Preparedness Convention (OPRC 1990), requiring ports to have in place oil pollution response plans.

Globally, ports have an enormous responsibility in the protection of the marine environment from many potentially harmful activities, including shipping, marine and atmospheric pollution, Illegal, Unreported and Unregulated (IUU) fishing, climate change and the violation of seafarers' rights. Indeed, ports are the natural point of control of enforcement of not only national laws on immigration, customs, sanitation and security, but also of internationally agreed and applicable standards relating to activities occurring not only in the harbour area, but also in the maritime zones of the port State and of other States and areas beyond national jurisdiction (high seas and the Area)[3] (Ng and Son 2010; Winnes et al. 2015). In recent years the subject matter of port State jurisdiction has received attention by legal academics and practitioners (Koppela 2016; Molenaar 2015; Molenaar 2007). Indeed, ports are increasingly seen as being "the first point of contact for industries engaged in activities harmful to the global commons" (Koppela 2016: 90), and harmful to the interests of the international community generally. In this respect, port State jurisdiction is developed as a tool to ensure the application of important standards for the protection of interests common to States individually and to the globalised international community, including the "global commons." Several key provisions in the UN Convention on the Law of the Sea (UNCLOS 1982) establish the principle of port State jurisdiction, and determine its extent. First, Sect. 211(3) allows that port States enact specific legislation as a condition of entry into its ports relating to the prevention, reduction and control of the marine environment, provided due publicity is made about it. Sect. 218(1) and (2) enable a port State to conduct investigations and institute proceedings against a ship with regard to any discharge in violation of applicable international rules and standards that occurred outside of the national jurisdiction of that State or of another State, that is to say in areas outside State jurisdiction. Finally, article 219 established the right of a port State to take administrative measures against ships within their ports that are in violation of applicable international rules and standards relating to the seaworthiness of vessels and may cause damage to the marine environment. There is therefore a legitimate jurisdictional basis for ports to take action as regards discharges that occurred even outside of the port area, and as regards the violation of standards of seaworthiness, that is to say standards relating to the Construction, Design, Equipment and Manning of ships, and that are international in nature.

41.4 An Example of the Role of Ports to Combat Marine Pollution from Ships: Port State Control

The system of Port State Control (PSC) is a key example of the role of ports in the action against marine environmental degradation. Through PSC, ports verify the application of the relevant international obligations binding ship owners and ship masters when the ships voluntarily call to their berths. Port State Control indeed complements flag State jurisdiction, which gives primary responsibility to the State

[3] The Area is defined in Article 1(1) of UNCLOS as: "the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction".

of registry of the ship for the application of the relevant international standards of safety and environmental protection. Through several networks of Port State Control agreements that cover all countries in the world with ports and a coastline, ships are submitted to a relatively uniform regime of control of applicable international norms.

There are nine regional Port State Control (PSC) Memoranda of Understanding (MOU), which effectively cover the whole surface of the globe. They are:

- Paris MOU of 2 December 1980.
- Viña del Mar MOU of 5 November 1992.
- Tokyo MOU of 1 December 1993.
- Mediterranean MOU of 11 July 1997.
- Caribbean MOU of 9 February 1996.
- Indian Ocean MOU of 5 June 1998.
- Abuja MOU of 22 October 1999.
- Black Sea MOU of 1 April 2000.
- Riyadh MOU of 30 June 2004.

The United States are not signatory to any MOU on Port State Control, but they operate their own PSC system. In other words, ships navigating the world's sea routes and calling at ports are always subject to a regime of PSC inspections, and cannot have recourse to "port shopping" (Bang and Jang 2012: 172) to avoid compliance with applicable environmental and safety standards. In total, 145 States are part of the PSC system (McCarthy and Sage-Fuller, Chap. 38), through the various MOUs. What makes PSC effective is that the various MOUs have for objective the implementation of standards established in applicable international conventions on maritime safety. Sect. 1.2 of the Paris MOU for example states that each party will:

"Maintain an effective system of Port State Control with a view to ensuring that, without discrimination as to flag, foreign merchant ships calling at a port of its State, or anchored off such a port, comply with the standards laid down in the relevant instruments listed in Sect. 2." (Paris MOU).

Sect. 2 then goes on to list the "relevant instruments." All MOUs integrate the five most prominent international conventions:

- 1966 International Convention on Load Lines (LL).
- 1973 International Convention for the Prevention of Pollution from Ships (MARPOL).
- 1974 International Convention for the Safety of Life at Sea (SOLAS).
- 1978 International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW).
- 1972 Convention on the International Regulations for Preventing Collisions at Sea (COLREG).

Other conventions that are integrated by five or six MOUs include the SOLAS Protocols of 1978 and 1988, the Tonnage Convention of 1969 and ILO 147 Convention of 1976. Through this system, ports facilitate a system of targeting, inspections and detentions of sub-standard ships by Port State Control inspectors. Indeed, Sect. 2.3 specifies that States party to the MOU apply the instruments to which they are party, as amended and up to date. Further, the ships flying the flag of States not party to certain instruments do not receive a more favourable treatment according to Sect. 2.4, and a specific procedure applies to them (Annex 1). Annex 7 to the Paris MOU specifies the "generic and historic parameters" used to identify and target ships for inspection. These criteria include:

- The type of ship: chemical tanker, gas carrier, oil tanker, bulk carrier or passenger ship;
- The age of the ship;
- Its flag's classification (White, Grey or Black);
- The results of the IMO Audit, conducted in accordance with IMO Resolution 1067(28), Framework and Procedures for the IMO Member State Audit Scheme;
- Performance of the classification society;
- Shipping company performance based on its detention and deficiency history;
- Ship deficiency index;
- Ship detention index.

Other criteria refine the targets for inspection, and include reporting by another Member State, ships involved in a collision, grounding or stranding on their way to port, ships accused of having violated standards on the discharge of harmful substances or effluents, ships that have manoeuvred erratically, that have a reported problem with their cargo, etc. (Annex 7, Paris MOU; Cariou and Wolff 2015).

41.5 An Example of the Role of Ports to Combat Land-Based Pollution and Environmental Degradation

The sustainable development of ports emphasise their strategic environmental role as regards land use. The development and expansion of ports normally requires the application of planning and environmental laws. Construction work, land reclamation and dredging are specific types of port activities that are regulated for environmental protection purposes. For example, in Europe, the Wild Birds Directive of 1979 (codified in 2009) (EU Wild Birds Directive 2009/147/EC) and the Habitats Directive of 1992 (EU Habitats Directive 92/43/EEC) have entirely changed the legal framework within which ports carry out their activities and expansions (ESPO 2015; Stojanovic et al. 2006). The two Directives are seen as the backbone of EU nature conservation law. They establish a detailed series of obligations for the conservation of species and their habitats, when the latter are at risk of being negatively affected by port activities, such as dredging or the construction of a new terminal. The core of EU nature conservation law was to create a network of protected sites under the Directives, commonly known as *Natura 2000* sites, on land, in coastal areas and estuaries. These sites are designated under the Birds Directive as Special Protected Areas (SPAs) and under the Habitats Directive as Special Areas of Conservation (SACs). They benefit from specific measures of protection in order to protect species and their habitats, as listed in annexes to the directives. This way, throughout Europe, over 5.5 million hectares of estuaries, coastal lagoons, large shallow inlets and bays, sandbanks, mudflats and sand flats are designated as *Natura* 2000 sites. Europe also boasts some 1200 merchant ports along its 100,000 km of coastline, which have had to integrate their legitimate developmental plans and ambitions with the EU's objectives of environmental protection and nature conservation (EU Commission, Guidance Document 2011: 10). Capital and maintenance dredging, shipping operations, land reclamation and land use and the presence of industries on port grounds are all likely to affect Natura 2000 sites. Article 6 (2)–(3) of the Habitats Directive requires an "appropriate assessment" of the "likely significant impacts" of proposed projects on the sites, and the consideration of alternatives in the event that adverse effects can be foreseen. In addition, Strategic Environmental Assessments (SEAs) and Environmental Impact Assessments (EIAs) are also required under EU law (EU SEA Directive 2001/42/EC), (EU EIA Directive 2001/92/EU), to determine the impacts on the environment of proposed developments. Under article 6(4) of the Habitats Directive, if "likely significant impacts" are identified as a result of the Appropriate Assessment, the projects will not be allowed to go ahead, unless it can be demonstrated that there are "imperative reasons of overriding public interest" to justify them. In this case, compensatory measures must be adopted to protect the overall coherence of the *Natura* 2000. The constraints imposed by the *Natura* 2000 network of protected sites should be considered in the wider context of land management by ports, particularly the general land leasing trend observed for the past 20 years in ports. Indeed, ports more and more adopt a model of landlord port, whereby they keep ownership of their asset, but lease out various parts of it to interested parties, for varying durations (Farrell 2012: 11). An ESPO survey in 2010 found that 60% of European ports award port land to third parties, durations of between 4 and 65 years (ESPO 2011: 30). The survey found that while there were divergences between ports' practices on the matter, there were significant points of convergence on the contents of the various types of agreements. For example, port authorities indicated that they viewed these agreements as a powerful factor to control and influence the future prosperity of ports and their communities. Indeed, clauses are inserted in concession agreements, which role is to optimize the resources of the land, such as throughput clauses and renewal and extension clauses, penalty clauses. Interestingly however, it is noted there is considerable scope to integrate purposeful environmental clauses in concession agreements, beyond merely stipulating that the concessionaires will be required to comply with environmental legislation. Specific environmental performance and strategy clauses, for example relating to the compulsory use of specified environmental management and reporting systems, and emissions levels can help considerably furthering the "greening" agenda of ports (Notteboom 2010; Port Strategy n.d.).

41.6 Ports' Role Regarding Specific Issues

41.6.1 Climate Change and Air Pollution

The mechanism of Port State Control is believed to be called to play a significant role in the global action against Climate Change and air pollution in general (Bailey and Solomon 2004). Goal 13 of the United Nations' Sustainable Development Agenda 2030 concerns Climate Change, and Goal 14 is to prevent and reduce significantly by 2025 marine pollution of all kinds, including by air (UNGA 2015). The regulation of shipping for environmental protection purposes is firmly framed in the terms of international environmental protection globally, including in relation to air pollution by ships. The 2015 Paris Agreement on Climate Change ties in with the IMO Global Maritime Energy Efficiency Project which aims to improve vessels efficiency and help reduce their carbon footprint (IMO 2015). In this context, the adoption by the IMO Marine Environmental Protection Committee (MEPC) of amendments to Annex VI of MARPOL in July 2011 (MEPC 2011) is likely to be a major contributor to the Global Maritime Energy Efficiency Project mentioned above. In force on 1 January 2013, the amendments set mandatory CO2 emissions, and has been structured by IMO in the shape of the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP). The EEDI gives a measure the energy efficiency of equipment and engines on ships. The index provides a specific figure or an individual ship design in grams of CO2 per ship tonne-mile. It is planned to tighten targets every 5 years. Initially adopted for oil tankers, bulk carriers, gas carriers, general cargo ships, container ships, refrigerated cargo carriers and combined carriers, the EEDI was extended in 2014 to LNG carriers, ro-ro cargo ships (vehicles and passenger ships) and cruise ships having non-conventional propulsion. Therefore nowadays, the EEDI applies to 85% of ships generating pollution.

The shipping industry is responsible for 10–15% of global nitrogen oxides (NOx) emissions, and 4–9% of global sulphur oxides (SOx) emissions (Gritsenko and Yliskylä-Peuralahti 2013: 10). There is already a regulatory framework designed to be effective at international level, through Annex VI of MARPOL 73/78, in force since 19 May 2005 (and revised in 2008) which aims at gradually reducing emissions of SOx, NOx and particulate matter. The sulphur oxides emission limits are currently at 3.5%, and they will be further reduced to 0.5% by 1 January 2020. The nitrogen oxides emissions are set according to the year of construction of ships, and are also being gradually tightened (IMO Sulphur Limit Emissions n.d.). Annex VI also created Emission Control Areas (ECAs) for both nitrogen and sulphur oxides (Baltic and North Sea, North America, Japan-East-Asia and US-Caribbean Sea emissions), where emissions limits are even stricter (0.1% SOx since 1 January 2015 (IMO Prevention of Air Pollution from Ships n.d.). The burden of complying with these international standards is substantial for the shipping industry, and ports are called once again to play a crucial role in ensuring that standards are adhered to.

In this respect, Port State Control will be important to check on the application of the SOx and NOx emission standards, for instance by checking the Air Pollution Prevention Certificates issued by the national administrations, or by inspecting the Exhaust Gas Cleaning Systems (or "open loop washwater scrubbers") fitted on board ships that can clean exhausts when the use of low content SOx oil was not possible (Gritsenko and Yliskylä-Peuralahti 2013: 9).

41.6.2 Non-indigenous Aquatic Species

One area where ports have a critical role to play (Verna and Harris 2016; Liu et al. 2014), relates to Non-Indigenous Aquatic Species (NIAS) that are involuntarily transferred throughout the globe by the discharge of ballast water (see also Köck and Magsig, Chap. 48). Ballast water is used to ensure the stability of ships, and because of the dramatic increase in maritime transport, the spreading of NIAS has become an alarming problem endangering the marine environment. NIAS include bacteria, microbes, invertebrates, eggs, cysts, larvae, etc. which settle in new environments, often at the expense of indigenous species. The IMO considers that NIAS is "one of the greatest threats to the ecological and economic well-being of the planet" (IMO Ballast Water Management n.d.). In 2009 it was estimated that because 10 billion tons of ballast water are discharged every year globally, about 3000 species of plants and animals are transferred to new ecosystems every day (UNGA 2009: 244). NIAS can devastate natural ecosystems and undermine biodiversity, as well as threaten human health. For example, a strain of cholera previously only known in Bangladesh was found simultaneously in three Peruvian ports in 1991, before spreading to the whole of South America, affecting over 1 million people and killing at least 10,000. The zebra mussel, native to the Black Sea, was introduced in Western and Northern Europe and the East coast of North America. It disrupted indigenous ecosystems, by displacing native species and altering habitats. It also severely damaged human infrastructures and vessels, costing between 750 million and 1 billion USD to the US government in the period 1989–2000 (IMO Global Ballast Water Management n.d.). Some port States have already adopted measures to counter the problem (Verna and Harris 2016; Liu et al. 2014; Lehtiniemi et al. 2015). The IMO introduced international guidelines for the control and management of ships' ballast water in 1991 (MEPC 1991), and regularly updated them (IMO 1993; IMO 1997). In 2004, the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) was adopted. It requires putting in place a ballast water management plan, to carry a Ballast Water Record Book and to carry out ballast water management procedures in accordance with agreed standards. These standards are the ballast water exchange standard (95% efficiency per volumetric exchange of ballast water) and the ballast water performance standard (an agreed number of organisms per unit volume). Further, if management systems use Active Substances to neutralise NIAS, they must be approved by IMO to assess the levels of risk of those substances to the environment, human health, property or resources. The Convention entered into force on 8 September 2017 (IMO Status of Conventions n.d.).

41.6.3 Port Reception Facilities for Pollutants

Another issue that shows the role that ports have to play in the fight against the degradation of the marine environment by shipping relates to the availability in ports of reception facilities for various types of pollutants and substances that ships carry. Annexes I (oil), II (noxious liquid substances in bulk), IV (sewage), V (garbage) and VI (air pollution) of MARPOL (MARPOL 73/78) all require that specific waste reception facilities are made available to ships calling at loading terminals, repair ports and other ports where ships carrying these pollutants are calling. There is an uneven degree of compliance with these requirements, which has prompted the MEPC to adopt several Action Plans (MEPC 2006a; MEPC 2006b; MEPC 2012; MEPC 2014) to tackle this issue. Indeed, without adequate port reception facilities, compliance with the zero discharge at policy is very difficult.

41.7 Summary and Perspectives

This overview of the environmental legal framework applicable to ports shows that they are key players to gradually implement the ethos and policy of sustainable development in respect of their own activities, particularly as regards their development (Sislian et al. 2016). They are obliged to comply with demanding environmental constraints (EIA, mitigating measures to preserve the conservation status of protected areas, water quality standards, etc.). They are expected to work proactively with other stakeholders towards the application of precautionary and ecosystem approaches for the improvement of the coastal and marine environment locally, regionally and globally. Ports are often near cities, and the social aspect of their activities is reflected in their relationship with their neighbours in terms of employment, connectivity for industries but also environmental quality, particularly air quality. What is also remarkable, is that the globalisation trend has also made ports a key link in the global environmental law enforcement chain. Port State jurisdiction and Port State Control have gained considerable importance, and are seen now as essential in the fight against marine pollution from ships, IUU fishing and climate change. Ports are not only required to "green" themselves, they are helping in "greening" the planet.

References

Bailey D, Solomon G (2004) Pollution prevention at ports: clearing the air. Environ Impact Assess Rev 24:749–774

Bang HS, Jang DJ (2012) Recent developments in regional memorandums of understanding on port state control. Ocean Dev Int Law 43:170–187

Brennan J, Fitzsimmons C, Gray T, Raggatt L (2014) EU marine strategy framework directive (MSFD) and marine spatial planning (MSP): which is the more dominant and practicable contributor to maritime policy in the UK? Mar Policy 43:359–366

Cariou P, Wolff FC (2015) Identifying substandard vessels through port state control inspections: a new methodology for concentrated inspection campaigns. Mar Policy 60:27–39

De Jonge VN, Pinto R, Turner RK (2012) Integrating ecological, economic and social aspects to generate useful management information under the EU directives' 'ecosystem approach'. Ocean Coast Manage 68:169–188

European Commission (2011) Guidance document - the implementation of the birds and habitats directives in estuaries and coastal zones, with particular attention to port development and dredging. Publications Office of the European Union, Luxemburg

European Sea Ports Organisation (2011) European port governance- report of an enquiry into the current governance of European seaports. ESPO Publications, Brussels

European Sea Ports Organisation/EcoPorts (2016) Port environmental review 2016. ESPO/Ecoports Publications, Brussels

European Sea Ports Organisation/European Federation of Inland Ports Position paper of the European Sea Ports Organisation and the European Federation of Inland Ports on the fitness checks of the birds and habitats directives. (2015). http://www.espo.be/views/espo-efip-position-paper-on-the-birds-and-habitats. Accessed 17 October 2017

European Union Directive 92/43/EEC of the European Union and of the Council of 21 may 1992 on the conservation of natural habitats and of wild fauna and flora. Official Journal of the European Union, 22.7.1992, L 206/7 (n.d.-a)

European Union Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy. Official Journal of the European Union, 22.12.2000, L 327/ 73 (n.d.-b)

European Union Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the evaluation of the effects of certain plans and programmes on the environment (SEA Directive). Official Journal of the European Union, 21.7.2001, L 197/30 (n.d.-c)

European Union Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). Official Journal of the European Union, 25.6.2008, L 164/19. Preamble, p. 8, 19 (n.d.-d)

European Union Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (codified version). Official Journal of the European Union, 26.1.2010, L 20/7 (n.d.-e)

European Union Directive 2011/92/EU of the European Parliament and of the Council on the assessments of the effects of certain public and private projects on the environment (codified version) of 13 December 2011. Official Journal of the European Union, 28.1.2012, L26/1. As amended by Directive 2014/52/EU of 16 April 2014. Official Journal of the European Union, 25.4.2014, L124/1 (n.d.-f)

European Union Regulation EU/2015/757 of the European Parliament and of the Council of 29 April 2015 on the monitoring and verification of carbon dioxide emissions from maritime transport, and amending Directive 2009/16/EC. Official Journal of the European Union, 19.5.2015, L123/55 (n.d.-g)

Farrell S (2012) The ownership and management structure of container terminal concessions. Marit Policy Manage 39:7–26

Fenton P (2015) The role of port cities and transnational municipal networks in efforts to reduce greenhouse gas emissions on land and at sea from shipping- an assessment of the world port climate initiative. Mar Policy 75:271–277. doi:10.1016/j.marpol.2015.12.012

Gritsenko D, Yliskylä-Peuralahti J (2013) Governing shipping externalities: Baltic ports in the process of SOx emission reduction. Marit Stud 12:10–31

Hartnett M, Wilson JG, Nash S (2011) Irish estuaries: water quality status and monitoring implications under the water framework directive. Mar Policy 35:810–818

International Maritime Organisation (1991) Marine Environmental Protection Committee Resolution 50(31) on the International Guidelines for preventing the Introduction of Unwanted Aquatic Organisms and Pathogens from Ships' Ballast Water and Sediment Discharges, 1–5 July 1991

International Maritime Organisation (1993) Assembly Resolution A774 (18) on Guidelines for preventing the introduction of unwanted organisms and pathogens from Ships' ballast waters and sediment discharges

International Maritime Organisation (1997) Assembly Resolution A868 (20) on Guidelines for the Control and Management of Ships' Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens

International Maritime Organisation (2006a) Marine Environmental Protection Committee Resolution 54 of March 2006, development of a port reception facility database as part of the IMO Global Integrated Shipping Information System (GISIS)

International Maritime Organisation (2006b) Marine Environmental Protection Committee 55 of October 2006 on Action Plan to tackle the inadequacies of port reception facilities

International Maritime Organisation (2011) Marine environmental protection Committee Resolution 203(62), MEPC 62, July 2011

International Maritime Organisation (2012) Marine Environmental Protection Committee Resolution 63 of March 2012 on amendments to MARPOL Annex V to facilitate Small Island Developing States' compliance

International Maritime Organisation (2014) Marine Environmental Protection Committee Resolution 66 of April 2014, circular MEPC 1/circ834 on the Consolidate guidance for port reception facility providers and users

International Maritime Organisation (2015) Update on IMO's work to address emissions from fuel used for international shipping, Note by the International Maritime Organisation to the forty-third session of the Subsidiary Body for Scientific and Technological Advice (SBSTA 43), 1–4 December 2015

International Maritime Organisation Ballast water management. (n.d.-a). http://www.imo.org/en/OurWork/Environment/BallastWaterManagement/Pages/Default.aspx. Accessed 20 May 2017

International Maritime Organisation Frequently asked questions- sulphur limits in emission control areas from 1 January 2015. (n.d.-b). http://www.imo.org/en/MediaCentre/HotTopics/GHG/Documents/sulphur%20limits%20FAQ.pdf. Accessed 20 May 2016

International Maritime Organisation Global ballast water management- ten of the most unwanted. (n.d.-c). http://globallast.imo.org/wp-content/uploads/2015/01/TenMostWanted_English.pdf. Accessed 20 May 2016

International Maritime Organisation Prevention of air pollution from ships. (n.d.-d). http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Air-Pollution.aspx. Accessed 20 May 2016

International Maritime Organisation Status of conventions as of 13.9.2017. (n.d.-e). http://www.imo.org/en/About/Conventions/StatusOfConventions/Pages/Default.aspx. Accessed 20 September 2017

Koppela S (2016) Port-State jurisdiction, extraterritoriality, and the protection of global commons. Ocean Dev Int Law 47:89–130

Kotrikla AM, Lilas T, Nikitakos N (2017) Abatement of air pollution at an agean island port utilizing shore side electricity and renewable energy. Mar Policy 75:238–248. doi:10.1016/j.marpol.2016.01.026

Kuznetsov A, Dinwoodie J, Gibbs D, Sansom M, Knowles H (2015) Towards a sustainability management system for smaller ports. Mar Policy 54:59–68
Lam Jasmine SL, Notteboom T (2014) The greening of ports: a comparison of port management tools used by leading ports in Asia and Europe. Transp Rev 34:169–189
Lehtiniemi M, Ojaveer H, David M, Galil B, Gollash S, Mckenzie C, Minchin D, Occhipinti-Ambrogi A, Olenin S, Pederson J (2015) Dose of truth- monitoring marine non-indigenous species to serve legislative requirements. Mar Policy 54:26–35
Liu TK, Chang CH, Chou ML (2014) Management strategies to prevent the introduction of non-indigenous aquatic species in response to the ballast water convention in Taiwan. Mar Policy 44:187–195
Molenaar EJ (2007) Port state jurisdiction: towards comprehensive, mandatory and global coverage. Ocean Dev Int Law 38:225–257
Molenaar EJ (2015) Port and coastal states. In: Rothwell DR, Oude Elferink AG, Scott K, Stephens T (eds) The Oxford handbook of the law of the sea. Oxford University Press, Oxford, pp 280–303
Ng AKY, Son S (2010) The environmental impacts of pollutants generated by routine shipping operations on ports. Ocean Coastal Manage 53:301–311
Notteboom T (2010) Green concession agreements - how can port authorities integrate environmental issues in the terminal awarding process? Port Technol Int 47:36–38
Paris Memorandum of Understanding on Port State Control (2015). As amended up to July 1, 2015. https://www.parismou.org/system/files/Paris%20MoU%2C%20incl%2038th%20amendment%20%28final%29_0.pdf. Annex 8. Accessed 16 June 2016
Port of Brisbane, About us. (n.d.). https://www.portbris.com.au/about-us/about-us. Accessed 19 May 2016
Port Strategy Go green early in concession negotiations. (n.d.). http://www.portstrategy.com/news/environment/green-leases. Accessed 19 May 2016
Puig M, Wooldridge C, Casal J, Darbra RM (2015) Tool for the identification and assessment of environmental aspects in ports (TEAP). Ocean Coastal Manage 113:8–17
Raakjaer J, Van Leeuwen J, Van Tatenhove J, Hadjimichael M (2014) Ecosystem-based marine management in European regional seas call for nested governance structures and coordination – a policy brief. Mar Policy 50:373–381
Sislian L, Jaegler A, Cariou P (2016) A literature review on port sustainability and ocean's carrier network problem. Res Transp Bus Manage 19:19–26. doi:10.1016/j.rtbm.2016.03.005
Stojanovic TA, Ormerod SHD, Wooldridge CF (2006) The impact of the habitats directive on European port operations and management. GeoJournal 65:165–176
UNCTAD (United Nations Conference on Trade and Development) (2015) Cooperation, training and development: review of maritime transport 2015. United Nations Publications, New York
United Nations (1982) United Nations Convention on the Law of the Sea. 1833 UNTS 3
United Nations (2009) General assembly resolution a/64/66/Add1, oceans and law of the sea-report of the secretary general, 25 November 2009
United Nations (2012) General assembly resolution 66/288, the future we want, 11 September 2012
United Nations (2015) General assembly resolution A/Res/70/1, transforming our world: the 2030 agenda for sustainable development, 25 September 2015
Verna DE, Harris BP (2016) Review of ballast water management policy and associated implications for Alaska. Mar Policy 70:13–21
Walker TR (2016) Green marine: an environmental program to establish sustainability in marine transportation. Mar Pollut Bull 105:199–207
Winnes H, Styhre L, Fridell E (2015) Reducing GHG emissions from ships in port areas. Res Transp 17:73–82
1966 International Convention on Load Lines (LL), 640 UNTS 133 (n.d.)
1969 International Convention on Civil Liability for Oil Pollution Damage (1969 CLC), 973 UNTS 3

1969 International Convention on Tonnage Measurement of Ships (Tonnage), 1291 UNTS 3 (n.d.)
1972 Convention on the International Regulations for Preventing Collisions at Sea (COLREG), 1050 UNTS 16 (n.d.)
1973 International Convention for the Prevention of Pollution from Ships (MARPOL), 1340 UNTS 184 and 1978 Protocol relating to the International Convention for the Prevention of Pollution from Ships, 1340 UNTS 61. Annex I (Oil) Regulation 38. Annex II (Noxious liquid substances in bulk) Regulation 18, Annex IV (Sewage) Regulation 12, Annex V (Garbage) Regulation 7 and Annex VI (Air pollution) Regulation 17 (n.d.)
1974 International Convention for the Safety of Life at Sea (SOLAS), 1184 UNTS 278, as amended by the 1978 Protocol relating to the International Convention for the Safety of Life at Sea, 1226 UNTS 237 and the 1988 Protocol relating to the International Convention for the Safety of Life at Sea, IMO Doc.: HSSC/CONF/11 (n.d.)
1976 ILO Convention No. 147 Concerning Minimum Standards on Merchant Ships (ILO 147), 1259 UNTS 335 (n.d.)
1978 International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), 1361 UNTS 2; as amended by the 1995 Protocol (Amendments to the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers 1978) 2052 UNTS 94) and the Manila Amendments (Amendments to the annex to the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978) STCW/CONF.2/33 (n.d.)
1979 International Convention on Maritime Search and Rescue (SAR), 1405 UNTS 97 (n.d.)
1982 Memorandum of Understanding on Port State Control in Implementing Agreements on Maritime Safety and Protection of the Marine Environment (Paris MOU), 21 I.L.M. 1 (1982)
1982 United Nations Convention on the Law of the Sea (UNCLOS) (1833) UNTS:3
1992 Protocol to amend the International Convention on Civil Liability for Oil Pollution Damage of 29 November 1969 (CLC PROT 1992) (1956) UNTS:255
1996 International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea (HNS), 35 I.L.M. 1415 (1996); as amended by the 2010 Protocol to the International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea, IMO Doc. LEG/CONF.17/10
2001 International Convention on the Control of Harmful Anti-Fouling Systems on Ships (Anti-Fouling Convention), (2008) ATS 15/AFS/CONF/26
2004 International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWC), IMO Doc. BWM/CONF/36 (n.d.)
2006 Maritime Labour Convention (MLC), 45 I.L.M. 792 (2006)

Chapter 42
Offshore Windfarms

Greg Severinsen

Abstract The Earth is endowed with a bounty of natural energy sources. So far, fossil fuels have simply proven the simplest to exploit on a large scale. But we have reached a point where the governments of most developed countries have recognised the perils of fossil fuel reliance—for both energy security and environmental reasons—and responded by (to varying extents) consciously diversifying national energy portfolios. Globally, wind generation is a small but growing source of electricity, and offshore wind is making great strides. This chapter considers offshore wind energy specifically, the management and regulatory challenges it poses, and emerging best practice in this relatively new area. It concludes that strategic marine spatial planning, an ecosystem approach to environmental impact assessment, and the precautionary approach are becoming three vital tools in striking an appropriate balance between the need to deploy offshore wind generation on the one hand, and the need to safeguard the marine environment on the other.

Keywords Offshore wind farms • Marine regulation • Marine management • Marine spatial planning • Environmental impact • Environmental effects • Precaution

42.1 Introduction

The Earth is endowed with a bounty of natural energy sources. So far, fossil fuels have simply proven the simplest to exploit on a large scale. But we have reached a point where the governments of most developed countries have recognised the perils of fossil fuel reliance—for both energy security and environmental reasons—and responded by (to varying extents) consciously diversifying national energy portfolios. New Zealand is a prime example, where renewables account for over 70 percent of total electricity generation (Ministry of Economic Development 2011). Globally,

G. Severinsen, B.A./L.L.B.(Hons.), Ph.D.
Faculty of Law, Victoria University of Wellington, Wellington, New Zealand
e-mail: greg.severinsen@gmail.com

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_42

wind generation is a small but growing source of electricity, and offshore wind is making great strides (International Energy Agency 2013). This chapter considers offshore wind energy specifically, the management and regulatory challenges it poses, and emerging best practice in this relatively new area.

42.2 Opportunities and Challenges for Offshore Wind Farm Deployment

Offshore wind generation, simply put, involves the harnessing of energy from natural movements in the air in offshore areas. The technology involved is basically the same as in onshore projects, but the naturally strong and less turbulent winds occurring in some offshore locations present an attractive prospect; although often hard to predict, they can offset the substantially higher costs involved in operating in the marine environment (Scott 2006: 89–118; Ministry for the Environment 2005). The wind turns the blades of a turbine, and the energy generated from this movement is converted into electrical energy and fed into the grid.

The last decade has seen a proliferation of wind farm developments offshore, which currently comprise the leading form of offshore energy (Appiott et al. 2014: 58–64). This has been especially noticeable in the northern part of Europe (Long 2013: 15–52; Kaplan 2004: 177–219), with concerns over nuclear generation, climate change and energy security at the foundations of policies that are driving development (Scott 2006: 89–118; Long 2014: 690–715; see also Dir 2009/28/EC; Barton et al. 2004; Barnes 2014: 573–599). The United Kingdom now possesses a number of offshore projects, including the large “London Array” at the approaches of the Thames, and many exist also in the low countries, Germany and Sweden (Scott 2006: 89–118; International Energy Agency 2013). Chinese developments are expected to increase significantly (Long 2014: 690–715). The United States is also taking the first (albeit somewhat faltering) steps down the road to deployment, with an approved project in Nantucket Sound.

Offshore wind farms represent a significant opportunity for sustainable global energy. However, they also present substantial challenges. If it were simple to do, many more projects would exist. Such challenges are of several kinds: operational, commercial, legal and policy. Operational and commercial hurdles to the deployment of offshore wind farms are substantial, but appear to be steadily reducing. Technical innovation has played a large role here. Historically, offshore wind generation has been confined to shallow coastal waters (of up to 40–50 m) (Scott 2006: 89–118; Ministry for the Environment 2005). However, recent technological advancements have enabled the construction of turbines in deeper waters, and “floating” turbines, although perhaps not yet commercially viable, are capable of operation many miles from shore (International Energy Agency 2013; Long 2014: 690–715). Scaling of turbines has been significant in achieving efficiencies, and alternative foundation designs to the traditional “monopile” show promise (International Energy Agency 2013). While offshore projects remain expensive compared to terrestrial projects, construction and operating costs have fallen in recent years (International Energy Agency 2013; Scott 2006: 89–118). A focus has been on increasing competition in supply, improving farm design, increasing economies of scale, promoting mass production, and reducing commercial risk (International Energy Agency 2013). Predictable yet flexible public subsidies or tax credits are seen as one way forward to enhance the competitiveness of wind generation and accelerate its deployment, while not dis-incentivising the private innovation that is essential to long-term cost reduction and technological improvement (International Energy Agency 2013; Long 2014: 690–715; Kaplan 2004: 177–219; Gibbons 2013). Encouraging international collaboration on research and development is another (International Energy Agency 2013).

Yet technical and commercial challenges remain (International Energy Agency 2014); in particular, turbines must operate in an environment that is usually less hospitable than on land, contending with adverse weather conditions and withstanding extreme ocean forces. Access for maintenance and repairs is also challenging, leading to a focus on developing preventative maintenance and an ability to control operations remotely (International Energy Agency 2013). Investors also require early assurances that electricity generated will have access to and be purchased at market (International Energy Agency 2013; Long 2014: 690–715).

42.3 Blowing Hot Then Cold: Legal and Policy Challenges for Offshore Wind

Legal and policy challenges are, in some ways, more difficult. While technical and commercial developments are driven by clear goals (basically, efficiency and feasibility), the legal and policy space is characterised by different goals that may conflict. It would be naïve to think that the overriding goal of marine environmental law and policy is to enable the exploitation of offshore wind at *any* cost. The benefits of doing so must be weighed against interests of the marine environment and those who use it (or wish to use it in the future) for other purposes (Caine 2014: 89–127). Close management is therefore needed to ensure that while the benefits of wind are exploited, it does not come at an unacceptable cost to people or the environment with which they exist in what has been called a "dynamic tension" (New Zealand Parliamentary Commissioner for the Environment 2006). At the risk of stating the obvious, the overriding legal and policy challenge facing offshore wind farm deployment seems to be striking an appropriate balance between these interests in a way that is stable, predictable and participatory (Long 2014: 690–715; Sustainable Development Commission 2005; Leitch 2010: 182–199). Many more specific management issues can be understood in this light. Perhaps resolving the "messy reality" of weighing so many interests requires an interdisciplinary approach; for example, one author has sought to apply an "economic sociology of law" to the issues posed by wind farms (Perry-Kessaris 2013: 68–91; see also Aitken 2010: 1834–1841). Yet at the same time we cannot ignore the particularly important role that policy and regulation play in enabling and restricting projects. A balance needs to be sensitive both to the needs of people, and the needs of the environment.

42.3.1 Recognising and Balancing Effects on People

Direct effects on people are a key consideration for regulators. In particular, it is important that decision-makers recognise the *benefits* of offshore wind generation for people. It is all too easy to be drawn into the negative rhetoric surrounding the risks posed by individual projects, without seeing the bigger picture. Incorporating wind into broader energy strategies, roadmaps and coastal planning mechanisms in a clear and transparent way is essential to provide signals for future investment and to reduce costs associated with policy risk (International Energy Agency 2013), thereby realising the substantial energy security benefits that wind farms have for people (see e.g., New Zealand Coastal Policy Statement 2010; policy 6(1)(g)). Although the main policy driver of wind farms is not economic benefit per se, projects can also have substantial economic and social value; they generate employment and can provide a stable price for electricity not dependent on volatile international prices (like fossil fuels are) (International Energy Agency 2013).

Active planning for renewable generation more generally can be seen in the European Union, where robust targets are imposed on member states (International Energy Agency 2013; Dir 2009/28/EC), and in New Zealand, where the Government's energy strategy specifically aims for 90 percent of electricity to be generated from renewable sources by 2025 (Ministry of Economic Development 2011). Offshore wind does not have a specific mention in those documents, but it offers an attractive policy option for meeting such targets; one reason is that offshore wind farms can avoid to a large extent the "not in my backyard" (NIMBY) concerns that often plague terrestrial projects (Ministry for the Environment 2005; Ewea 2010). Further offshore a wind farm is located, the lower such concerns are likely to become (Long 2014: 690–715). Opposition is often strongly linked to a sense of place (Manzo and Devine-Wright 2014), and visual or amenity impacts are most likely to give rise to NIMBYism. This has certainly proved the case in the United Kingdom, the United States, other parts of Europe and New Zealand (Scott 2006: 89–118; New Zealand Parliamentary Commissioner for the Environment 2006), despite broad public support for wind power as an industry (New Zealand Parliamentary Commissioner for the Environment 2006; Giddings 2011: 75–86; Marinakos 2012: 82–117). People want it, but not near them.

In the exclusive economic zone, such problems are likely to be minimal. Yet projects closer to shore and visible from the coast may arouse similar negative feeling (Scott 2006: 89–118; International Energy Agency 2013; Long 2014: 690–715; Marinakos 2012: 82–117). To be effective, large numbers of turbines must be dispersed along a relatively wide coastal area, and while proximity to the coast may reduce costs (International Energy Agency 2013), it may increase objections. There is no silver bullet management solution to such tensions. An individual coastal landowner, for example, should not be accorded a right to veto a proposal in which the wider public has a substantial interest. However, genuine objections to amenity impacts should not be dismissed; this is particularly so if they are culturally-based, an issue that has arisen in the United States and also in New Zealand in relation to terrestrial wind farms (Unison Networks Ltd. v. Hastings District Council, NZEnvC Auckland 2009; O'Brien 2013–2014: 411–434). Consultation and real consideration of local views are important in a participatory system of environmental law, although not necessarily determinative of an outcome. International experience shows that the best route may be extra-legal; public education concerning the benefits of wind, early consultation on specific projects, and direct community benefits are valuable to allay NIMBY concerns and smooth a path for deployment (International Energy Agency 2013; Devine-Wright 2005: 125–239). If terrestrial learnings are transferable, it may be that incentives for substantial local ownership and management of farms could accelerate public acceptance (New Zealand Parliamentary Commissioner for the Environment 2006). In this light, some commentators have applied a Danish proverb: “your own pigs don’t stink” (Thomson 2008). One’s own windmills may not look all that bad.

One can even hope that public acceptance of turbines, if strategically sited, may develop over time and evolve into an overt sense of pride that symbols of sustainable energy generation are on prominent display (New Zealand Parliamentary Commissioner for the Environment 2006). While natural coastal beauty is important, and should be safeguarded in places, it is also essential not to take a dogmatic or static view of amenity. After all, in contrast to (e.g.,) physical effects on marine life, the visual value of our environment is ultimately a subjective human construct (New Zealand Parliamentary Commissioner for the Environment 2006; Good 2006: 76–89). We can shape what we consider beautiful through our attitudes towards it. Turbines may, just as the early skyscrapers of the modernist architects, come to be seen as sculptural symbols of a progressive, enlightened and sustainable age (Maniototo Environmental Society Inc. v. Central Otago District Council, NZEnvC Christchurch 2009). In that sense, it is to be hoped that conceptual opposition to early projects may prove the most vehement, and decline as public acceptance of wind generation grows. Again, education and practical examples of deployment may allay many fears.

However, not all the effects of offshore wind farms can be overcome by the changing of attitudes over time. We cannot simply stride ahead on the assumption that *all* wind power is a good thing for people (New Zealand Parliamentary Commissioner for the Environment 2006). For one, construction and turbines can produce a great deal of noise. Here, offshore projects have policy advantages over their terrestrial counterparts. This is because, to some extent, noise amenity is an anthropocentric concept (determined by its effect on humans). It recalls the old adage "if a tree falls in a forest, and no one is around to hear it, does it make a sound?" In terms of environmental management, the answer is generally that is makes a less *important* noise if *people* cannot hear it. Far fewer people spend time offshore than on land, and generally no one lives there. Where sites are proposed close to land, the challenge of noise can be overcome to some extent by sensible spatial planning; objections are likely to be less pronounced and effects less marked where noise is already produced near pre-existing industrial zones such as ports.

Of course not all those affected by offshore wind farms would be land-based. The large areas required for turbines may require substantial exclusion zones and restrict the navigation of vessels, or pose navigational hazards (Scott 2006: 89–118). They may also impact on aircraft, military uses, and prevent the utilisation of fisheries in areas where cables and other infrastructure need to be protected (Scott 2006: 89–118). A process is needed whereby legitimate interests are considered and not unduly affected, particularly where they are reflected in legally conferred rights. While specific solutions to this challenge will vary according to a country's development priorities (should a new wind farm override existing interests in other, less publicly important resources?), equity and environmental justice are broadly important considerations in assigning rights to use areas or resources (International Energy Agency 2013; see generally Marinakos 2012: 82–117).

42.3.2 Environmental Effects

Offshore wind farms do not only affect people directly. They also have impacts on the broader notion of the "environment." Such impacts are equally significant, but substantially different, to those experienced as a result of wind generation on land, and can arise in the exploration, construction, operation and decommissioning stages. They form important considerations in striking an appropriate balance between various interests. The impacts of offshore energy have been discussed generally in Chap. 9 (see also Pelc and Fujita 2002: 471–479; OSPAR Commission 2008a).

Of course many environmental effects of offshore wind farms are context-specific, and some (such as the destruction of particularly vulnerable ecosystems) can be avoided through the protection of specific areas. Others are of more general concern. Seismic surveying, construction and operation present a substantial amount of noise and vibration, potentially excluding fish from important habitats and harming marine mammals (Scott 2006: 89–118; Caine 2014: 89–127). Other impacts on biodiversity may stem from increased turbidity from construction (Caine 2014: 89–127), and electrical cables, which could affect sharks and rays (Scott 2006: 89–118; Adair et al. 1998: 576–587). There is also a risk of bird strike by turbines (Scott 2006: 89–118; Adair et al. 1998: 576–587). Area-specific assessments performed in the United Kingdom concluded that bird strike posed a significant risk, as did exclusion from important habitats (Scott 2006: 89–118. This problem can to some extent be mitigated through the configuration of farms (including spacing between turbines), turbine design and dimensions, and blade speed (Powlesland 2009). Above all, site selection remains key (OSPAR Commission 2008b). Some discharge of contaminants into the water column is also inevitable as part of the construction process, and the abandonment of infrastructure once a project had been decommissioned can be seen as a form of dumping, which is subject to strict controls under international law and most domestic laws (OSPAR Commission 2008b; United Nations Convention on the Law of the Sea 1833; Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1996). That said, the actual physical destruction of seafloor ecosystems is generally limited; the overall area required is large, but the footprint of turbines and cables is small. Overall, some have concluded that adverse environmental effects tend to be no more than moderate (Giddings 2011: 75–86). As with effects on people, it is important to recall that some impacts are positive. The reduction of greenhouse gas emissions is an obvious example; wind energy has been projected to account for a significant proportion of the global CO_2 reductions necessary in the electricity sector, and forms a key part of modelling in scenarios designed to limit global temperature increases to 2°C (International Energy Agency 2013). But offshore wind farms may also lessen the wider environmental impacts of electricity generation when compared to alternatives such as hydro or onshore wind farms.

42.4 A Positive Spin? Legal and Policy Frameworks for Addressing Challenges

The discussion above has identified some challenges faced by marine wind generation. The key problem is striking a balance between various interests, both human and environmental. Yet it is important to remember that, in management terms, these challenges arise and must be addressed within coherent legal and policy frameworks. At its most basic, the law provides a transparent and consistent way for regulators to determine whether a proposal should proceed—if the balance between interests is acceptable. International law has comparatively little to say about offshore wind farms specifically, although it impacts upon aspects of their regulation. International climate law encourages deployment indirectly (United Nations Framework Convention on Climate Change 1992), while various marine treaties require environmental protections and for the interests of other states to be safeguarded. For the most part, international law enables coastal wind projects as long as certain matters are considered and addressed. The general global regime concerning the protection of the marine environment, found in UNCLOS, does not impose hard and fast environmental rules on wind farms—only general obligations in relation to pollution reduction and management (United Nations Convention on the Law of the Sea, arts. 192–195). But although it may be difficult to claim that the authorisation of any particular project infringed UNCLOS obligations, most states are parties to other more specific agreements which elaborate on these general provisions. Exact obligations will vary according to the conventions to which a state is party, but many exist concerning the protection of the marine environment from dumping (Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1996; Convention for the Protection of the Marine Environment of the North East Atlantic), the protection of cetaceans (Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North

Seas) and the protection of biodiversity and particular species of animals (Convention of the Conservation of Migratory Species of Wild Animals; Convention on Wetlands of International Importance; Convention on the Conservation of European Wildlife and Natural Habitats). Members of the European Union must also comply with a number of directives concerning wildlife (Dir 79/409/EEC; Dir 92/43/EEC). In siting farms, states must also take care to comply with international law concerning ships' freedom of navigation in the exclusive economic zone and right of innocent passage through the territorial sea (United Nations Convention on the Law of the Sea). Authorisation could not be granted to projects resulting in interference with the use of recognised sea lanes essential to international navigation (Scott 2006: 89–118).

Perhaps more importantly, one observes that national environmental laws in most countries are capable of providing for decisions to be made concerning wind farms. But they may not always do so in a way that strikes an appropriate balance over the long-term. Rather than providing a detailed account of specific instruments, this section introduces some general ideas and strategies that can be seen as underpinning effective decision-making frameworks.

First, fragmented regimes involving multiple statutory authorisations and agencies are generally undesirable and inefficient (International Energy Agency 2013; Young 2015: 148–174; International Energy Agency 2014). In this vein, the United Kingdom, Germany, and Denmark have implemented processes by which a single agency coordinates the permissions needed for a project (International Energy Agency 2013; Young 2015: 148–174). The hurdles that a fragmented regulatory environment in the European Union can pose for the offshore wind industry is well-attested (Long 2014: 690–715). In many jurisdictions, permitting frameworks continue to be divided along resource-specific lines (such as fisheries, navigation, pollution, petroleum) rather than integrated according to coherent areas of geographical space.

Secondly, particular projects should not necessarily be authorised simply because a general energy strategy demands it. Local concerns and effects must also be weighed. Some protective considerations may be considered to be "bottom lines" that must not be infringed, while others may more appropriately be weighed against the benefits a project would offer at a decision maker's discretion. For example, it may legitimately be decided that wind generation is an inappropriate (and therefore entirely prohibited) activity in protected marine areas (see generally Caine 2014: 89–127). In areas already proximate to industrial activities, considerations in favour of development may outweigh the benefits of absolute protection. In others, there may be more room for discretion and compromise.

Thirdly, although the need for some discretion is unavoidable, there should be a degree of certainty as to what legally relevant considerations will mean for applicants, decision makers, and the public. Regulatory uncertainty can be a significant hurdle to deployment. As well as a clear process, substantively the law should provide a fairly good idea as to what kinds of effects are acceptable and whether an application could be successful.

Fourthly, within a decision-maker's set of legally relevant considerations, it is important that the law accords appropriate weight to *benefits*. This includes strong guidance to the effect that discretion is to be exercised in a way that recognises the potential for the technology to provide for long-term energy security (Scott 2006: 89–118; McCormick and Vats 2012: 12–13). But it must also emphasise the *global* benefits of offshore wind farms. If deployed widely, they have potential to contribute significantly to climate change mitigation. Yet because decision making is the preserve of states, it may often be tempting for national or local concerns to override those of the global climate, particularly if a state has untapped fossil fuel reserves. This is the tragedy of the commons in action, and is a temptation that must be resisted. To some extent it can be overcome by placing a robust and stable price on carbon under an emissions trading scheme or tax, thereby attracting private finance for alternatives to fossil fuels, like wind (International Energy Agency 2013). In the long-term, this is likely to be dependent on an effective global agreement on carbon emissions, which may or may not be provided by the recent climate agreement reached in Paris. But the global benefits of wind farms also need to be built into national regulatory provisions as a counter-consideration to a project's adverse effects. Financial incentives under a carbon tax or ETS to submit an application mean very little in practice if commercially viable projects are then defeated through the regulatory process. Again, this does not presuppose that any particular project should be authorised, but at a strategic national level it *does* mean that the global and national benefits of offshore wind farms should be accorded substantial weight when compared to local adverse impacts.

Fifthly, it is important that *adverse* effects are also recognised in national legal frameworks, and weighed against benefits (Caine 2014: 89–127). In doing so, the law should clarify the relative weight to be given to local and national effects. The benefits of wind farms are usually disproportionately national and global (long-term energy security and climate mitigation), while adverse impacts are disproportionately local (e.g., impacts on marine ecosystems or amenity concerns) (New Zealand Parliamentary Commissioner for the Environment 2006). A decision maker, which may often (depending on the legal system) be local, should not be invited to decline authorisation for nationally beneficial projects simply because it chooses to focus on avoiding local impacts (Genesis Power Ltd. v. Franklin District Council, NZ EnvC Auckland 2005). If this occurred, nationally important projects could seldom come to fruition. This tendency can be exacerbated if local decision makers are comprised of elected officials, being concerned more with placating local NIMBY concerns than acting in the national interest (Giddings 2011: 75–86). Offshore wind farms will often reflect a national community of interest, and may need to be decided either by national level agencies or by local decision makers guided firmly by policies reflecting the national interest.

42.5 Charging Ahead: Emerging Best Practice in Regulating Marine Wind Farms

Several aspects of best practice have developed over the last decade or so concerning offshore wind farm regulation. This section briefly considers three of them.

First, an appropriate balance between various interests should be struck proactively at a strategic level, not only reactively at a project level. This means that law and policy-makers should be active in identifying particular areas where wind farms may and may not be appropriate *before* applications are made. Key to this is preventing development in areas identified in advance as protected. For example, guidelines produced under the OSPAR Convention (designed to protect the environment of the north-west Atlantic) recommend that the construction of installations should not occur in conservation sites or ecologically valuable areas (OSPAR Commission 2008b). That said, some have lamented the fact that states have been reticent to implement such recommendations in practice (Scott 2006: 89–118). Substantial work remains to be done in this space; in New Zealand, for example, legislation governing marine reserves has progressed only slowly.

A strategic approach to authorisation also involves the identification of areas where development would be *most* appropriate. We do not only want to prevent and mitigate environmental harm; we also want to ensure positive effects are actually achieved for social and environmental reasons. Whether this means a structured tendering process where only limited areas are opened up for wind development (see Caine 2014: 89–127), or whether it simply means the implementation of policies incentivising development in some areas over others, authorities should begin to take an active rather than passive role in shaping activities in offshore areas within their jurisdiction. This is particularly important where demand for offshore space is high, and where activities like wind farms require a great deal of space and room to expand. One may learn from experience in the oil and gas sector, where the strategic release of acreage is now the norm. In the United Kingdom, strategic environmental assessments (SEAs) have been undertaken to identify zones suitable for wind farms, while guidelines under the OSPAR and Bonn Conventions expressly recognise the importance of SEAs (Scott 2006: 89–118). These are, in essence, a process for predicting and evaluating the environmental implications of a policy, plan or programme (Ministry for the Environment 2005). Such pro-active assessment may be costly, but it is more likely than a system relying on ad hoc applications to nurture important activities while providing protection to more sensitive areas of the environment (Scott 2006: 89–118).

The more sophisticated concept of marine spatial planning (MSP) has also received much attention over the last few years (see Azzellino et al. 2013: e11–e25). This has been utilised in the European Union and elsewhere to mitigate what has been described as a “haphazard” approach to offshore wind deployment in what are increasingly congested areas (Dir 2014/89/EU; Long 2014: 690–715; Young 2015: 148–174; Douvere and Ehler 2009: 77–88). The concept is described in more detail in Chap. 54. In short, MSP involves a highly integrated strategic assessment of how different spaces should be developed for environmental, social, cultural and economic reasons, and how different activities and concerns can interact and conflict (Douvere and Ehler 2012: 111–133; Douvere 2010). It provides a degree of certainty as to how offshore space is to be developed in a way that is efficient and likely to maximise the benefits of development, and is particularly important where space is congested, in high demand, or crosses jurisdictional boundaries. Central to spatial planning is the idea that the specific use of limited space is important not only for reasons of environmental protection (although this is often an important part of it), but also to achieve strategic development aims, promote the equitable distribution of public resources, and to mitigate conflict (Young 2015: 148–174). It is a pro-active, rather than reactive, management approach, based on a "clearly articulated vision" (Young 2015: 148–174; International Energy Agency 2014). For example, it may be considered inappropriate to authorise the exclusive use of offshore geological formations for petroleum extraction where social and environmental aims would be better served by using it for carbon geo-sequestration (or both together). Marine areas with high wind and lower natural amenity value may be better reserved for wind farms.

Conflict management is extremely important in a spatial planning approach to offshore wind generation. All stakeholders, including those in potentially affected industries, like shipping, and recreational users, should have a voice in the strategic planning process (Scott 2006: 89–118; OSPAR Commission 2008b). Of course, this includes those with an interest in developing wind farms. Strategic areas for wind farm development should be identified in advance in order to minimise risks to navigation and other existing or future activities (spatial separation), and it is important that remaining risks be managed on an ongoing basis. But MSP also recognises that some activities can co-exist if managed carefully. Strict separation is a blunt instrument, and exclusive rights are not always necessary for viable development (or a particularly efficient use of finite space). One can picture the substantial space between offshore turbines that could be used for other socially and economically valuable purposes. Some have identified "unexpected synergies" that may exist between, for example, power generation and petroleum mining or fishing (Young 2015: 148–174; Diffen 2008: 240). Yet others have pointed out that MSP does not itself ensure sustainability; much depends on the substantive priorities that are determined at the political and practical levels and the weight that is placed on protecting the environment (Santos et al. 2014: 59–65). MSP could be used, for example, to prioritise oil and gas extraction. Yet it is a useful tool if used responsibly.

Secondly, it remains important for a detailed assessment of a wind farm at the *project* level. It is not enough to identify an area generally suitable for development and then allow it to proceed; close scrutiny of individual proposals and their adverse effects is needed. This should generally involve the provision of a detailed environmental impact assessment (EIA), which provides authorities with a sound information base on which to consider potential effects. In general terms, these are required under several international agreements concerning the marine environment and European law (see Scott 2006: 89–118; OSPAR Commission 2008b). EIAs should also be developed and assessed using an ecosystem approach. This involves a focus on environmental impacts as they affect entire ecosystems, including cumulative effects from different or existing activities, including where they cut across different laws, policies, and responsible agencies. It encourages a holistic, rather than sectoral, approach to managing different kinds of environmental impacts, and has been emphasised in OSPAR, among other international instruments (Convention for the Protection of the Marine Environment of the North East Atlantic). It is particularly important that permitting regimes and environmental assessments are harmonised across jurisdictional boundaries, such as that between the territorial sea and exclusive economic zone (Long 2014: 690–715; Young 2015: 148–174). After all, this is an artificial legal line that does not reflect the reality of natural systems, and separate regimes can introduce regulatory uncertainty and duplication of processes for applicants. (Indeed, given the work being done on floating turbines, it is timely to ensure that appropriate permitting structures are in place in the EEZ; this was addressed, e.g., by New Zealand in 2012 in new environmental legislation concerning the EEZ). An ecosystem approach to EIAs does not itself determine substantive outcomes, but is an important example of procedural good practice. As a project-level tool, it complements well the strategic-level tool of MSP.

Thirdly, in striking a balance both at the strategic and project levels, weight should be given not only to *known* adverse effects on the environment, but also to *potential* effects. In other words, offshore wind farms should be assessed according to a relatively strong version of the precautionary principle. This is a legal version of the old maxim "it is better to be safe than sorry," and provides most commonly that a lack of scientific certainty as to the adverse effects of an activity should not be used as reason to take no measures to address them. While considerable debate continues as to the status of this principle in customary international law (see Freestone 1999: 135–164; Cameron and Abouchar 1991: 1–27), it makes its presence strongly felt in a number of conventions touching upon the marine environment specifically, often in stronger language than its most well-known general formulation in the Rio Declaration (Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1996; Convention for the Protection of the Marine Environment of the North East Atlantic).

Yet even a robust precautionary approach does not require the elimination of *all* risk. The response taken to risk should be proportionate to the likelihood, magnitude, irreversibility and significance of potential effects, and authorisation should not be refused where risks can be effectively and safely managed (see generally Gillespie 2011: 264–385; Iorns Magallanes and Severinsen 2015: 201–234). Not all wind farm proposals can be treated alike. Moreover, comparative risk assessment is important. While the risks to the local environment of implementing a particular wind farm may be substantial, at a strategic level the environmental risks of inaction (reliance on fossil fuel generation) may be *greater*. Wind farms may *themselves* be conceived of as a precautionary response to the problems of climate change and energy security. Risk may also be *managed* rather than eliminated, and precautionary approaches may sometimes be implemented through adaptive management. This is where a proposal occurs at a reduced intensity or scale, which may be gradually increased as effects prove to be acceptable. In practice, this may see a wind farm begin by constructing and operating fewer turbines or restricting the area or times in which they operate, while undertaking extensive monitoring and review that feeds back into management decisions.

Precaution also suggests that decisions authorising offshore wind farms should not signal the end of the regulatory process. It is important for authorities to retain oversight over a project, not only to monitor and enforce conditions but also to review them if unexpected effects arise. This includes being satisfied, before authorisation is granted, that appropriate safeguards are in place for decommissioning. While UNCLOS itself does not prohibit the abandonment of turbines, nevertheless best practice suggests removal is necessary. A resolution of the IMO has strongly recommended that infrastructure be removed in almost all situations likely to apply to offshore windfarms (IMO Resolution 1989, A.672(16)). Moreover, while abandonment or toppling may not technically be a prohibited form of disposal under general international dumping law, it is not allowed under the more specific dumping regime applicable to those states parties to the OSPAR Convention where much development is occurring (Scott 2006: 89–118).

42.6 A Revolution Per Minute: Striding Bravely into a Low Carbon Energy Future

The last decade has witnessed a proliferation of offshore wind energy projects, notably in northern Europe. To some extent many challenges presented by the technology have been or are in the process of being overcome, and technological refinements are increasing its potential. The dual issues of climate change and energy security demand that renewable energy sources are exploited, and offshore wind generation presents an exciting opportunity to do so. However, as with any industrial scale activity in the oceans, we must take care. Exploration, construction, operation and decommissioning present numerous potential adverse effects on people and the environment, and these challenges do not look likely to go away. Environmental law must provide a framework within which numerous competing interests can be resolved.

In many areas of national law, best practice has emerged or is emerging. This chapter has considered a few of them. Most fundamentally, frameworks for decision making must provide a mechanism that expressly recognises both the benefits and risks of wind farms, and a matrix within which they can be weighed consistently and transparently. This should occur both at a strategic level, through the use of spatial planning and wide consultation, and at a project level, through the use of robust EIAs and a holistic focus on ecosystems. Decision makers should hold the precautionary principle or approach at the forefront of their minds when considering projects; however, this should involve comparative risk analysis and risk may be managed rather than eliminated. Consistent with this "look before you leap" ethos ingrained in the precautionary principle is a need for consenting mechanisms to look well into the future, and to plan for the decommissioning process from the outset.

The local risks of offshore wind farms should certainly not be ignored. But the focus needs to be on the avoidance, mitigation and management of adverse local effects and a recognition of substantial potential for positive effects at a national and global level, rather than relying wholly on arbitrary bottom line standards concerning the local environment to determine when a project should proceed. The success of an offshore wind farm industry relies on a balanced, yet receptive, legal and policy landscape. Looking to the future, and the advent of floating wind farms capable of being sited in deeper water, some may even wish to tackle the more difficult (but presently theoretical) issues associated with management on the high seas. Although not explored here, it is worth noting that international law (UNCLOS) presents much more substantial barriers to projects on the high seas and their regulation by coastal states (see Young 2015: 148–174).

References

Adair RK, Astumian RD, Weaver JC (1998) Detection of weak electric fields by sharks, rays, and skates. Chaos 8:576–587

Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS), 1772 UNTS 217 (opened for signature 17 March 1992, entered into force 29 March 1994)

Aitken M (2010) Why we still don't understand the social aspects of wind power: a critique of key assumptions within the literature. Energy Policy 38:1834–1841

Appiott J, Dhanju A, Cicin-Sain B (2014) Encouraging renewable energy in the offshore environment. Ocean Coast Manage 90:58–64

Azzellino A, Ferrante V, Kofoed JP, Lanfredi C, Vicinanza D (2013) Optimal siting of offshore wind-power combined with wave energy through a marine spatial planning approach. Int J Mar Energy 3(4):e11–e25

Barnes RA (2014) Energy sovereignty in marine spaces. Int J Mar Coastal Law 29:573–599

Barton B, Redgwell C, Ronne A, Zillman DN (2004) Energy security: managing risk in a dynamic legal and regulatory environment. Oxford University Press, Oxford

Caine C (2014) The Dogger Bank offshore wind farm proposal: a study of the legal mechanisms employed in the construction of an offshore wind farm. North East Law Rev 2:89–127

Cameron J, Abouchar J (1991) The precautionary principle: a fundamental principle of law and policy for the protection of the global environment. BC Int'l Comp Law Rev 14:1–27

Convention for the Protection of the Marine Environment of the North East Atlantic 2354 UNTS 67 (opened for signature 22 September 1992, entered into force 25 March 1998) (OSPAR Convention)

Convention on the Conservation of European Wildlife and Natural Habitats (opened for signature 19 September 1979, entered into force 6 June 1982) (Bern Convention)

Convention on the Conservation of Migratory Species of Wild Animals 1651 UNTS 356 (opened for signature 23 June 1979, entered into force 1 November 1983) (Bonn Convention)

Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Dumping Convention) (1996) 1046 UNTS 120 (signed 29 December 1972, entered into force 30 August 1975) Protocol to the convention on the prevention of marine pollution by dumping of Wastes and other Matter (London dumping protocol), 36 ILM 1 (signed 7 November 1996, entered into force 24 March 2006)

Convention on Wetlands of International Importance 996 UNTS 245 (opened for signature 22 February 1971, entered into force 21 December 1975) (Ramsar Convention)

Devine-Wright P (2005) Beyond NIMBYism: towards an integrated framework for understanding public perceptions of wind energy. Wind Energy 8:125–239

Diffen BH (2008) Energy from above and below: who wins when a wind farm and oil and gas operations conflict? Texas J Oil Gas Energy Law 3:240

Dir 2009/28/EC (n.d.)

Dir 2014/89/EU (n.d.)

Dir 79/409/EEC (n.d.)
Dir 92/43/EEC (n.d.)
Douvere F (2010) Marine spatial planning: concepts, current practice and linkages to other management approaches. Ghent University, Ghent
Douvere F, Ehler C (2009) New perspectives on sea use management: initial findings from European experience with marine spatial planning. J Environ Manage 90:77–88
Douvere F, Ehler C (2012) Marine spatial planning: identifying the critical elements for success. In: Ciccotelli E, Benigno C (eds) Spatial planning: strategies, developments and management. Nova Sciences Publishers, Hauppauge, pp 111–133
EWEA (2010) Wind barriers: administrative and grid access barriers to wind power. EWEA, Brussels
Freestone D (1999) International fisheries law since Rio: the continued rise of the precautionary principle. In: Boyle A, Freestone D (eds) International law and sustainable development: past achievements and future challenges. Oxford University Press, Oxford, pp 123–164
Genesis Power Ltd. v. Franklin District Council, NZ EnvC Auckland (2005) A148/2005, 7 September 2005
Gibbons BM (2013) Second wind: a legal and policy-based evaluation of the block Island wind farm and the legislation that saved it. Connecticut Law Rev 45(4):1457
Giddings NC (2011) Go offshore young man! The categorical exclusion solution to offshore windfarm development on the outer continental shelf. George Washington J Energy Environ Law 2:75–86
Gillespie A (2011) Precautionary New Zealand. NZULR 24:364–385
Good J (2006) The aesthetics of wind energy. Hum Ecol Rev 13:76–89
IMO Resolution A (1989) 672(16), adopted 19 October 1989
International Energy Agency (2013) Technology roadmap: wind energy. IEA, Paris
International Energy Agency (2014) How2Guide for wind energy: roadmap development and implementation. IEA, Paris
Iorns Magallanes C, Severinsen G (2015) Diving in the deep end: precaution and seabed Mining in New Zealand's exclusive economic zone. New Zealand J Public Int Law 13:201–234
Kaplan CS (2004) Congress, the courts, and the army corps: siting the first offshore wind farm in the United States. BC Envtl Aff L Rev 31:177219
Leitch V (2010) Securing planning permission for onshore wind farms: the imperativeness of public participation. Environ Law Rev 12:182–199
Long R (2013) Offshore wind energy and ecosystem-based management: are the EU regulatory answers really blowing in the wind? In: Nordquist M, Norton Moore J, Chircop A, Long R (eds) The regulation of continental shelf development: rethinking international standards. Martinus Nijhoff, Leiden, pp 15–52
Long R (2014) Harnessing offshore wind energy: legal challenges and policy conundrums in the European Union. Int J Mari Coastal Law 29:690–715
Maniototo Environmental Society Inc. v. Central Otago District Council NZEnvC Christchurch (2009) C103/2009, 6 November 2009
Manzo L, Devine-Wright P (2014) Place attachment: advances in theory, methods and applications. Routledge, New York
Marinakos MW (2012) A mighty wind: the turbulent times of America's first offshore wind farm and the inverse of environmental justice. Earth Jurisprudence Environ Justice 2:82–117
McCormick N, Vats V (2012) Marine-based renewable energy. In: Green economy in a Blue World. UNEP, Nairobi, pp 12–13
Ministry for the Environment (2005) Offshore options: managing environmental effects in New Zealand's exclusive economic zone. Ministry for the Environment, Wellington
Ministry of Economic Development (2011) New Zealand energy strategy 2011–2021. Ministry of Economic Development, Wellington
New Zealand Coastal Policy Statement (2010)
New Zealand Parliamentary Commissioner for the Environment (2006) Wind, power people and place. Parliamentary Commissioner for the Environment, Wellington

O'Brien C (2013–2014) Continuing controversy over cape wind: the lasting effects of legal and regulatory hurdles on the offshore wind farm. Georgetown Int Law Rev 26:411–434
OSPAR Commission (2008a) Assessment of the environmental impact of offshore wind farms
OSPAR Commission (2008b-3) OSPAR guidance on environmental considerations for offshore wind farm development
Pelc R, Fujita R (2002) Renewable energy from the ocean. Mar Policy 26:471–479
Perry-Kessaris A (2013) Anemos-ity, apatheia, enthousiasmos: an economic sociology of law and wind farm development in cyprus. J Law Soc 40(1):68–91
Powlesland RG (2009) Impacts of wind farms on birds: a review. Department of Conservation, Wellington
Santos C, Domingos T, Adelaide Ferreira M, Orbach M, Andrade F (2014) How sustainable is sustainable marine spatial planning? Part i—linking the concepts. Mar Policy 49:59–65
Scott KN (2006) Tilting at offshore windmills: regulating wind farm development within the renewable energy zone. J Environ Law 18(1):89–118
Sustainable Development Commission (2005) Wind power in the UK. Sustainable Development Commission, London
Thomson G (2008) Community small scale wind farms for New Zealand: a comparative study of Austrian development, with consideration for New Zealand's future wind energy development. Master's thesis: Lincoln University
Unison Networks Ltd. v. Hastings District Council, NZEnvC Auckland (2009) W11/2009, 23 February 2009
United Nations Convention on the Law of the Sea (UNCLOS) (1833) UNTS 3 (opened for signature 10 December 1982, entered into force 16 November 1994)
United Nations Framework Convention on Climate Change (1771) UNTS 107 (signed 9 May 1992, entered into force 21 March 1994)
Young M (2015) Building the blue economy: the role of marine spatial planning in facilitating offshore renewable energy development. Int J Mar Coastal Law 30:148–174

Chapter 43
Wave and Tidal Energy

Kate Johnson and Sandy Kerr

Abstract Wave and tidal energy is a visible expression of the power of nature. Ambition to convert the natural energy bound up in marine systems into something useable by mankind goes back a long way and practical measures date from at least the 1940s. In the twenty-first Century efforts have increased enormously in response to the search for clean energy sources, a reduction in emissions of greenhouse gases and the mitigation of the effects of climate change. Hundreds of millions of Euros have been invested in research and development and much has been learned. However, the solutions to a viable Ocean Energy industry remain elusive. The outstanding challenges are daunting in scale:

1. The engineering challenge in the search for a device technology which will convert marine energy to usable energy with a degree of operational and economic efficiency.
2. The operational challenge of installing, servicing and maintaining thousands of floating and fixed structures in high energy marine environments.
3. The environmental and social challenge of understanding and managing the ecosystem and spatial impacts of such a heavy industrial intrusion into mainly coastal waters.

There have been recent setbacks with the failure of companies promoting what seemed to be promising technical solutions. However, the level of investment in research remains high involving ten or more nations including China, Japan, the United States and the United Kingdom. It must be expected that the ambition will be realised in the medium term. This chapter explores the state of the industry and the management challenges it reveals. The central challenge for the planning and management of a future wave and tidal energy industry is to move from a very early developmental stage in the lifecycle to a mature activity in a measured and sustainable way. Best practice in management and the step by step approach to precaution is examined.

Keywords Wave and tide • Offshore energy • Marine energy • Marine renewable energy • Ocean energy • Management challenge

K. Johnson (✉) • S. Kerr
ICIT Heriot-Watt University, Old Academy, Orkney, Scotland
e-mail: k.r.johnson@hw.ac.uk

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_43

43.1 Introduction

Wave and tidal energy is a visible expression of the power of nature (Fig. 43.1). Harvesting and using the energies embodied in ocean waves and tides are included in a suite of developing technologies generally grouped together under the heading of Marine Renewable Energy (MRE) or Ocean Energy (OE). The other energy sources included under this heading are thermal and salinity gradients. The International Energy Agency (IEA) sponsored initiative Ocean Energy Systems estimates the world potential to develop capacity from these sources to be 748GW by 2050 (OES 2011). Offshore wind is not included under this heading and has created its own successful niche. While research into all the OE sources is active, wave and tide have attracted most OE investment to date with commercial deployment a real possibility within a medium term timeframe—say 10–20 years. Having said that, the wave and tidal technologies have enjoyed mixed fortunes in the last decade as optimism about imminent commercial deployment has risen and fallen with the availability of funding for research and testing and the success of the research, or the lack of it.

Although wave and tidal sources of energy are usually classed together and share many characteristics, they also exhibit very significant differences and ultimately need to be considered separately. They share a characteristic of being future, and not existing, industries. Technologies are at the very early development and testing stage and no commercial installations exist so far. The potential is very attractive and great efforts are being made to overcome the challenges but writing now (in 2016) is a snapshot in time. A sense of direction may be discerned but the destination and the way to get there is not clear and subject to change. Wave and tidal energy also share the characteristic of being spatially invasive activities in coastal waters close to shore supported by significant terrestrial infrastructure. Interaction with other coastal activities and environments will be large. Offshore possibilities

Fig. 43.1 Wave energy in Shetland (Photo: R Robertson)

exist at a time further into the future but they are even more uncertain. Finally, the two activities exhibit high costs compared to other sources of electricity generation with no indication of how rapidly this will reduce with time. The industry association, Renewable UK, estimates that strike prices of €380/MWh for tide and €405/MWh for wave are needed to *"…catalyse the industry and to allow the necessary economies of scale and learning to be realised…"* (Renewable UK 2013). This compares to prices of less than €190/MWh for offshore wind and less than €127/MWh for most fossil and nuclear sources.

Tidal energy has advanced close to commercial feasibility with successful testing of several power take-off (PTO) technologies. It takes two forms:

- Barrage—large tidal barrage infrastructure dates back to the 1960s with the 240 MW facility at La Rance in France. More recent developments in South Korea will bring the globally installed total to more than 1GW by 2017. The huge civil engineering structures employed make the process expensive with high estuarine or coastal environmental impact. High initial investment leads to high financial risk even if returns are ultimately attractive. Suitable sites are rare and, however successful, it will always remain a niche power producer. A current proposal is the Swansea barrage in Wales which combines power generation with aquaculture and marina facilities to provide additional revenues.
- Tidal Stream—the ambition to harvest and use the power of tidal streams is active in perhaps a dozen countries across the world but mainly at an early research and planning stage. The first major array of tidal stream devices is under construction by company MeyGen (www.meygen.com) in the Inner Sound of the Pentland Firth in Scotland. Six devices of 1 MW capacity each are being installed in 2016 with a further eighty consented. Installation of all 86 turbines depends upon the success of the initial six turbine investment. After several years of testing the horizontal axis turbine is the favoured PTO technology for tidal stream, similar to wind turbines but underwater. The various companies involved differ in their approach to the securing and operating of the devices and their position in the water column. Most are bottom mounted or secured to pilings at mid-water level. One device designed by Scotrenewables (www.scotrenewables.com) is a floating solution with retractable turbines secured underneath the 'vessel'. Bottom mounting is more efficient and allows more dense arrays. Floating offers accessibility and operational advantages. Tidal streams suitable to development are rare not least because many are remote from markets with no reasonable solutions to the export of electricity (Fig. 43.2). The Pentland Firth and the Orkney Waters (PFOW) in Scotland and the Bay of Fundy in Nova Scotia stand out as the two sites where most investment has been concentrated and plans for commercial arrays are most advanced.

Wave research and testing has fared less well than tide. Wave is a greatly more ubiquitous and powerful resource (Fig. 43.3) but a large scale commercial PTO technology has so far evaded researchers. As with tide the research effort spreads across the globe with ten or so countries contributing to the effort to find a solution

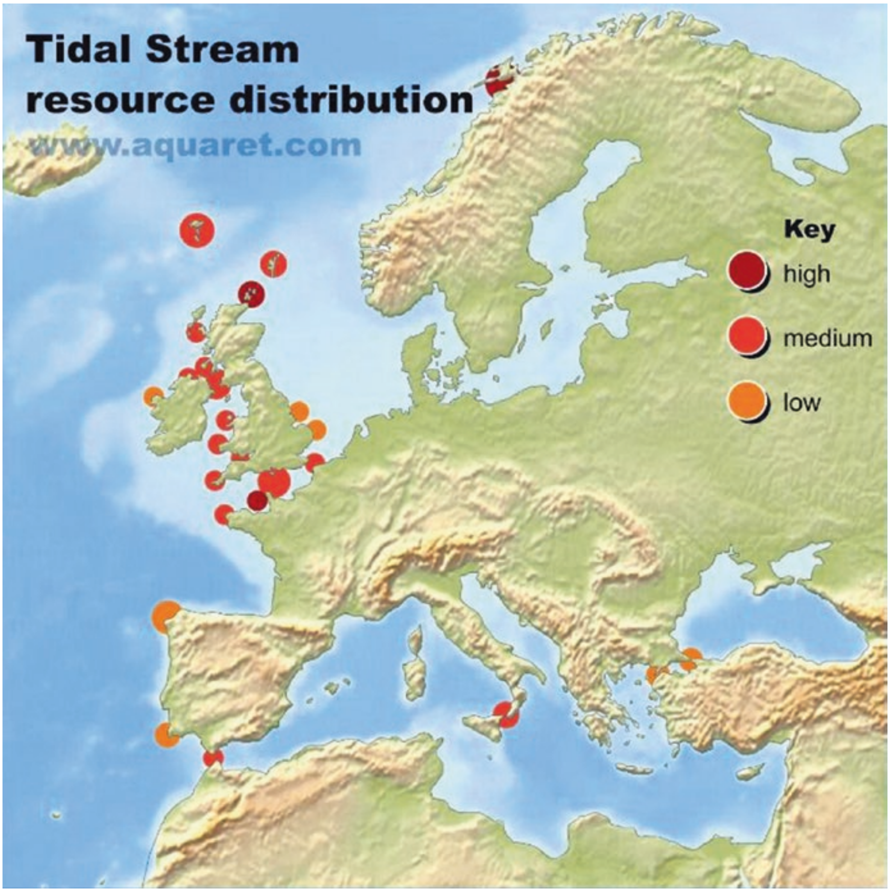


Fig. 43.2 Tidal stream resource distribution in Europe [www.aquaret.com]

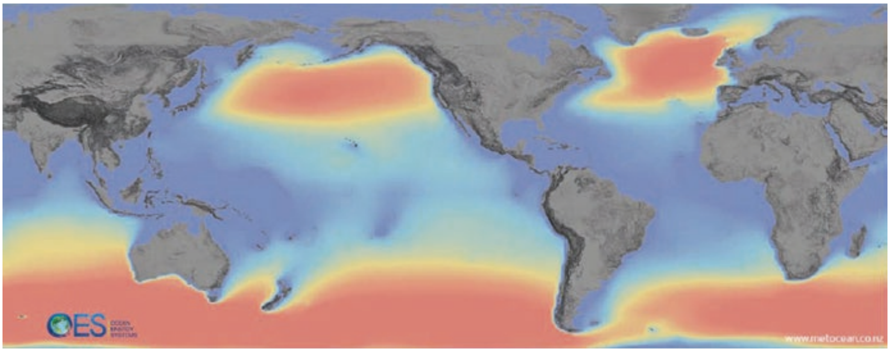


Fig. 43.3 Global wave resource distribution (*red strongest*; *dark blue lightest*) [www.ocean-energy-systems.org]

to an efficient conversion system from wave power to useable power. The waves are produced by wind action and are therefore an indirect form of solar energy. The possibility of converting wave energy into usable energy has inspired numerous inventors and more than one thousand patents had been registered by 1980, the number has increased markedly since then. Yoshio Masuda may be regarded as the founder of modern wave energy technology, with studies in Japan since the 1940s (OES 2016). He developed a navigation buoy powered by wave energy, equipped with an air turbine, which was in fact what was later named as a floating oscillating water column. European efforts were advanced by the European Commission (EC) decision in 1991 to include wave energy in their research programme on renewable energies (OES 2016).

Progress on wave technologies accelerated after about 2003 with significant political and funding support. Prototype devices fall into several categories (Fig. 43.4) and many full scale prototypes have been tested at the European Marine Energy Centre (EMEC) in Orkney, Scotland. Two leading technologies had emerged by about 2012: the Pelamis P2 attenuator—a series of floating connected cylinders generating hydraulic pressure as the joints flex under wave action; and the Aquamarine Oyster oscillating wave surge converter—bottom mounted flaps close to shore raised and lowered by wave action to generate hydraulic pressure. Both achieved a substantial state of readiness for commercial arrays and some were actually consented. However, development costs, performance under testing and delays in commercialisation exceeded the patience of investors. Pelamis went into administration in 2014 and Aquamarine in 2015. No successors have so far emerged to take their advanced place but many inventors continue to try. Scotland has become the leading area for OE development in the world first, because of the quality and quantity of the resource; second, because of the establishment of EMEC attracting devices for testing from across the world; and third, support from the Scottish government with funding and a supportive regulatory framework. Even so, the target to install 0.6 GW of wave power and 1GW of tidal power in Orkney waters by 2020 (over 1000 machines based on current technology) now looks to have been absurdly optimistic. It had remained the expectation even as late as 2013 and has not been officially downgraded (Crown Estate 2013; Scottish Government 2016).

DEVICE TYPE	ATTENUATOR	OVERTOPPING	OSCILLATING WATER COLUMN (OWC)	POINT ABSORBER	OSCILLATING WAVE SURGE CONVERTR (OWSC)
DESCRIPTION	Attenuator devices are generally long floating structures aligned in parallel with wave direction,which then absorbs the waves. Its motion can be selectively damped to produce energy.	Overtopping devices are awave surge/focusing system, and contains a ramp over which waves travel into a raised storage reservoir.	In an OWC, a column of water moves up and down with the wave motion, acting as a piston, compressing and decompressing the air. This air is ducted through an air turbine.	A point absorber is a floating structure absorbing energy from all directions of wave action due to its small size compared to the wavelength.	An OWSC extracts energy from the surge motion in the waves, They are gegerally seabed-mounted devices located in nearshore sites.
DIAGRAM					

Fig. 43.4 Typology of wave energy prototype devices [www.ocean-energy-systems.org]

Estimates for the growth of global OE generating capacity vary widely by an order of magnitude and are very uncertain. Bloomberg New Energy Finance estimates a globally installed capacity of only 148 MW for tide and 21 MW for wave by 2020 (Bloomberg 2014). Previous estimates had planned the installation of 1600 MW of tide and wave capacity in the Pentland firth and Orkney Waters alone by 2020. Seabed leases had been awarded and consenting plans advanced but the industry was unable to respond. In the longer term the International Energy Authority (IEA) estimates a global range of 9/23GW from the combination of tide and wave sources by 2035 (Renewable UK 2013). The UK Carbon Trust estimates a world total 55GW of installed tide capacity and 190GW of wave by 2050 (Renewable UK 2013). There is no way of knowing what such a capacity will look like over such a long timeframe. Both production and storage technology may have changed out of all recognition. The example of the offshore wind industry shows individual turbine capacities increasing from 0.5 MW to up to 10 MW each over the last decade which has changed the whole structure of the emerging industry.

OE ambition at European and international levels remains strong but so far unfulfilled. An extension to this ambition promoted especially by the European Commission (EC) is the development of offshore multi-use platforms (MUPs), fixed or floating 'islands', supporting several maritime economic activities and powered by wave or wind. The EC anticipate higher returns on investment and more efficient use of space at reduced environmental impact from such platforms. Large research funds have recently been committed by the EU to such projects as MARINA, TROPOS, MERMAID, H2OCEAN and MARIBE, all designed to advance the deployment of MUPs (www.maribe.eu).

43.2 Why Is Management Required—Central Issues

The wave and tidal industry has yet to emerge but so large is the prize, and so consistent the ambition, that it looks to become a component of world energy supply over the next few decades. Although the timescale for the commercial launch has slipped significantly, a huge amount has been learned from the research and testing of the last 10 years. Management measures need to be planned while retaining the flexibility to adapt to the shape and characteristics of the industry that develops. Central issues for management include:

- Wave and tidal arrays are spatially invasive mainly in coastal waters. Interactions with other activities and the natural environment are extensive in what are already the most and naturally productive and heavily used areas of the marine environment.
- These are heavy industries comprising large machines, steel, concrete, moorings and a high level of maintenance vessel activity.
- Dependence on terrestrial infrastructure is high with consequences for land planning systems. Some technologies, such as the Aquamarine Oyster harvest energy

at sea but generate electricity on land. Generating stations, sub- stations, electricity grids and service support centres (ports, workshops, social provision) are required in coastal locations.
- Little is known about the effects of removing large amounts of hydrokinetic energy from maritime systems.

Wave and tidal energy is a public good to the extent that it reduces harmful emissions in the provision of useable power and helps to mitigate the effects of climate change. However, it is also introduces heavy industry into previously open and often pristine areas of coast and sea. Planning and management is an essential component of OE development (Johnson et al. 2012; O'Hagan 2016). The central challenge for the planning and management of a future wave and tidal energy industry is to move from a very early developmental stage in the lifecycle to a mature activity in a measured and sustainable way.

43.3 The Management Challenge

European and national government stated policies are to promote sustainable development of the maritime economy with priority given to energy security, especially renewable energy, and food security, especially fisheries and aquaculture (EC 2012). With little experience of the impacts of OE devices, and no experience of large scale arrays, Management and planning has to look to what might be considered similar activities, modelling and the progressive results of research and monitoring. The management challenge is to produce sufficient knowledge of impacts and interactions to permit sustainable development and ecological integrity. Bell and Side (2011) identify four key areas for investigation.

- Extraction of hydrokinetic energy impinging on the natural functioning of physical and ecological processes.
- Device operation and the activities associated with constructing, connecting, operating, maintaining and decommissioning developments having direct effects on marine habitats and organisms.
- New ecological space being provided by the introduction of anthropogenic structures into marine environments.
- Modifying impacts from other marine and terrestrial human activities by displacing them from development areas and imposing economic and social change.

43.3.1 The Extraction of Hydrokinetic Energy

Change induced by the extraction of hydrokinetic energy has effects on physical processes. Wave and tidal current energy extraction has the clear potential to impact upon sedimentary processes but there is little information on what might happen in practice. There is a need for more research specifically aimed at identifying the ways in which wave and tidal energy developments might change sediment dynamics and coastal processes in general (Amoudry et al. 2009). An improved understanding of potential far-field effects is particularly important. Site specific studies with sediment dynamics incorporated as transport processes within large-scale hydrodynamic models such as SUNTANS, MIKE3 and DELFT 3D have been started (Baston et al. 2014). Transport of larvae and other propagules of marine organisms is another crucial linkage in marine ecosystems that could potentially be impacted by intervention in hydrodynamic processes. Shields et al. (2011) advocate the use of sentinel species that are sensitive to changes in hydrodynamic conditions. Such species may not necessarily be of conservation concern in their own right, but can provide indications of more systemic changes which may be of concern. Want et al. (2014) provide examples of monitoring strategies for rocky shores based on sentinel species that may respond to commercial extraction of wave energy, and put particular emphasis on detecting responses against a background of concurrent climate change.

43.3.2 Direct Effects

43.3.2.1 Physical

The direct effects of construction and operation include physical damage to the seabed and water column; noise; and collisions with marine fauna. Wave and tidal energy developments are likely to be extremely variable in the details of their design and operation, and all these aspects will have a bearing on the level and nature of potential impacts. All installations will require some contact with the seabed in the form of either moorings or the device itself, as well as electrical cables or pipes connecting devices to the shore. These structures are substantial, and it is inevitable that seabed habitats will be damaged or modified by their presence. In many cases this type of direct impact may be of small concern. However, the presence of high conservation value biogenic reef structures such as horse mussel (*Modiolus modiolus*) beds may be a relevant factor in determining areas suitable for development.

43.3.2.2 Noise

The OSPAR Commission (2009) provide a general review of impacts of underwater anthropogenic noise (see Boebel et al. in this book; see also Markus and Silva-Sanchez in this book). Technical measures for the mitigation of noise have been investigated such as the use of bubble curtains. However, the general approach adopted has been to require a marine mammal observer (MMO) on board a suitable attendant vessel during operations. If marine mammals are present in the vicinity, the start of operations will be delayed. Where practical a slow start will be made to noisy activities like pile driving, gradually ramping up to full production. Particular emphasis has been placed on studies of underwater noise in relation to sensitive sites for cetaceans such as the Moray Firth Special Area of Conservation in Scotland and the EMEC tidal device test site in Orkney where seal haul-outs during seal pupping may be particularly sensitive to disturbance from underwater sound.

43.3.2.3 Collisions

Collisions with marine fauna are also risks to be addressed by OE projects. Most at risk are the larger plankton such as jellyfishes floating in the water column. It has also been hypothesised that fatal injury to fishes may occur (van Haren 2010). Fatalities to seals have been alleged from the animals being drawn through ducted propellers on vessels (Thompson et al. 2010). Most concerns are focused on seals, cetaceans and diving seabirds. For the SeaGen trial tidal turbine development in Strangford Lough, Ireland, the developers were required to have a MMO on watch during all periods of generation for the first six months. The device was stopped if seals were sighted upstream. After this initial period the MMO was replaced by a forward-looking sonar which has resulted in the device shut-down on numerous occasions. Scotrenewables and Meygen are deploying collision detection hydrophones and cameras on their devices.

43.3.3 New Ecological Space

Built infrastructure on the seabed is of high potential value as new living space for marine organisms with possible benefits for marine biodiversity, productivity and fisheries. This may well be true of marine renewable energy developments. As noted by Inger et al. (2009), marine renewable energy developments may act as fish aggregation devices (FADs), particularly where devices have floating components. Fish will aggregate around floating objects (e.g., Castro et al. 2002). Fishermen may take advantage of increases in local density, but the population level consequences of this behaviour are not clear. Inger et al. (2009) highlight that FADs may increase fishing mortality whilst contributing nothing towards increased recruitment levels. Other harmful factors of new ecological space are bio-fouling and devices acting as stepping stones in the distribution of invasive species.

43.3.4 Activity Displacement

All maritime renewable energy installations require very large areas of space. As the offshore wind industry has matured, the high output of individual turbines (up to 10 MW) has led to increased spacing between adjacent piled towers in relatively offshore situations (>12 nm). Coexistence with fisheries and tourism is increasingly seen to be possible. However, wave and tide devices as currently envisaged, differ substantially in character and location. The relatively small output of the first devices leads to plans for fairly dense arrays in areas close to shore (0/6 nm). Floating devices are further complicated by a network of mooring lines and anchors. Visual impact for wave devices, and some tide, is therefore very high and coexistence with other existing activities such as fisheries, tourism and recreation is more difficult. The social, cultural and economic factors inherent in the introduction of effectively private space into an open marine commons are significant.

43.4 Legal and Institutional Framework

There is currently no dedicated legal framework for the prospective wave and tidal power industry. The activities are regulated through the existing network of international, regional (e.g., European) and national laws governing the oceans and seas. Many of the OE regulatory issues fit quite well within this framework—requirements for states jurisdiction; Strategic Environmental Analysis (SEA); Environmental Impact Analysis (EIA); pollution and dumping controls; Marine Protected Areas (MPAs) and transboundary cooperation; Marine Spatial Plans (MSPs); habitats appraisal; sustainability appraisal; social and economic appraisal; consenting and participatory mechanisms. Other governance issues are of concern. Wave and tide arrays, like wind farms, introduce unprecedented demand for exclusive use of large areas marine space. The oceans and seas are in the main *res nullius* or *res communis* without property rights and with guaranteed freedoms to navigate and fish (Kerr et al. 2015; Johnson et al. 2012). Renewables companies and investors need clear and long term authority to occupy the space they use but such enclosure of the marine commons is controversial and far from resolved (Todd 2012). Agreement and participation among stakeholders is a way forward but when coastal recreation and seascape are taken into account the stakeholder base extends to the general public as a significant political issue. The question of community benefits, *cui bono*, is also raised.

The European legislative framework, promulgated in a series of policies and directives, perhaps exhibits best the emerging regulation of OE and the associated industry. The EU Integrated Maritime Policy (IMP) sets out the economic ambitions for so called ‘Blue Growth’. The Renewable Energy Directive (RED) establishes legal obligations to develop low carbon energy solutions and to reduce emissions. The Marine Spatial Planning Directive (MSPD) requires member states to plan the waters under their control and to cooperate with neighbouring plans (see Schubert in this book). The IMP describes the Marine Strategy Framework Directive (MSFD) as its environmental pillar. The MSFD requires Member States to introduce measures to achieve Good Environmental Status (GES) in their waters by 2020. The law requires assessment and monitoring against eleven descriptors supported by ecosystem based management (EBM), a network of MPAs, and transboundary cooperation. Four of the eleven descriptors have particular relevance to OE.

- Permanent alteration of hydrographical conditions must not adversely affect marine ecosystems.
- The introduction of energy, including underwater noise, must be at levels that do not adversely affect the marine environment.
- Sea floor integrity must be maintained at a level that ensures the structure and functions of the ecosystems are safe guarded and benthic ecosystems in particular are not adversely affected.
- Non-indigenous species introduced by human activities must be at levels that do not adversely alter ecosystems.

Uncertainty about the shape and characteristics of OE is such that neither developers nor regulators are able to give firm assurances in response to these statutory requirements leading to the use of flexible and adaptive management processes—a step by step approach.

43.5 Management—Instruments, Strategies and Best Practice

The international community generally signs up to the ‘Precautionary Principle’ in planning for the marine environment. At the same time it seeks, in the interests of energy security and climate change mitigation, to promote low carbon energies and to encourage the development of technologies like wave and tide. Subsidies, supportive policies and a reduction in obstacles to development are widespread in the sector. Only two jurisdictions, Scotland and Nova Scotia, have moved beyond the mere experimental in OE towards consenting of large commercial arrays. For wave power it is only evident in Scotland so far. OE management in Scotland takes the form of a step by step approach often described as ‘deploy and monitor’. To overcome uncertainty about outcomes, a progressive consenting of installations is to be closely monitored and the cumulative impact of subsequent proposals assessed as knowledge about impacts builds. These are very early days for OE but the direction of emerging best practice may be discerned both in Scotland and elsewhere (Johnson et al. 2012).

- Comprehensive and statutory marine planning, including spatial planning, at national and local levels subjected to SEA. Plans may be policy based, as in Scotland, or zoned, as in Belgium. Scottish marine planning is policy based because of uncertainty about future uses and their impacts. In Europe the MSFD is the environmental pillar of planning policy.
- Sectoral plans and regional locational guidance—data gathered in the planning process is used to give non-statutory guidance to OE developers about where development might be consented and where it is unlikely to be granted permission. Figure 43.5 shows the renewable energy guidance for the waters around Shetland in the form of a ‘constraints map’.

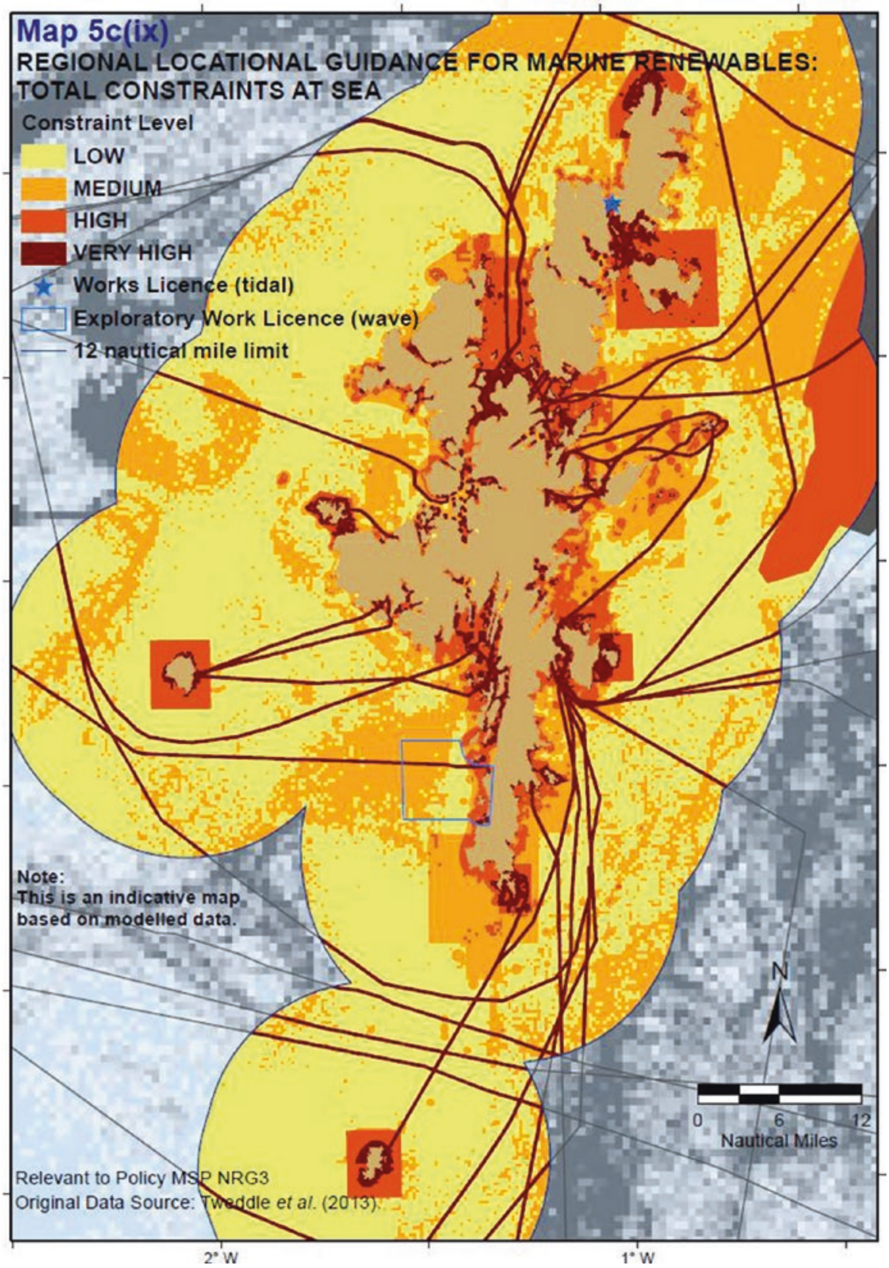


Fig. 43.5 Shetland Islands marine plan—marine renewables constraint map [www.shetland.gov.uk]

- A policy of 'deploy and monitor' for arrays of wave and tidal energy devices with a strong emphasis on cumulative impact in subsequent consent proposals (Marine Scotland 2012a). A step by step approach to the precautionary principle.
- Assessment and implementation of a network of marine protected areas (MPAs) and measures in support of the marine strategy framework directive (MSFD). A policy of multi-use MPAs is applied in Scotland (Scottish Government 2009).
- Increasingly streamlined or 'one-stop shop' provisions for the consenting of OE developments. Traditional marine governance has required multiple applications to several government agencies in the consenting of developments. Single points of regulatory contact, such as Marine Scotland, are believed to increase efficiency and capitalise on experience. Consenting decisions focus on the developer's EIA in relation to the statutory marine plan. (Marine Scotland 2012b).
- Ambition to integrate marine and terrestrial planning. Full integration may never be possible given the differences in planning system foundations like property rights. However, nearly all developments have elements which cross the sea/land divide and a working relationship between the systems is essential (Kerr and Johnson 2014).
- Social, cultural and economic study of all maritime developmental projects and activities engaging the general population as well as directly affected stakeholders. International academic networks such as ISSMER (International Network for the Social Studies of Marine Energy—www.issmer-network.org) are established to explore the issues surrounding the new industries and enclosure of the marine commons (Kerr et al. 2013).

43.6 Management Results and Next Steps

The management results for this first 10 years or so (2006–2016) of intensive research and development into wave and tidal energy are a huge increase in the understanding of the technologies, their effects and their interactions. A clear path towards the needs of management and best practice is apparent. However, the longer term, and even the shorter term, shape and character of these industries is far from clear. Tidal stream will be a significant producer of electricity in the medium term, but always a niche producer because of the limited number of suitable sites. Research into wave has so far concentrated on the potential of the resource to be a bulk producer of electricity like offshore wind. This looks to be quite a long term ambition both in terms of cost, the PTO technology and the sheer difficulty of managing so many floating devices in high energy marine environments. The management of even single prototypes has proved to be challenging with devices brought to shelter in storm conditions. Wave may find more success in the shorter term as a niche producer providing local power to offshore platforms (MUPs) and regions remote from national grids. The next steps focus on more research, testing, monitoring and a cautious but progressive approach to larger installations involving multiple devices with evaluation and analysis of experience at every stage. Planning, regulation and management will build around the results.

References

Amoudry L, Bell PS, Black KS, Gatliff RW, Helsby R, Souza AJ, Thorne PD, Wolf J (2009) A scoping study on: research into changes in sediment dynamics linked to marine renewable energy installations NERC Marine Renewable Energy Theme Action Plan Report, 120

Baston S, Waldman S, Side J (2014) Modelling energy extraction in tidal flows. http://www.masts.ac.uk/media/35456/140828_position_paper_tidal_energy_extraction_rev21.pdf. Accessed on Wednesday 16th March 2016

Bell M, Side J (2011) ER20: Tidal Technologies: Key issues across planning and development for environmental regulators. Scotland and Northern Ireland Forum for Environmental Regulators. Edinburgh

Bloomberg (2014) Tidal stream and wave power - a lot still to prove. http://about.bnef.com/press-releases/tidal-stream-wave-power-lot-still-prove/. Accessed on Wednesday 16th March 2016

Castro JJ, Santiago JA, Santana-Ortega AT (2002) A general theory on fish aggregation to floating objects: an alternative to the meeting point hypothesis. Rev Fish Biol Fish 11:255–277

Crown Estate (2013) Pentland Firth and Orkney waters strategic area review project. http://www.thecrownestate.co.uk/media/5446/pfow-strategic-area-review-project-2012.pdf. Accessed on Wednesday 16th March 2016

EC (2012) Blue Growth - opportunities for marine and maritime sustainable growth. 494

Inger R, Attrill MJ, Bearhop S, Broderick AC, Grecian WJ, Hodgson DJ, Mills C, Sheehan E, Votier SC, Witt MJ, Godley BJ (2009) Marine renewable energy: potential benefits to biodiversity? An urgent call for research. J Appl Ecol 46:1145–1153

Johnson K, Kerr S, Side J (2012) Accommodating wave and tidal energy - control and decision in Scotland. Ocean Coastal Manage 65:26–33

Kerr S, Johnson K (2014) Planning at the edge: integrating across the land sea divide. Mar Policy 47:118–225

Kerr S, Watts L, Colton J, Conway F, Hull A, Johnson K, Jude S, Kannen A, MacDougall S, McLachlan C, Potts T, Vergungst J (2013) Establishing an agenda for social sciences research in marine renewable energy. Energy Policy 67:694–702

Kerr S, Colton J, Johnson K, Wright G (2015) Rights and ownership in sea country: implications of marine renewable energy for indigenous and local communities. Mar Policy 52:108–115

Marine Scotland (2012a) Discussion document about the policy of 'Deploy and Monitor'. www.scotland.gov.uk/Resource/Doc/295194/0119338.doc. Accessed on Wednesday 16th March 2016

Marine Scotland (2012b) Marine Scotland licensing and consents manual. http://www.gov.scot/resource/0040/00405806.pdf. Accessed on Wednesday 16th March 2016

O'Hagan AM (2016) Maritime spatial planning and marine renewable energy. Exploring the winners and losers of marine environmental governance. Plann Theory Pract 17:121–151

OES (2011) An international vision for ocean energy. Ocean energy systems. https://www.ocean-energy-systems.org/library/articles/document/an-international-vision-for-ocean-energy-2011-/. Accessed on Wednesday 16th March 2016

OES (2016) What is ocean energy. Ocean energy systems. https://www.ocean-energy-systems.org/what-is-ocean-energy/waves/. Accessed on Wednesday 16th March 2016

OSPAR Commission (2009) Overview of the impacts of anthropogenic underwater sound in the marine environment. Report 441/2009. OSPAR Commission, London, p 133

Renewable UK (2013) Wave and Tidal Energy in the UK - conquering challenges, generating growth. http://www.renewableuk.com/en/renewable-energy/wave-and-tidal/. Accessed on Wednesday 16th March 2016

Scottish Government (2009) Marine (Scotland) bill, Policy Memorandum, vol 54. Scottish Parliamentary Corporate Body, Edinburgh, p 12

Scottish Government (2016) Scotland National Marine Plan. Renewable energy and power cables Pentland firth and Orkney waters strategic area. http://www.gov.scot/Topics/marine/seamanagement/nmpihome/Productive/strategicarea. Accessed on Wednesday 16th March 2016

Shields MA, Woolf DK, Grist EPM, Kerr SA, Jackson AC, Harris RE, Bell MC, Beharie R, Want A, Osalusi E, Gibb SW, Side J (2011) Marine renewable energy: the ecological implications of altering the hydrodynamics of the marine environment. Ocean Coastal Manage 54:2–9

Thompson D, Bexton S, Brownlow A, Wood D, Patterson A, Pye K, Lonergan M, Milne R (2010) Report on recent seal mortalities in UK waters caused by extensive lacerations. Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews, Scotland

Todd P (2012) Marine renewable energy and public rights. Mar Policy 36:667–672

van Haren H (2010) Tidal power? No thanks. New Sci 206:20–21

Want A, Beharie RA, Bell MC, Side JC (2014) Baselines and monitoring methods for detecting impacts of hydrodynamic energy extraction on intertidal communities of Rocky Shores. In: Shields MA, Payne AIL (eds) Humanity and the seas: marine renewable energy and environmental interactions. Springer, Netherlands, pp 21–38

Chapter 44
Deep-Seabed Mining

Philomene Verlaan

Abstract Deep-seabed mining (DSM) is an emerging marine industry that presents particularly complex challenges due to its multi-faceted political, economic, technological, scientific, environmental, social, industrial and legal aspects, all of which must be addressed to achieve commercially viable results. Furthermore, these aspects are either governed by or must take into account the burgeoning regulatory regime promulgated by the International Seabed Authority under the auspices of the 1982 United Nations Convention on the Law of the Sea, which also governs regional and national DSM regimes. This chapter briefly reviews the international DSM management regime and identifies innovative approaches to these myriad challenges that may also assist in informing the responsible development of other new deep-sea industries.

Keywords United Nations Convention on the Law of the Sea • Deep-seabed mining • International Seabed Authority • The Area • Marine minerals • Environmental impact assessment • Common heritage of mankind

44.1 Introduction

Deep-seabed mining (DSM) is an emerging marine industry that presents particularly complex challenges due to its multi-faceted political, economic, technological, scientific, environmental, social, industrial and legal aspects, all of which must be addressed to achieve commercially viable results. Furthermore, these aspects are either governed by or must take into account the burgeoning regulatory regime promulgated by the International Seabed Authority under the auspices of the 1982 United Nations Convention on the Law of the Sea, which also governs regional and national DSM regimes. This chapter briefly reviews the international DSM

P. Verlaan
Department of Oceanography University of Hawaii, Honolulu, HI, USA
e-mail: pverlaan@gmail.com

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_44

management regime and identifies innovative approaches to these myriad challenges that may also assist in informing the responsible development of other new deep-sea industries.

44.2 Central Issue: Why Is Management Required?

Management is required because DSM is one of the many uses of ocean space, which "are closely interrelated and need to be considered [and therefore managed] as a whole." (United Nations Convention on the Law of the Sea 1982, Preamble).

44.3 What Are The Management Requirements and What Are The Challenges?

In keeping with the focus of this Handbook, this chapter addresses environmental management requirements and challenges facing DSM. Management of DSM is required to "promote peaceful use …, the equitable and efficient utilization of [these resources], … and the study, protection and preservation of the marine environment". (*Ibid.*) Deep-seabed mining presents particularly complex challenges: it features multi-faceted political, economic, technological, scientific, environmental, social, industrial and legal aspects that must all be managed to achieve environmentally responsible and commercially viable results. To achieve the Law of the Sea Convention's overarching vision, DSM management will need to adopt an approach that is holistic, ecosystem-based, precautionary, inter-disciplinary, transparent, adaptive, cost-effective and inclusive of all stakeholders. This list of requirements also sets out the challenges. In keeping with the focus of this Handbook, this chapter addresses only environmental management requirements and challenges facing DSM.

44.4 Existing International and Regional Legal and Institutional Framework on DSM

44.4.1 International Legal: The 1982 United Nations Convention on the Law of the Sea

The 1982 United Nations Convention on the Law of the Sea (LOSC) covers DSM both inside and outside national jurisdiction. The LOSC has 167 parties out of—currently—193 members of the United Nations as of 25 June 2016. It is our planet's "Constitution for the Oceans" (Koh 1983). Comprised of 320 Articles and 9 Annexes, and now accompanied by two Implementing Agreements, one wholly devoted to DSM, the LOSC is probably the longest and most complex multi-lateral treaty extant. It is also, so far, the most powerful and comprehensive multi-lateral treaty governing human activities on this planet. This is because the LOSC applies where human activities, including land-based and atmospheric activities, adversely affect or are likely to adversely affect the marine environment. The concern of the LOSC's drafters for the marine environment permeates this treaty. For example, in addition to an entire chapter (Part XII, see further below) being dedicated to the marine environment, the LOSC's very first Article (i.e., Art. 1(1)(4)) sets out an all-encompassing definition of 'pollution of the marine environment':

> "pollution of the marine environment" means the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities;"

Essential to the LOSC's power is the usually mandatory, unqualified, and exception-free nature of its provisions. The LOSC generally employs the mandatory verb 'shall', which is used in international treaty parlance to establish binding obligations. Such weakening phrases as 'in accordance with capabilities,' 'as appropriate,' 'as far as possible,' 'as far as practicable,' are generally absent. Exceptions in the LOSC usually apply only to "warship[s], naval auxiliary[ies], other vessels or aircraft owned or operated by a State and used…only on government non-commercial service" (LOSC Art. 236), but even in that context States must ('shall'), albeit diluted with qualifications, ensure that these vessels act consistently with the LOSC. Furthermore, LOSC Art. 309 explicitly prohibits reservations or exceptions, and LOSC Art. 310 reinforces this prohibition for States becoming parties to the LOSC. Finally, most of its provisions, including all of the environmental ones, are now considered to have codified, or to have become, customary international law (see, e.g., Oxman 1996; Birnie et al. 2009; Nordquist 2011), thereby making it exceedingly difficult under international law even for non-parties to act inconsistently with those provisions (see, e.g., Aust 2010).

The LOSC provides the overarching legal and institutional framework within which DSM is conducted, and it is designed to set minimum standards (see, e.g., Oxman 1996; Birnie et al. 2009; Nordquist 2011) for many aspects (e.g., flag state duties, shipping, marine environmental protection) of DSM in areas beyond national jurisdiction (ABNJ), which must be no weaker in areas under national jurisdiction (see, e.g., LOSC Arts. 94, 197, 208, 209, 211). Therefore the present chapter principally addresses the LOSC provisions applicable to DSM in ABNJ, where the legally binding environmental management regime is also most advanced. Of these provisions, the most important are LOSC Part XI, LOSC Annexes III and IV, the 1994 Implementing Agreement (IA; in force 28/07/1996; 147 parties as of 20 June 2016) and Parts XII and XIII. The IA and the LOSC are interpreted and applied as a single instrument; if the two conflict, the IA prevails (IA Annex, Art. 2).

These provisions apply to: that part of the seabed and subsoil in ABNJ denoted as the 'Area' (LOSC Art. 1(1)(1)); to 'resources of the Area', defined as "all solid, liquid, or gaseous mineral resources *in situ* in the Area at or beneath the seabed"

(LOSC Art. 133(a)); and to 'activities in the Area', defined as "all activities for exploration for, and exploitation of, the resources of the Area (LOSC Art. 1(1)(3). These provisions also set the jurisdiction of the International Seabed Authority (ISA; see further below), the institutional body established under the LOSC (Part XI Sect. 4; IA, Annex) to administer and regulate the Area's activities and resources.

44.4.1.1 Legal Status of the Area and Its Resources

Both the Area and its resources are the 'common heritage of mankind' (LOSC Art. 136), an as yet judicially undefined status. No state may "claim or exercise sovereignty or sovereign rights over any part of the Area or its resources" (LOSC Art. 137(1)) and rights in resources of the Area (i.e., minerals) are "vested in mankind as a whole," on whose behalf the ISA acts (LOSC Art. 137(2)), but only for those specific rights. Hence, the legal status in the Area of non-mineral resources, such as, e.g., marine genetic resources, is unclear (see, e.g., Glowka 2000, 2010); this adds an additional layer of complexity to the management of the Area.

44.4.1.2 Other Parts of the LOSC Relevant to Environmental Management of DSM

Environmental Aspects: Part XI, Annex III, Implementing Agreement

- Part XI (Art. 145): prevent/reduce/control pollution and other hazards to and interference with the ecological balance of the marine environment; protect and conserve the natural resources of the Area and prevent damage to the flora and fauna of the marine environment.
- Part XI (Art. 147(1)&(3)): conduct other activities in the Area and in the marine environment with reasonable regard for mineral resource related activities and *vice-versa.*
- Annex 44.III Art. 17—sets out what ISA must regulate: marine environment: (1)(b)(xii) & 2(f).
- Annex 44.III Art. 14(2): marine environmental data are not proprietary.
- IA: Preamble; Sect. 1(g),(h,)(i), (k).

Environmental Aspects: Part XII (Protection and Preservation of the Marine Environment)

- Art. 192: "States have the obligation to protect and preserve the marine environment".
- Art. 194(5): requires measures to protect and preserve rare or fragile ecosystems [and] depleted, threatened or endangered species and other forms of marine life.

- Arts. 204 & 206: require both environmental impact assessment and monitoring.
- Art. 208: marine environmental protection requirements for “seabed activities subject to national jurisdiction,” which includes the requirement that national requirements shall be “no less effective than international rules, standards and recommended practices and procedures (Art. 208(3)).
- Art. 209: marine environmental protection requirements specifically for the Area; includes flag states.
- Art. 215: enforcement of marine environmental protection rules in the Area (see also Art. 153(5) Part XI).

44.4.1.3 Part XIII (Marine Scientific Research)

- Art. 240(d): Marine scientific research is subject to Part XII (marine environmental protection) rules (see, e.g., Verlaan 2012); see also Art. 87(1) on high seas freedoms: these include marine scientific research and their exercise is not unrestricted). All high seas freedoms must be exercised with due regard for activities in the Area (Art 87(2)).
- Art. 256: Marine scientific research may be conducted in the Area (see also LOSC Art. 87(2) and LOSC Part XI Art. 143) by the ISA, States Parties and other competent international organizations.
- Arts. 242 and 243: International cooperation in general and between ISA, States Parties and Contractors in particular on marine scientific research is encouraged, especially on the marine environment and related research (International Seabed Authority 2002; see also LOSC Art. 143 on marine scientific research in the Area). This cooperation is essential for developing and implementing cumulative environmental impact management systems for DSM.

44.4.2 International Legal and Institutional

44.4.2.1 International Seabed Authority

Headquartered in Kingston, Jamaica, the ISA implements the LOSC and the IA on DSM. All LOSC parties are ISA members. The ISA has the exclusive right to manage seabed minerals in the Area, and the exclusive right to issue exploration and exploitation licenses (contracts) for minerals in the Area. At present it is not empowered to address non-mineral activities in the Area, even in areas for which it has issued an exploration (or, in future, exploitation) license for DSM activities. It is not empowered to issue licenses for activities related to non-mineral resources in the Area. The ISA observes the LOSC Art. 169 requirement to consult and cooperate with intergovernmental organizations (IGOs) and with non-governmental organizations (NGOs) recognized by the UN Economic and Social Council (ECOSOC), all of whom may express their views, even in the annual meetings of the ISA Council and Assembly, according to procedures established by the ISA. International NGOs, both environmental and technical, participate actively in the ISA's work. Procedures to express views directly, rather than through their sponsoring state, in these latter meetings have not yet been established for DSM contractors. The UN General Assembly (UNGA) follows ISA activities closely. For example, every year the ISA Secretary General provides a report to the UNGA on the activities of the ISA in that year, the Oceans and Law of the Sea agenda item of the annual UNGA meeting always includes an item on DSM, as does the yearly report of the UN Secretary-General to the UNGA on Oceans and Law of the Sea. These are all available on the UNGA website.

44.4.2.2 International Tribunal for the Law of the Sea

Established pursuant to LOSC Art. 287(1)(a) and operating according to its statute under LOSC Annex VI, the International Tribunal for the Law of the Sea (ITLOS), based in Hamburg, Germany, has 21 Judges who serve 9-year (re-electable) terms and are appointed by vote of the LOSC parties. LOSC Art. 186 established an ITLOS Seabed Disputes Chamber with 11 Judges. On DSM, the Chamber issued a pioneering Advisory Opinion (pursuant to LOSC Art. 191) on responsibilities and liabilities of states engaging in DSM (LOSC Art. 139), especially with regard to the marine environment, holding, *inter alia*, that all countries, regardless of their developmental status and financial and technical capabilities, must comply with LOSC/ISA DSM environmental regulations (International Tribunal for the Law of the Sea 2011).[1]

44.4.2.3 International Maritime Organization

Headquartered in London, the International Maritime Organization (IMO; www.imo.org) has promulgated and continues to develop and update an extensive suite of environmental and safety treaties for the global shipping community, on topics including (for environmental aspects) air pollution, anti-foulants, ballast water, chemicals, garbage, greenhouse gas emissions, noise, oil, pollution response, sewage and ship recycling (for an overview see, e.g., Verlaan 2008). The scope of the IMO's safety treaties is equally extensive. The IMO's rules implementing the treaties are usually legally binding and set minimum national standards, as do the treaties themselves. The IMO's treaties and rules govern the operation of ships that will engage in DSM. Cooperation between the ISA and IMO is formalized in a Memorandum of Understanding (MoU).

[1] For an excellent scholarly overview of this groundbreaking opinion, see Freestone 2011.

44.4.2.4 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter and Its 1996 Protocol

Although its Secretariat is hosted by IMO, the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter and its 1996 Protocol (known as the London Convention and Protocol; LC/LP) constitute a separate and powerful environmental treaty system that is relevant to DSM. The LC/LP parties meet annually in London for a week, usually in the autumn. Their dedicated Scientific Groups also meet annually for a week, usually in the spring.

Although the LC/LP exclude "the disposal {or storage—LP} of wastes or other matter directly arising from, or related to the exploration, exploitation and associated off-shore processing of seabed mineral resources" (LC Art. III(1)(c); LP Art. 1(4)0.3), the LC/LP and the ISA share environmental concerns with regard to DSM that will benefit from cooperative approaches; an MoU between them is under discussion. Note also the recent work by the LC/LP and the Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) on the disposal at sea of land-based mine wastes (see, e.g., GESAMP 2015).

44.4.3 Regional Institutional

44.4.3.1 South Pacific

The ISA's work informed the development of the Pacific/ACP States Regional Legislative and Regulatory Framework for Deep Sea Minerals Exploration and Exploitation (Secretariat of the Pacific Communities (SPC) and European Union (EU) 2012) and underpins the current work on the SPC/EU Pacific Island Regional Environmental Management Framework For Deep Sea Minerals Exploration And Exploitation (Secretariat of the Pacific Communities SPC and European Union EU 2016), to be completed in late 2016. For an overview of environmental management requirements in a commercial context (see Secretariat of the Pacific Communities SPC 2013). Although the study focuses on the South Pacific, the environmental advice is generally applicable. See http://gsd.spc.int/dsm/index.php/publications-and-reports for all.

44.4.3.2 European Union

The work of the European Union (EU) on DSM environmental management is also informed by the ISA's activities. In addition to the South Pacific template legislation described above, MIDAS | Managing Impacts of Deep Sea Resource Exploitation, a multi-disciplinary EU-funded research program to investigate environmental impacts of extracting mineral resources from the deep sea, will develop recommendations for best practice in the mining industry and concomitant legislation. Set up in November 2013 for 3 years, MIDAS has 32 European partners of scientists, industry, social scientists, lawyers, NGOs and Small/Medium-sized Enterprises; its final report is due in late 2016 (MIDAS 2016).

44.5 Central Management Instruments and Strategies

The ISA develops legally binding regulations governing DSM. So far these address the exploration for polymetallic ferro-manganese nodules (International Seabed Authority 2000/2013), cobalt-rich ferro-manganese crusts and polymetallic sulphides. The ISA is now developing exploitation regulations for these resources, in which it is employing an innovative international consultation process. Because the Area's resources are the common heritage of mankind, the ISA decided to consult mankind on how these resources are to be exploited and their proceeds allocated (see, e.g., International Seabed Authority 2015a; Center for International Law 2015). All responses to ISA consultations are on the ISA website.

The ISA sponsors research, workshops, and technical publications (see, e.g., International Seabed Authority 2011a) on DSM, all available on the ISA website. Much of the ISA's technical activity is channelled through its Legal and Technical Commission (LTC). Composed of 25 (in 2016) scientists and lawyers, and holding 2 week-long meetings annually (usually February and July) in Jamaica, the LTC has an increasingly heavy workload. For example, it reviews draft regulations and recommendations, examines and recommends actions by the ISA Council on applications for work in the Area, monitors and comments on the contractors' work in the Area through the annual reports the latter must submit (see, e.g., International Seabed Authority 2015b), and deals with the implementation of the extensive marine environmental protection duties imposed by the LOSC for DSM activities (see, e.g., International Seabed Authority 2001b/2010/2013).

The ISA's principal management challenge at present is the implementation of the LOSC's environmental requirements for DSM. It has developed extensive regulations, guidelines and recommendations accordingly, initially for exploration, which are kept under review to ensure that best practices are applied as they are created and evolve. Further instruments are now being developed for exploitation. Extensive environmental data are needed, to establish a baseline and to monitor operations during and after mining. The ISA must engage in both regional and local environmental management of the Area, including assessment and management of cumulative and local impacts of DSM (see, e.g., International Seabed Authority 2001a).

The areas requiring regional management are huge: for example, the 6-million-km^2 Clarion-Clipperton Zone (CCZ) in the Northeast Pacific Ocean, covers the currently most prospectively interesting DSM resource (polymetallic ferro-manganese nodules) in the world's oceans, and is likely to be the first part of the ABNJ to be mined. For an area the size of the CCZ, and with (as of 25 June 2016) 16 different contractors from 20 different countries, this is a daunting challenge. The ISA's CCZ Environmental Management Plan (International Seabed Authority 2011b; Lodge et al. 2014) is the first international effort to address DSM on such a scale in an environmental context. Similar areas requiring ISA management are also found in the Atlantic and Indian Oceans. The temporal DSM environmental management scale is another challenge: biological processes in the deep sea are poorly known and extremely slow. After mine closure, for example, long-term (at least 15 years) monitoring of mined and control sites is likely to be needed.

44.6 Best Practices

- Wide-ranging, transparent consultations with stakeholders.
- Preservation reference zones and impact reference zones in mining areas.
- Large-scale collaborative international marine environmental research programs.
- Adaptive management principles applied to environmental impact assessment.
- Standardization of environmental data and information collection and reporting.
- Incorporation of environmental impact assessment in legislative framework to support precautionary approach during assessment and execution of DSM.
- Design of DSM methods and technology to minimize environmental impacts.

The Code for Environmental Management of Marine Mining developed by the International Marine Minerals Society (www.immsoc.org/code) takes a useful approach to this rapidly evolving subject. It sets broad directions in a context of shared values (i.e., it does not prescribe specific practices), provides benchmarks to develop and implement environmental management plans, and offers advice on best fit-for-purpose environmental practices.

44.7 Status and Results of Management Efforts, Perspectives and Next Steps

The ISA decided (International Seabed Authority 2015c) to embark on its LOSC-mandated (Art. 154) operational review, as its current structure, staffing, and budget are under increasing strain from the burgeoning number of exploration licenses under its management (27 as of 15 December 2015, for the three currently most prospectively interesting categories of deep-sea mineral resources (i.e., nodules, sulphides and crusts), located over large swathes of the deep seabed in the Pacific, Atlantic and Indian Oceans). The exploration licenses are for 15 years; seven of these licenses, all for nodules in the CCZ, will expire in 2016 (6) and 2017 (1). Applications for extensions of these licenses are being received by the LTC, as per the requirements set by the LOSC for granting extensions to exploration licenses. The annual reports of the contractors conducting exploration under ISA license must also be reviewed by the LTC.

The exploitation regulations must be developed and adopted with some urgency, as DSM cannot begin without them, and several of the contractors hope to begin exploitation within approximately the next seven years (as per May 2016). The next draft of the exploitation regulations is expected to be presented at the next annual meeting of the ISA in July 2016.

The ISA recognizes that its operations urgently need to be adjusted to cope with these growing demands. An interim report on the Art. 154 review will be presented to the ISA in July 2016, and the final report, including draft recommendations, in July 2017.

The issue of potentially conflicting activities in the Area is being addressed by the UN General Assembly, which on 19 June 2015 approved by UNGA Resolution A/RES/69/292 (currently available as A/69/L.65) a recommendation by the *Ad Hoc* Open-ended Informal Working Group [on] ….. Conservation and Sustainable Use of Marine Biological Diversity Beyond Areas of National Jurisdiction (BBNJ Working Group) the development of a third, legally binding, LOSC implementing agreement: this one is for conservation and sustainable use of marine biological diversity in BBNJ (http://www.un.org/Depts/los/biodiversityworkinggroup/). This instrument will regulate in ABNJ: marine genetic resources (including benefit-sharing); area-based management tools (e.g., marine protected areas, environmental impact assessments, capacity-building), and transfer of marine technology. The ISA will be intensively involved in these discussions.

Other useful aspects of the ISA's marine environmental management work for other emerging marine sectors to follow include: the elaboration of State environmental responsibility and liability rules, especially their equal applicability to all states regardless of their level of economic development; the practical application under conditions of great uncertainty of the precautionary approach; development of a realistic operational definition of *cumulative* environmental impact in light of the actual context, such as the extent of the area (e.g., in the CCZ:~6 million km^2), its spatial and temporal environmental variability (e.g., spatially, in the CCZ, E-W; N-S), and where and when mining will occur and over what part of a given concession.

At the regional and national level, it is important to ensure that the requirements for environmentally responsible DSM as promulgated by the ISA are translated into consistent, effective and fully implemented and enforced legislation that is no less effective than the ISA's requirements.

Early, sustained, pro-active, well-informed and constructive engagement at the international, regional and national levels by all stakeholders is essential.

The LOSC mining provisions and their implementation by the ISA are central to useful developments in law of the sea and international law for all emerging—and existing—marine activities.

References

Aust A (2010) Handbook of international law, 2nd edn. Cambridge University Press, Cambridge

Birnie PW, Boyle AE, Redgwell C (2009) International Law and the Environment, 3rd edn. Oxford University Press, Oxford

Center for International Law/National University of Singapore/ISA Joint Workshop on Exploitation of Minerals in the Area (2015). https://www.isa.org.jm/sites/default/files/files/documents/bp4-final-web.pdf. Accessed 20 June 2016

Freestone DF (2011) Advisory opinion of the seabed disputes chamber of international tribunal for the law of the sea on "Responsibilities and obligations of states sponsoring persons and entities with respect to activities in the area". ASIL Insights. 15(7). http://www.asil.org/insights110309.cfm. Accessed 20 June 2016

GESAMP (2015) The impact of mine tailings on the marine environment: report of the workshop. http://www.dicapi.mil.pe/taller/en/down_workGesamp.html. Accessed 20 June 2016

Glowka L (2000) Bioprospecting, alien invasive species, and hydrothermal vents: three emerging legal issues in the conservation and sustainable use of biodiversity. Tulane Environ Law J 13(2):329–360

Glowka L (2010) Evolving perspectives on the international seabed area's genetic resources: fifteen years after the 'deepest of ironies'. In: Vidas D (ed) Law, technology and science for oceans in globalisation. Brill, Leiden, pp 397–419

International Seabed Authority (2000/2013) Regulations on Prospecting and Exploration for Nodules in the Area, ISBA/6/A/18, 2000; updated ISBA/19/C/17 (2013)

International Seabed Authority (2001a) Standardization of environmental data and information: guidelines. ISA/02/02, ISBN 976–610–486-7. https://www.isa.org.jm/files/documents/EN/Pubs/2001-Standards.pdf. Accessed 20 June 2016

International Seabed Authority (2001b/2010/2013) Recommendations for guidance of contractors to assess possible environmental impacts from exploration for nodules in the Area, ISBA/7/LTC/1/Rev.1, updated by: ISBA/16/LTC/7; updated by: Recommendations … Marine Minerals in the Area, ISBA/19/LTC/8 (2013)

International Seabed Authority (2002) Prospects for international collaboration in marine environmental research to enhance understanding of the deep sea environment. http://www.isa.org.jm/files/documents/EN/Pubs/2002-Collab.pdf. Accessed 20 June 2016

International Seabed Authority (2011a) Environmental management needs for exploration and exploitation of deep sea minerals. ISA Technical Study 10. http://www.isa.org.jm/files/documents/EN/Pubs/TS10/index.html#/10/. Accessed 20 June 2016

International Seabed Authority (2011b) Environmental management plan for the Clarion-Clipperton zone (ISBA/17/LTC/7)

International Seabed Authority (2015a) Report to Stakeholders (ISBA/Cons/2015/1)

International Seabed Authority (2015b) Recommendations for the guidance of contractors on the content, format and structure of annual reports (ISBA/21/LTC/15)

International Seabed Authority (2015c) Decision of the assembly regarding the first periodic review of the international regime of the Area pursuant to Article 154 of the United Nations Convention on the Law of the Sea (ISBA/21/A/9)

International Tribunal for the Law of the Sea (2011) http://www.itlos.org/fileadmin/itlos/documents/cases/case_no_17/adv_op_010211.pdf. Accessed 20 June 2016

Koh TTB (1983) A constitution for the oceans. In: The law of the sea. United Nations Publication No. E.83.V.5, New York, pp xxxiii–xxxvii

Lodge M et al (2014) Seabed mining: international seabed authority environmental management plan for the Clarion–Clipperton zone. A partnership approach. Mar Policy 49:66–72

MIDAS (2016) Final report.. http://eu-midas.net. Accessed 20 June 2016

Nordquist MH (2011) Series editor-in-chief, United Nations Convention on the law of the sea: A Commentary (seven volumes to date; Center for Oceans Law and Policy, University of Virginia School of Law—known as the Virginia Commentary). Martinus Nijhoff, Leiden

Oxman BH (1996) The rule of law and the United Nations Convention on the Law of the Sea. Eur J Int Law 7:353–371

Secretariat of the Pacific Communities (SPC) (2013) In: Baker E, Beaudoin Y (eds) Deep sea minerals: deep sea minerals and the green economy, vol 2.. http://gsd.spc.int/dsm/index.php/publications-and-reports. Accessed 20 June 2016

Secretariat of the Pacific Communities (SPC) and European Union (EU) (2012) Pacific/ACP States regional legislative and regulatory framework for deep sea minerals exploration and exploitation. http://gsd.spc.int/dsm/index.php/publications-and-reports. Accessed 20 June 2016

Secretariat of the Pacific Communities (SPC) and European Union (EU) (2016) SPC/EU Pacific Island regional environmental management framework for deep sea minerals exploration and exploitation. http://gsd.spc.int/dsm/index.php/publications-and-reports Accessed 20 June 2016

Verlaan P (2008) Overview of opportunities under the law of the sea to improve marine environmental conservation affected by maritime traffic. In: Oral N, Simard F (eds) Maritime traffic effects on biodiversity in the Mediterranean Sea, vol 2. IUCN Centre for Mediterranean Cooperation, Malaga, pp 9–48. ISBN#978-2-8317-1080-8

Verlaan P (2012) Marine scientific research: its potential contribution to achieving responsible high seas governance. Int J Mar Coastal Law 27(4):805–812

Chapter 45
Marine Biodiversity: Opportunities for Global Governance and Management Coherence

Daniela Diz

Abstract Marine biodiversity has been declining globally due to overexploitation, habitat destruction and alteration, pollution, increased pressures from climate change and ocean acidification. A number of legal instruments are in place to address marine biodiversity pressures through appropriate conservation and management measures, with the most notable ones being the United Nations Convention on the Law of the Sea (UNCLOS) and the UN Convention on Biological Diversity (CBD). This chapter provides a brief overview of the relationship between UNCLOS and the CBD with respect to marine biodiversity management through the lens of a promising integrative and emerging tool—the CBD ecologically or biologically significant marine areas (EBSAs). It argues that the EBSA process—a global exercise to describe marine areas of ecological importance—can inform decision-making and assist in the conservation and sustainable use of marine biodiversity. In this connection, the categorisation of EBSAs can provide a first step towards the identification of management options, which can be further developed through the use of cumulative impact assessments of biodiversity pressures for each EBSA and respective EBSA features.

Keywords Marine biodiversity • Ecologically or biologically significant marine areas (EBSAs) • Impact assessments • Cumulative effects • UN convention on the law of the sea • Convention on biological diversity

45.1 Introduction

Current rates of marine biodiversity loss induced by human activities are unprecedented (Rocha et al. 2015). McCauley et al. (2015) suggest that although defaunation has been less severe in the oceans than in terrestrial ecosystems, humans have considerably modified all major marine ecosystems. The fourth edition of the

D. Diz
University of Strathclyde, School of Law, Glasgow, UK
e-mail: dizdani@gmail.com

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_45

Global Biodiversity Outlook, measuring the progress (or lack thereof) towards the CBD Aichi Biodiversity Targets,[1] noted that "based on the current trends, pressures on biodiversity will continue to increase at least until 2020, and that the status of biodiversity will continue to decline" (CBD Secretariat 2014a: 10).

Nevertheless, UNCLOS—also regarded as the Constitution for the Oceans, establishes an absolute obligation to protect and preserve the marine environment (Art. 192 UNCLOS), and to adopt necessary measures "to protect and preserve rare or fragile ecosystems as well as the habitat of depleted, threatened or endangered species and other forms of marine life" (Art. 194 (5) UNCLOS), these general obligations depend on more specific guidance for their implementation by coastal states or those exercising jurisdiction and control over their activities in areas beyond national jurisdiction.

Guidance and generally agreed standards have been adopted by a number of competent organisations, including the UN, in the form of UN General Assembly (UNGA) resolutions, particularly those on Oceans and the Law of the Sea, and Sustainable Fisheries, FAO instruments, Regional Fisheries Organizations (RFMOs), Regional Seas Conventions, the International Maritime Organization (IMO), the International Seabed Authority (ISA; Diz 2013).

UNCLOS does not refer to marine biodiversity per se, as at the time of its negotiations, the term was not widely utilised and understood, especially with regards to areas beyond national jurisdiction (ABNJ). Nevertheless, UNCLOS second implementing agreement—the 1995 Fish Stocks Agreement—establishes the obligation of states to protect marine biodiversity, including through their duty to cooperate in regional fisheries management organisations (RFMOs) or Arrangements. Importantly, guidance can also be provided by related conventions, most notably, the 1992 Convention on Biological Diversity.

The CBD—a quasi universal treaty, has among its objectives the conservation of biodiversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilisation of genetic resources (Art. 1, CBD). The Convention applies to the marine and terrestrial environments, however, with respect to areas beyond national jurisdiction (ABNJ), its application is limited to processes and activities (Art. 4 (b), CBD).[2] And not to biological components per se since these cannot be subject to the jurisdiction and control of any particular state (de Lafayette 2009).

In this respect, the relationship between the CBD and UNCLOS is expressly recognised under CBD's article 22 (2), which states that "Parties shall implement this Convention with respect to the marine environment, consistently with the rights and obligations of States under the law of the sea". The exception to this provision

[1] Decision X/2, CBD (2010).

[2] It would be reasonable to assume that article 4 (b) confers legitimacy to CBD parties to adopt management measures for activities under the jurisdiction or control of any state in areas beyond national jurisdiction. However, parties have taken a political decision to not establish those measures in ABNJ, but have recognised the scientific and technical role of the CBD in assisting the implementation of UNCLOS.

is provided by article 22 (1), which establishes that "CBD provisions shall not affect the rights and obligations of any Party deriving from any existing international agreement, except where the exercise of those rights and obligations would cause a serious damage or threat to biological diversity." For this reason, Birnie et al. note that in case of conflict, the CBD would prevail over UNCLOS, but any attempt to regulate marine biodiversity would come from UNCLOS rather than the CBD (Birnie et al. 2009). Negotiations of regulations such as these are currently taking place under a UN General Assembly (UNGA) Preparatory Committee (PrepCom) tasked to elaborate the elements of a third implementing agreement to UNCLOS on conservation and sustainable use of marine biodiversity in areas beyond national jurisdiction. In establishing this preparatory process, the UN General Assembly stressed the need for a "comprehensive global regime to better address the conservation and sustainable use of marine biodiversity in areas beyond national jurisdiction" (UNGA 2015, 5th preambular para). Achieving such a comprehensive regime will require building upon the existing relationship between UNCLOS and the CBD (and other relevant instruments), including by benefiting from the scientific knowledge-base accumulated under CBD processes. In exploring these connections, this chapter focuses on the role that the CBD ecologically or biologically significant marine areas (EBSAs) can play if properly conserved and managed by states and competent organisations in contributing towards this desirable coherent regime. It will therefore recall the emergence of the EBSA concept under the CBD and highlight possible management approaches for tackling (at least in part) marine biodiversity loss.

It is beyond the scope of this chapter to discuss all international instruments related to marine biodiversity (e.g., Convention on Migratory Species, Ramsar Convention, among several others), but instead, it focuses on the EBSA criteria and process as a powerful cross-cutting tool for all relevant biodiversity-related instruments—including future ones—as well as natural resources and sectoral regulatory and management bodies in considering the impacts of their regulated activities on marine biodiversity.

45.2 Biodiversity Loss and Management Challenges

The loss of marine biodiversity poses significant threats to marine ecosystems and respective ecosystem services and functions. It has been calculated that marine vertebrates have declined by approximately 52% in the past 40 years (WWF 2015). The main drivers of biodiversity loss and change are (see Hiscock 2014; FAO 2016):

1. Overfishing of targetted and untargeted species (e.g., bycatch) (see FAO 2016);
2. Habitat loss (e.g., bottom fishing impacts on benthic species and features, such as deep sea corals, sponges and seamounts; mangrove alteration or destruction for other uses such as aquaculture, coastal development);
3. Pollution (from land-based sources, sewage, chemicals, agricultural runoffs, etc.) and from activities at sea (e.g., oil pollution, underwater noise);

4. Invasive alien species;
5. Climate change; and
6. Maritime traffic (e.g., collision with marine mammals).

Moreover, with deep seabed mining starting in the near future, additional (large scale and irreversible) benthic impacts will inevitably occur due to the nature of the activity—even if further environmental regulations are in place (Johnson et al. 2016). Furthermore, the increasing rate of ocean acidification (UN 2016, Chap. 54)[3] (26% higher from pre-industrial levels) and its effects on marine biodiversity have been highlighted as a cause for concern that should be urgently addressed through both mitigation and adaptation measures (CBD Secretariat 2014b), preferably integrated in all marine management measures. Climate change effects such as warming also alter the structure of ecosystems, migration patterns, and habitat alteration and destruction (e.g., coral bleaching).

Fishing practices (both within and beyond national jurisdiction) have significantly altered marine ecosystems and biodiversity through overfishing and habitat destruction. FAO estimates that approximately 31.4% of fish stocks are overfished and 58.1% of stocks are fully exploited without any room for further growth (FAO 2016). However, these numbers might be even higher considering a recent reconstruction of fishing catch data, which estimated catches being three times higher than previously estimated by FAO (Pauly and Zeller 2016). In addition to fishing above sustainable levels or overfishing,[4] habitat alteration and destruction prevents stocks' and ecosystem's rebuilding and drives further biodiversity loss.

In turn, marine biodiversity can enhance ecosystem resilience from multiple pressures (Roberts 2012; Hiscock 2014). Given the connectivity and dynamic nature of marine species and ecosystems, management needs to occur in an integrated manner. To this end, ecosystem-based management (EBM) has been promoted in a number of policy and legal instruments to achieve a holistic and integrated management of the world's oceans.[5] Nevertheless, the operationalization of EBM is challenged by isolated sectoral measures—a reflection of the current fragmented oceans governance regime. This lack of coordination, collaboration, and perhaps even oversight over sectoral bodies (e.g., International Maritime Organization, Regional Fisheries Bodies, International Seabed Authority, Regional Seas Conventions) is not conducive of an ecosystem approach (Diz 2013). Furthermore, such fragmentation constraints efforts regarding the assessment of cumulative impacts from multiple pressures and stressors.

Addressing cumulative impacts from multiple sectors and pressures requires coordination and collaboration among specialised agencies and government

[3] Impacts of ocean acidification include: reduced growth rates and damage to calcium carbonate in species, including shellfish, specific species of corals, etc., affecting the structure and function of the ecosystems where these species occur.

[4] This level should be calculated in accordance with article 6 of the Fish Stocks Agreement on the precautionary approach. See Diz (2013).

[5] E.g. Johannesburg Plan of Implementation (2002); The Future We Want (2012); Decision VII/11, CBD.

departments responsible for the regulation and management of marine biodiversity and resources (Salomon and Dross, Chap. 49). In areas beyond national jurisdiction, such coordination is also required and perhaps even some sort of oversight to ensure policy and management coherence. Against this background, and after a decade of discussions on the fragmented nature of the current governance regime (see Diz 2013; Ban et al. 2014) at a UN General Assembly ad hoc open ended working group, the UNGA recognised the need for a comprehensive global regime on biodiversity in ABNJ through the development of a third implementing agreement to UNCLOS to this end (UNGA 2015), as mentioned above. The UNGA shall decide on the convening of an intergovernmental conference on the adoption of such an agreement by the end of its 72nd session.

Achieving policy and management coherence in both areas—within and beyond national jurisdiction, is a challenging undertaking due to different sectoral interests and priorities, insufficient information-sharing among organisations, including on marine areas that require enhanced conservation measures due to their biological or ecological features. As discussed in the next section, it is argued here that the EBSA description can provide a focus and starting point for integrated oceans management through the identification of area-based management tools capable of addressing these multiple pressures and preventing significant adverse impacts on important ecosystem features.

45.3 An Emerging International Scientific Process & Its Cross-Cutting Management Potential

This section provides a brief account of the EBSA process under the CBD since the development and adoption of the EBSA criteria as a background to an ensuing discussion of emerging conservation approaches adopted by some States and regions, such as Australia and West Africa in this connection. In discussing conservation approaches, the role of environmental impact assessments in avoiding significant adverse impacts to areas meeting the EBSA criteria and EBSA features is particularly emphasised. The last section addresses emerging thinking around categorisation of EBSAs to inform management measures choices towards more effective planning.

45.3.1 EBSAs

The CBD EBSA criteria was adopted in 2008 at its 9th Conference of the Parties (COP 9) in response to CBD's obligation regarding *in situ* conservation and previous COP decisions, as well as the 2002 World Summit on Sustainable Development's (WSSD) Johannesburg Plan of Implementation (JPOI), which called for the establishment of marine protected areas (MPAs) networks globally by 2012. Within this context, the CBD Ad-Hoc Working Group on Protected Areas invited a group of experts to collate existing habitat criteria and to develop a set of criteria that harmonize different approaches and that could benefit the CBD as well as sectoral organizations such as the International Maritime Organization (IMO) and the Food and Agriculture Organization of the United Nations (FAO; Dunn et al. 2014).

In order to avoid biodiversity loss and to maintain ecosystem structure and function, it is important to know where areas of particular ecological or biological significance are located, so that area-based management tools and other conservation and management measures can be properly adopted. Thus, the CBD EBSA scientific criteria for the identification of areas in need of protection comprise: uniqueness or rarity; special importance for life-history stages of species; importance for threatened, endangered or declining species and/or habitats; vulnerability, fragility, sensitivity or slow recovery; biological productivity; biological diversity; and naturalness (Decision IX/20, Annex I, CBD).

As noted above, this set of criteria builds upon existing criteria and tools from different instruments,[6] providing a comprehensive and widely accepted (by all 196 parties of the CBD) cross-cutting tool for describing important habitats and biodiversity hot spots. Hence, areas described as EBSAs under the CBD have the potential to inform respective policy and management decisions at relevant fora. For instance, IMO members could assess the potential threats from shipping on areas that meet the EBSA criteria or on specific EBSA features[7] when proposing new PSSA areas.

In the same decision, CBD Parties also adopted scientific guidance for selecting areas to establish a representative network of marine protected areas, including in open-ocean waters and deep-sea habitats (Decision IX/20, Annex II, CBD). The required network properties and components include areas described as EBSAs, as well as areas important for representativity, connectivity, replicated ecological features, and adequate and viable sites. It is therefore clear that the EBSA description can directly contribute to the design of ecologically representative MPA networks, however, as noted in the next section, the strong focus on using the EBSA criteria solely for MPA planning has been broadened to other conservation tools and approaches including impact assessments and marine spatial planning.

45.3.2 The EBSA-Process

The CBD EBSA process has evolved since the criteria was adopted in 2008. The nuances of the EBSA process need to be understood in light of the political sensitivities associated with jurisdictional issues, as noted in this section, so that the

[6] Such as Important Bird Areas, Ramsar Convention wetland criteria, Particularly Sensitive Sea Areas (PSSAs), vulnerable marine ecosystems (VMEs), and the Canadian criteria to identify ecologically and biologically significant areas.

[7] E.g. threats of shipping collision, pollution or underwater noise on cetacean habitats contained in the EBSA description could be assessed to determine the adoption of new PSSAs.

EBSA potential as an integrative tool can be contextualised as a pragmatic proposition rather than an unrealistic attempt.

In 2010, COP 10 requested the CBD Secretariat to organize regional workshops to facilitate the 'description' of EBSAs. In this context, parties also noted that the application of the EBSA criteria is a scientific and technical exercise, and that areas found to meet the criteria may require enhanced conservation and management measures. It was also noted that this can be achieved through a variety of means, including MPAs[8] and impact assessments, emphasizing that the 'identification' of EBSAs and the selection of conservation and management measures is a matter for States (if in coastal waters) and competent intergovernmental organizations (if in ABNJ), in accordance with international law, including UNCLOS (Decision X/29, para. 26, CBD).

As part of the EBSA process, scientific and technical reports from the regional workshops are submitted to the CBD Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) which then recommends to COP the inclusion of these reports and respective areas described as meeting the EBSA criteria into the CBD EBSA repository[9] (which also serves as an information sharing mechanism) and the submission of these summary reports to States and competent organisations for appropriate conservation and management measures.

Since then, 12 CBD scientific regional workshops have been conducted globally to describe areas that meet the EBSA criteria, with 9 of these being previously considered by the CBD COPs 11 and 12, totalling the number of EBSAs officially included in the CBD repository to 204 to date, with about 55 of them located (partially or as a whole) in areas beyond national jurisdiction. The outcomes from three additional regional workshops held after COP 12 (NW and NE Indian Oceans and Seas of East Asia) were considered by SBSTTA-20, which recommended that COP 13 welcomes the respective reports, requesting the Secretariat to transmit them to States and competent organisations and to include the results in the repository (UNEP/CBD/SBSTTA/20/L.8 (2016)).

Some states (e.g., Australia, Canada, among others) have developed similar criteria and scientific processes for the description/identification of important biodiversity areas, and therefore, have not given consent to include their waters in the geographical scope of the CBD regional workshops. In light of this, COP 12 invited states to undertake national exercises to describe areas meeting the EBSA criteria and other relevant compatible and complementary nationally or intergovernmentally agreed scientific criteria in areas within national jurisdiction, and to make this information available through the EBSA repository or information-sharing mechanism as per Decisions X/29 and XI/17 (Decision XII/22, para. 7, CBD).

Despite progress being made on the description of EBSAs, little experience currently exists on a coherent systematic approach for the management of these areas. Nonetheless, experience is starting to accumulate on the use of the EBSA

---

8 See Chap. 7.6 of the current publication on MPAs.

9 EBSA repository, online: < https://www.cbd.int/ebsa/>

criteria in MPA network planning. Its potential for also contributing to ecosystem-based management more broadly could facilitate the delivery of integrated oceans management, and streamline related decision-making procedures by providing a focus for cumulative impact assessments and tailored conservation measures to protect EBSA features (e.g., spawning grounds, biodiversity hotspots, etc.).

45.3.3 Conservation Approaches Towards an Ecosystem-Based Management

The description of areas that meet the EBSA criteria can provide an opportunity to prevent biodiversity loss and promote ecosystem rebuilding through the identification and implementation of appropriate conservation and sustainable management measures, including, (but not restricted to) MPAs. For instance, in West Africa, coastal states are making progress in achieving the CBD Aichi Biodiversity Target 11 on MPAs (and other effective area-based management measures) through the use of scientific information contained in the CBD South East Atlantic EBSA workshop report (RAMPAO, PRCM 2015).

In addition to MPAs, the description of areas that meet the EBSA criteria can help with the identification of other area-based conservation tools, since these areas require an increased level of protection[10] and therefore risk averse approaches should be implemented (DFO 2004; Olsen et al. 2011). In other words, while the process for description of these areas are based on scientific assessments of biological and ecological features, the choice of management measures to be adopted can also be based on the likelihood of existing and future threats occurring in these areas. Ideally, the identification of appropriate conservation and management measures would be based on an ecosystem-based integrated oceans management context where cumulative impacts on EBSAs and EBSA features are fully considered. These risks and impacts should then be assessed within the context of Strategic Environmental Assessments (SEAs)—at an ocean basin level or biogeographic context, and through activity/project-based environmental impact assessments (EIAs), which should integrate methodologies able to quantitatively assess spatial patterns of all human activities and uses and their cumulative effects (see Halpern et al. 2009). Methodologies such as these can also incorporate climate change and ocean acidification effects (subject to data availability), enabling management to be much more precautionary and adaptive rather than reactive.

[10] See Decisions, IX/20; X/29; XI/17, XII/22, CBD.

Australia's management approach to EBSA-like areas

As noted above, experience in using EBSA or EBSA-like descriptions and information as a basis for management is just starting to be implemented. Australia, for instance, has adopted EBSA-like criteria for identifying key ecological features (KEFs) and Biologically Important Areas (BIAs). KEFs represent areas important for biodiversity, productivity or ecosystem function, while BIAs are areas important for different life-history stages of specific species in a given region. The identification of these areas contributes to the adoption of spatial measures, including MPAs, while informing impact assessments. In this context, Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) has proposed the following framework for the use of scientific information related to EBSAs for Marine Spatial Planning and Ecosystem Based Management:

"(1) Scoping—Understanding the political/institutional and social domain and motivations for management; (2) EBSA—Understanding the ecological/biological values in the system; (3) Impact—Understanding the interaction between ecological/biological values and pressures; (4) Informing a management response based on the values, pressures and socio-economic values; and (5) Monitoring the effectiveness of management through indicators that can detect changes on the values" (Dunstan et al. 2014, pp 6).

With respect to the third phase described above, Dunstan et al explain that "to identify which biodiversity values may be impacted and the cumulative impact of multiple sectors over time, models of the relevant subsystem that incorporate understanding of the ecosystem components are needed" (Dunstan et al. 2014, pp 8). The authors also underscore the importance of undertaking a formal (in the form of qualitative ecosystem models that allow for quantitative assessment) analysis of cumulative impacts and pressures on biodiversity and ecosystem values, but notes that at a initial stage, if relevant information is not available, a simple matrix of ecosystem values and pressures for each EBSA could be considered. As scientific information increases, thresholds can be determined as well as analyses of trends and resilience (Dunstan et al. 2014).

45.3.4 The Relevance of Impact Assessments to Management

Environmental impact assessments to protect the marine environment are required under article 206 of UNCLOS. These are also required under article 14 of the CBD with respect to marine (and terrestrial) biodiversity. With respect to fisheries, more specifically, the Fish Stocks Agreement requires states to "assess the impacts of fishing, other human activities and environmental factors on target stocks and species belonging to the same ecosystem or associated with or dependent upon the target stocks" (Art. 5 (d), UN Fish Stocks Agreement).

CBD parties have suggested EIAs and SEAs be conducted for activities that might pose impacts on EBSAs and EBSA features. In effect, other related CBD decisions should be considered in this context, including decision VIII/28, which endorsed the voluntary guidelines on biodiversity-inclusive environmental impact assessment, and decision XI/18, which took note of the Revised Voluntary Guidelines for the Consideration of Biodiversity in Environmental Impact Assessments and Strategic Environmental Assessments in Marine and Coastal Areas (CBD EIA Voluntary Guidelines 2012), complementing the original Guidelines with annotated comments specific for marine and coastal areas. With respect to the screening stage of the EIA, the CBD Guidelines recommend that it should be considered whether the activity would cause substantive pollution, or significant and harmful changes to an EBSA. It is further recommended that "any activity with the potential to cause substantial pollution of or significant and harmful changes should be subject to some form of initial screening and initial environmental evaluation" (CBD EIA Voluntary Guidelines 2012, para. 10(b)).

Since these guidelines do not provide guidance regarding specific EIA criteria and thresholds, another useful instrument to advance further understanding of significant adverse impacts on deep sea/benthic-related EBSAs is the FAO International Guidelines for the Management of Deep-sea Fisheries in the High Seas, which provide minimum standards and criteria for deep-sea fisheries EIAs to prevent impacts on vulnerable marine ecosystems (VMEs; FAO 2009, para. 47). The development of similar criteria and minimum standards for the protection of pelagic features would add value to management and enable a more comprehensive assessment of significant adverse impacts on different types of EBSAs and EBSA features from different types of activities.

In this connection, the Northwest Atlantic Fisheries Organization (NAFO) has assessed the impacts of its fishing activities on the Sargasso Sea EBSA, and as a result bottom trawling was banned from the Corner Rise and New England Seamount chains found within this EBSA. Furthermore, gear modification for mid-water trawl was required to avoid bottom contact that could impact cold-water corals and sponges found in those seamounts (also considered as vulnerable marine ecosystems by NAFO) (Diz 2016). Measures such as these—to assess significant adverse impacts on VMEs and protect habitats and fragile species—make part of NAFO's Ecosystem Approach to Fisheries Management Roadmap (NAFO 2013), and could be replicated by other RFMOs. Conversely, assessment of potential fishing impacts by RFMOs scientific bodies should also be expanded to all areas meeting the EBSA criteria within their respective regulatory areas.

In the context of an ecosystem approach (Decisions V/6 and VII/11, CBD), cumulative, additive and synergistic impacts, existing and potential pressures and stressors on EBSAs and EBSA features should also be considered[11] in order to enable the identification of conservation and management measures that can safeguard those areas, and possibly increase ecosystem resilience for coping with additional pressures such as climate change effects and ocean acidification (see CBD Secretariat 2014b). As noted by Dunn et al.:

[11] This understanding is consistent the CBD Voluntary EIA Guidelines (2012), as seen above.

"These assessments can benefit from knowledge of the properties of EBSAs and help guide the selection of measures that ensure the EBSAs receive a relatively higher level of precaution. This is particularly true for EBSAs that may experience cumulative or synergistic impacts. For example, information on spawning, breeding or feeding grounds or migratory corridors collected through the description of how areas meet EBSA criteria 2 and 3 (the life history and endangered species criteria) might be used to decrease the risk of ship strikes or harmful fisheries bycatch. The identification of unique or rare areas (EBSA criterion 1) or areas with high biological diversity (EBSA criterion 6) might indicate an increased probability of discovering new genetic diversity. Scientific discovery could be prioritized for such EBSAs within an [Marine Spatial Planning]." (Dunn et al. 2014: 144).

To this end, the use of scientific cumulative impacts assessments methodologies (see Halpern et al. 2015; Korpinen, et al. 2014; Murray et al. 2014) tailored for specific biogeographic regions could be further explored to advance policy and legal requirements on minimum individual and cumulative impact assessment standards and thresholds, and to better guide the development of adequate EBSA conservation and management measures.

In this light, the adoption of conservation and management measures for EBSAs can contribute to the achievement of CBD Aichi Biodiversity Targets, including targets 6 (sustainable fisheries), 10 (building resilience to climate change and ocean acidification), 11 (marine protected areas and other effective conservation measures), 12 (endangered species), among others (see Dunstan et al. 2014). In this connection, specific CBD decisions and workplans would be particularly relevant for further consideration of specific area-based tools and other conservation and management measures. For instance, the information contained in the EBSA reports can assist on the implementation of the Specific Workplan on Biodiversity and Acidification in Cold-Water Areas (to be considered at COP 13) and of the priority actions to achieve Aichi Biodiversity Target 10 for coral reefs and closely associated ecosystems (Decision XII/23, CBD). Achieving these targets is necessary for halting biodiversity loss at a global level and reverting this negative trend. Since the achievement of these targets requires ongoing efforts, the new UNCLOS implementing agreement on marine biodiversity in areas beyond national jurisdiction could provide the necessary institutional framework for maximising the results of concerted efforts in this regard. In turn, it could also benefit from the existing EBSA-related knowledge-base in the global oceans without having to start from scratch.

45.3.5 Management Approaches

In addition to MPAs[12] (or even within MPAs), a number of management measures can be considered for each EBSA depending on its characteristics. Each EBSA usually holds a diverse range of biological/ecological features. For example, the

[12] See Chap. 46 of this publication.

Sargasso Sea EBSA encompasses pelagic and benthic ecosystems comprised of seamounts, gyres, which provides habitat for endangered and vulnerable species. These might relate to each other, but the pressures on each system vary. This suggests that a number of targeted management interventions might be needed to prevent or minimise significant adverse impacts on a given area. Large EBSAs management could also benefit from disaggregated data from different sources. For instance, data from Birdlife International information on Important Bird Areas, IUCN on Important Marine Mammal Areas (IMMAs), FAO and RFMOs on VMEs, Ocean Biogeographic Information System (OBIS) on biodiversity and biogeographic data can better inform decision-making on conservation measure choices to be adopted for each EBSA and surrounding areas.

Other Conventions, such as the Convention on Migratory Species (CMS) has conducted further analysis on EBSAs which helped better understand the extent to which CMS listed species have contributed to each EBSA description. Information such as this could be a first step towards cumulative impact assessments on these habitats and cross-sectoral cooperation (e.g., among shipping, fishing, marine renewables, oil and gas, mining, and other sectors) for preventing and minimising significant adverse impacts on these areas. CMS parties have been considering means to use the EBSA scientific information and associated information on connectivity for investigating the need of enhanced conservation measures (CBD 2016a).

To better inform related management intervention, Rice (2016) suggests the classification of EBSA into four main categories:

1. Type 1: key features are fixed in space and time (e.g., a particular seamount).
2. Type 2: a set of similar fixed areas clustered in space, where physical gaps between areas meeting the criteria may occur (e.g., a seamount chain).
3. Type 3: larger polygon containing diverse sub-areas meeting the EBSA criteria on its own. The subareas may not be stable in space and time (seasonality) (e.g., spawning grounds, feeding areas, etc.).
4. Type 4: "… the location(s) with the combination of features meeting the criteria can be identified more or less homogeneously at any specified time, but that area moves over time." (Rice 2016: 11) Examples include shelf-ice edges and oceanographic fronts. In a fixed map, these areas are usually represented as encompassing very large areas so as to encompass the entire longitudinal and latitudinal range of the shifting feature. Examples include the Sargasso Sea, and the North Pacific Transition Zone.

This categorisation may help identify appropriate conservation and management measures for EBSAs. More specifically, Rice observes that Type 1 EBSAs could benefit in their entirety from a specific well-chosen conservation measure, while Type 2 could accommodate less uniform measures. In terms of management, more stringent conservation measures could be adopted on areas meeting the EBSA criteria within each polygon (e.g., each seamount) for instance. This approach would therefore require a more detailed level of data availability (Rice 2016). It is important to note that if less stringent conservation measures are adopted for the polygons' surrounding areas (e.g., waters in between each seamount in a seamount chain) connectivity between these areas should still be safeguarded. Type 3 EBSAs could benefit from dynamic ocean management (DOM) (see Maxwell et al. 2015).[13] DOM has been used successfully (with increased benefits to the fishing industry as well) in countries like the US and New Zealand for bycatch reduction and other purposes (Maxwell et al. 2015). Management for Type 4 EBSAs would also require consideration on the kind of activity proposed. If long-term installations are planned within a Type 4 EBSA, their potential impacts would have to be assessed as at a given time of the year, the EBSA would come in contact with these structures/activities (e.g., oil and gas platforms in the Arctic and its interaction with shelf-ice edges which varies depending on the time of the year). On the other hand, if the activity proposed is seasonal, the intervention could be targeted at that particular activity at a given time (e.g., preventive bycatch measures associated with the shelf-ice edge or oceanographic front) (Rice 2016).

In a recent EBSA expert workshop organised by the CBD Secretariat (CBD 2016b), experts recommended categorisation based on two main features, namely stability (benthic) and complexity (pelagic). Stable EBSAs include geographically stable with single feature (e.g., seamounts), and with aggregated features (e.g., seamount chains). While complex EBSA features comprise those that are geographically dynamic (e.g., oceanographic fronts, shelf-ice edges) with single and with aggregated EBSA features.

The Group of Experts also recommended the use of systematic approaches to augment the site-based approach. Furthermore, it is important to note that activities occurring outside of the EBSA could also negatively impact EBSA features. This should be taken into consideration when drafting new policies, EIA regulations, or considering specific conservation and management measures.

45.4 Concluding Remarks

The development of cross-sectoral policies and regulations mandating the assessment of potential significant adverse impacts (individually and cumulatively) on EBSAs could contribute to a more coherent biodiversity conservation regime in accordance with the ecosystem approach. Such coherence is still needed both within areas of national jurisdiction and beyond.

More specifically, EBSA information can contribute to the adoption of specific conservation and management measures for the long-term conservation and sustainable use of biodiversity. For instance, as noted above, the IMO PSSA criteria are quite similar to the EBSA criteria. Further assessments could be conducted to analyse the vulnerability of particular EBSAs and EBSA features to shipping

[13] In this context technology transfer and capacity building would most likely be needed.

activities. These assessments could then contribute to new PSSAs and associated protective measures by IMO. With respect to RFMOs, the NAFO experience in assessing the impacts of its fisheries on the Sargasso Sea EBSA and respective seamounts could be replicated by other RFMOs and expanded to all areas meeting the EBSA criteria within their respective regulatory areas. The International Seabed Authority could also require special attention be given in EIA requirements for deep seabed mining activities that could pose an impact to EBSAs and EBSA features (even if the activity occurs outside the EBSA polygon—given plume-related impacts,[14] among others). Furthermore, it is also important to assess cumulative effects of different activities and pressures on the marine environment and its biodiversity which requires the use of integrative spatial approaches and methodologies so as to avoid impacts beyond the ecosystems' ability to tolerate in a given time-frame. Overlaying EBSA maps and information (e.g., disaggregated data of EBSA features) with cumulative pressure maps could add value to the identification of best conservation and management measures required for a given area.

The EBSA scientific information and process can also directly contribute to the UNCLOS implementing agreement PrepCom discussions, by giving effect to and building upon the relationship between UNCLOS and CBD, in accordance with its article 22. Furthermore, the PrepCom does not have a scientific body and depends upon scientific information produced by other bodies. Given that area-based management tools, including MPAs, and EIAs constitute agreed elements to be incorporated by the implemented agreement (UNGA 2015), the EBSA process and the scientific information it provides are well-suited to play a key role in this new governance regime.

Therefore, the EBSA criteria—and other complementary criteria (e.g., VME), scientific information (e.g., from OBIS, etc.) and traditional knowledge can assist UNCLOS parties meet their obligation to protect the marine environment and specific habitats (Arts 192 and 194 (5), UNCLOS), as well as the CBD objectives and associated Biodiversity Strategic Plan 2011–2020 and Aichi Biodiversity Targets (Decision X/2, CBD). The operationalisation of this, depends upon specific policies and regulations to be adopted by coastal states, competent organisations, and also integrated into the new UNCLOS implementing agreement for the achievement of a coherent governance system. These policies and legal frameworks, could, for instance, require EIA and cumulative impact assessments (where the effects of climate change and ocean acidification can also be taken into account) for activities that are likely to cause significant adverse impacts to EBSAs or EBSA features in order to determine what type of management measure should be put in place. More importantly, proper conservation measures for these areas and management measures for activities that can impact these areas (including future activities) could also contribute to reversing the current trend of marine biodiversity loss.

[14] See Chaps. 11 and 44 on deep seabed mining of the current publication.

References

Ban N, Bax N, Gjerde K, Devillers R, Dunn D, Dunstan P, Hobday A, Maxwell S, Kaplan D, Pressey R, Ardron J, Game E, Halpin P (2014) Systematic conservation planning: a better recipe for managing the high seas for biodiversity conservation and sustainable use. Conserv Lett 7(1):41–54

Birnie P, Boyle A, Redgwell C (2009) International law & the environment. Oxford University Press, Oxford

CBD (2012) Marine and coastal biodiversity: revised voluntary guidelines for the consideration of biodiversity in environmental impact assessments and strategic environmental assessments in marine and coastal areas. Doc. UNEP/CBD/COP/11/23

CBD (2016a) Progress report on describing areas meeting the criteria for ecologically or biologically significant marine areas. Doc. UNEP/CBD/SBSTTA/20/3

CBD (2016b) Report of the expert meeting to share experiences and lessons learned on the scientific methodologies and approaches for the description of EBSAs. Doc. UNEP/CBD/SBSTTA/20/INF/20, Annex II

CBD Secretariat (2014a) Global biodiversity outlook 4. CBD, Montréal

CBD Secretariat (2014b) In: Hennige S, Roberts JM, Williamson P (eds) An updated synthesis of the impacts of ocean acidification on marine biodiversity, Technical Series no. 75. Montreal, CBD

De Lafayette L (2009) A new regime for the conservation and sustainable use of marine biodiversity and genetic resources beyond the limits of national jurisdiction. Int J Mar Coastal Law 24(2):221–280

DFO (2004) Identification of ecologically and biologically significant areas, DFO Canadian Science Advisory Secretariat Ecosystem Status Report. 2004/006

Diz D (2013) Fisheries management in areas beyond national jurisdiction: the impact of ecosystem based law-making. Martinus Nijhoff, Leiden

Diz D (2016) The seamounts of the Sargasso Sea: adequately protected? Int J Mar Coastal Law 31:359–370

Dunn D, Ardron J, Bax N, Bernal P, Cleary JA, Cresswell I, Donnelly B, Dunstan P, Gjeder K, Johnson D, Kaschner K, Lascelles B, rice J, von Nordheim H, Wood L, Halpin PN (2014) The convention on biological diversity's ecologically or biologically significant areas: origins, development, and current status. Mar Policy 49:137–145

Dunstan PK, Bax NJ, Dambacher JM, Hayes KR, Hedge PT, Smith DC, Smith ADM (2014) Using scientific information related to ecologically or biologically significant marine areas (EBSAs) to implement marine spatial planning and ecosystem based management. CSIRO, Canberra. Doc. UNEP/CBD/MCB/EM/2014/4/INF/2

FAO (2009) International guidelines for the management of deep-sea fisheries in the high seas. FAO, Rome

FAO (2016) The state of world fisheries and aquaculture 2016. Contributing to food security and nutrition for all. FAO, Rome

Halpern B, Kappel CV, Selkoe KA, Micheli F, Ebert CM, Kontgis C, Crain CM, Martone RG, Shearer C, Teck SJ (2009) Mapping cumulative human impacts to California current marine ecosystems. Conserv Lett 2(3):138–148

Halpern B, Frazier M, Potapenko J, Casey KS, Koenig K, Longo C, Lowndes JS, Rockwood RC, Selig ER, Selkoe KA, Walbridge S (2015) Spatial and temporal changes in cumulative human impacts on the world's ocean. Nat Commun 6:7615. doi:10.1038/ncomms8615

Hiscock K (2014) Marine biodiversity conservation: a practical approach. Earthscan from Routledge, Oxford

Johnson D, Weaver P, Gunn V, Spicer W, Mahaney S, Tladi D, Alvarez Perez A, Tawake A (2016) Periodic review of the international seabed authority pursuant to UNCLOS article 154: interim report. Seascape Consultants, Romsey

Korpinen S, Heiskanen A-S, Setälä O, Uusitalo L, Valanko S, Andersen JH, Niiranen S (2014) Towards management of multiple stressors in the context of the marine strategy framework directive: a Baltic Sea pilot study. Report of the STAGES project (EU FP7), Additional deliverable under WP2. http://www.stagesproject.eu/images/STAGES/deliverables/STAGES%20MSFD%20Programme%20of%20Measures%20Pilot%20Study.pdf. Accessed on 30 August 2017

Maxwell SM, Hazen EL, Lewison RL, Dunn DC, Bailey H, Bograd SJ, Briscoe DK, Fossette S, Hobday AJ, Bennett M, Benson S, Caldwell MR, Costa DP, Dewar H, Eguchi T, Hazen L, Kohin S, Sippel T, Crowder LB (2015) Dynamic ocean management: defining and conceptualizing real-time management of the ocean. Mar Policy 58:42–50

McCauley D, Pinsky ML, Palumbi SR, Estes JA, Joyce F, Warner RR (2015) Marine Defaunation: animal loss in the global ocean. Science 347(6219):1255641

Murray C, Mach M, Martone R (2014) Cumulative effects in marine ecosystems: scientific perspectives on its challenges and solutions. WWF-Canada and Center for Ocean Solutions, Vancouver

NAFO (2013) SC working group on ecosystem science and assessment: report of the 6th meeting of the NAFO scientific council working group on ecosystem science and assessment (WGESA). NAFO Headquaters, Dartmouth

Olsen E, Kleiven AR, Skjoldal HR, von Quillfeldt CH (2011) Place-based management at different spatial scales. J Coast Conserv 15:257–269

Pauly D, Zeller D (2016) Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. Nat Commun 7:10244

RAMPAO & PRCM (2015) Regional workshop on EBSA processes in West Africa protection of ecologically and biologically significant areas and vulnerable ecosystems off the coast and on the high seas of West Africa. Banjul, 29-30 September

Rice J (2016) Compilation of experiences and lessons learned from scientific methodologies and approaches for the description of areas meeting the EBSA criteria. Doc. UNEP/CBD/SBSTTA/20/INF/20, Annex I

Roberts C (2012) Ocean of life. Penguin Books, London

Rocha J, Yletyinen J, Biggs R, Blencker T, Peterson G (2015) Marine regime shifts: drivers and impacts on ecosystems services. Philos Trans R Soc Lond B Biol Sci 370(1659):20130273

UN, First Global Integrated Marine Assessment (UN, 2016), chapter 54. Online: accessed on 30 August 2017

UN General Assembly Resolution A/RES/69/292 (2015), Development of an international legally binding instrument under UNCLOS on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction

WWF (2015) Living blue planet report. WWF, Washington

Chapter 46
Marine Protected Areas: Global Framework, Regional MPA Networks and a National Example

Henning von Nordheim

Abstract In the last 15 years considerable progress has been made regarding the establishment of Marine Protected Areas (MPAs) and the implementation of a worldwide MPA network, despite of great regional differences and the long way still to go to reach the targeted 10% coverage of world's oceans by MPAs set by CBD for 2020 for all seas.

This article gives an overview of the latest developments within MPA networks, the state of play on global level, some examples stemming from Regional Sea Conventions and a national case study of the establishment of MPAs.

Most promising advances in global MPA establishment are the current "UN Prep Com-Process" that may lead to a stronger commitment of the United Nations within the framework of the UN Convention on the Law of the Sea (UNCLOS) and, possibly even more "fruitful", the achievements of the global Convention on Biological Diversity (CBD). The CBD has established a process to identify so-called "Ecologically and Biologically Significant Areas" (EBSA) in the global oceans in 2008 to inform states and international institutions. In the meantime these efforts have covered a high percentage of the global ocean and a total number of 280 EBSAs could already be identified and globally agreed by 2017. These are situated both in international waters as well as waters under the jurisdiction of individual states. At the same time very promising MPA activities are conducted by a large number of nations and under several Regional Sea Conventions, one of which, the Helsinki-Convention for the Baltic Sea, has already met the 10% MPA-coverage target.

Keywords MPA • Area based management • MPA networks • Regional sea conventions • MPA selection criteria • EBSA • CBD

H. von Nordheim (✉)
Federal Agency for Nature Conservation, Bonn/Isle of Vilm, Germany
e-mail: Henning.von.Nordheim@BfN.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection* ,
https://doi.org/10.1007/978-3-319-60156-4_46

46.1 Introduction

Human beings have used the seas for centuries and their activities have impacted habitats, ecological communities and species to varying degrees. It is globally recognised and laid out in this book that the marine environment and its biodiversity are increasingly under pressure from different human impacts worldwide: pollution, eutrophication, effects of climate change and over-exploitation plus degradation linked to direct activities such as fisheries, shipping, seabed mining, oil and gas extraction, military activities, offshore constructions such as offshore windfarms or from tourism (Halpern et al. 2008).

In light of these wide-ranging impacts and in order to keep the marine environment and nature ecologically intact or to re-establish natural conditions, the management of human activities should be addressed by two complimentary approaches.

On a global scale also in the marine realm human activities and management should be ecologically sustainable by applying key overarching principles such as the ecosystem approach (as defined by OSPAR 2003a), the precautionary principle, the principle of minimising negative impacts, the compensation principle, the polluter-pays principle and the principles of best environmental practice and best available technology (Winter 2016, in this book: Chap. 30). It is necessary and vital to identify and respect the sustainability limits of marine ecosystems and to give ample consideration to those limits in all human activities.

These global and general principles and concepts can be particularly well-implemented through area based management tools (ABMT) which address the needs of marine biodiversity conservation by concrete measures for the protection of habitats and species and the establishment of ecologically coherent networks of marine protected areas (MPA).

One can find a variety of different site protection or conservation categories for marine areas worldwide, e.g. national parks, marine parks, marine reserves or special conservation areas, depending on the legal status of these areas. MPAs are established in coastal zones as well as in the Exclusive Economic Zones (EEZ) of countries but also in Areas beyond National Jurisdiction (ABNJ).

46.2 The Role of MPAs in the Protection of Marine Biodiversity

In 2008 the International Union for Conservation of Nature (IUCN) defined a MPA in the following way: "A Marine Protected Area is a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values" (IUCN 2008). The following chapter discussing MPAs will be based upon this definition. Although representing only one of the instruments to manage human activities in a sustainable way, the implementation of marine

CBD Scientific Criteria for identifying Ecologically and Biologically Significant Areas (EBSAs)

1. Uniqueness or Rarity
2. Special importance for life history stages of species
3. Importance for threatened, endangered or declining species and/or habitats
4. Vulnerability, Fragility, Sensitivity, or Slow recovery
5. Biological Productivity
6. Biological Diversity
7. Naturalness

Fig. 46.1 Scientific criteria for EBSAs (CBD COP 9, 2008, Decision IX/20)

protected areas (MPAs) is generally considered as the most effective and pragmatic measure for the protection of marine ecosystems, despite a number of open or unsolved legal and governance questions that increase with distance from the shorelines to the "high seas". (Thiel 2003; Agardy and Staub 2006; IUCN-WCPA 2008; Mora et al. 2006; Parks et al. 2006; Gjerde 2012; Ban et al. 2013).

Detailed MPA selection criteria were developed and applied by HELCOM and OSPAR (OSPAR 2003b) and formed the basis for similar criteria of the Convention of Biodiversity (CBD) for selecting Ecologically and Biologically Significant Areas (EBSAs) in the global oceans (CBD 2008, Fig. 46.1). The conservation objectives of MPAs usually address the protection, conservation and/or restoration of site-specific values and features such as species, biotopes, habitats, ecosystems, morphological structures and hydrological features but also complex eco-functions such as migration routes, breeding grounds and feeding and resting sites.

To achieve such objectives in most cases human activities in the site or those that negatively impact the site from outside need to be regulated permanently or temporarily and/or spatially.

However, best results for MPA effectiveness were so far shown for regulations of human activities on-site. Of course the same MPA would also benefit from successfully initiating reduction of inflow of diffuse nutrients or pollutants and waste from outside the MPA or avoiding effects of climate change that may show severe effects in the MPA (example: Great Barrier Marine Park, Australia).

46.3 Global Processes

The necessity for marine biodiversity conservation became more prominent on political agendas globally after the Rio-conference and the signing of the Convention on Biological Diversity (CBD) in 1992, which was also considering the establishment of MPAs (UN 1992).

Further, the United Nations Convention on the Law of the Sea (UN 1982) entered into force in 1994, for the first time clearly also addressing the 'impact-side'. Often described as the constitution for the oceans, UNCLOS is the most important piece of international law providing rights and obligations for contracting parties as well as governing human activities occurring in the marine realm.

Furthermore, it establishes an obligation for states to protect and preserve the marine environment (e.g. UNCLOS Article 192). Thus, it provides a legal framework for nature conservation agreements both for the territorial seas and the exclusive economic zones (EEZ) as well as for open waters and “high” seas (areas beyond national jurisdiction, ABNJ). It is therefore of key importance for the process of implementation of individual MPAs and MPA networks, also in Europe (von Nordheim and Wollny-Goerke 2013). Since 2000 the United Nations General Assembly (UNGA) was supported in marine aspects by the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea (UNICPOLOS). This deals—amongst other issues—with aspects of conservation of marine biodiversity and the implementation of MPAs, an aspect that was comprehensively addressed as a start off for in-depth negotiations in a special workshop in the authors agency’s premises on Isle of Vilm, Germany in 2001 (Thiel and Koslow 2001). The necessity of marine biodiversity conservation has increasingly been emphasised in different UNGA Resolutions since then.

In the last 15 years the Convention on Biological Diversity became the most important global convention for the conservation of marine biodiversity. It aims to conserve the planets biodiversity in all its shapes. Its objectives include safeguarding biodiversity in general (genetic, species and habitats diversity), including in the marine environment. The CBD’s main decision-making body is the bi-annual Conference of the Parties (COP), which is supported by various thematic working groups and committees.

The UNCLOS and CBD negotiations on marine issues were fuelled by the outcomes of the World Summit on Sustainable Development (WSSD) in Johannesburg in 2002, where the global leaders agreed to establish a comprehensive and representative worldwide network of MPAs by 2012 and started to improve the status of oceans biodiversity (Johannesburg Plan of Implementation 2002) (UN 2002). The WSSD of 2002 can therefore be considered as the basic reference point for all global programmes, activities and initiatives concerning marine biodiversity conservation for states, international organisations, institutions and NGOs (von Nordheim et al. 2011).

In line with this successful World Summit, further meetings of the CBD COP specified the aim to achieve a significant reduction in the rate of biodiversity loss by 2010, including marine biodiversity and supported increasingly the development and implementation of MPAs and MPA networks in coastal areas, exclusive economic zones (EEZs) and above all in the so-called “High Seas” (ABNJ). In 2008 COP 9 agreed on a system and the application of scientific criteria for the selection of Ecologically and Biologically Significant Areas (EBSAs) in the high seas (CBD Decision IX/20) (DUNN et al. 2014). One needs to take into account that the CBD has no direct political mandate for areas beyond EEZs of states and global organisations, but enjoys a kind of scientific advisory role to states as regards marine issues in ABNJ, e.g. in the ongoing UNCLOS negotiations (Biodiversity Beyond National Jurisdiction, BBNJ) or in UNGA decision making processes.

COP 10 (CBD 2010a, b) specified the process on the identification of EBSAs. Furthermore, the Parties adopted a Strategic Plan for Biodiversity, including the

´Aichi Biodiversity targets for the 2011–2020-period. Thereby, they strongly confirmed the "10%-target" according to which the worldwide representative network of marine protected areas in the oceans should encompass at least 10% of the world's oceans (Target 11 of the Aichi Biodiversity targets). At the same time, the target year to fulfil this goal was shifted from originally 2012–2020 (CBD 2010a; b; CBD Decisions X/2 and X/29).

46.3.1 Ecologically and Biologically Significant Areas—EBSA

The development of the EBSA scientific criteria (CBD 2008) was a great opportunity to harmonise the identification and selection of marine areas of outstanding ecological value in the world's oceans (Fig. 46.1). The criteria are based on existing regional criteria that were already applied by international organisations like those for the HELCOM Baltic Sea Protected Areas (BSPAs), the OSPAR MPAs or for the Specially Protected Areas of Mediterranean Importance (SPAMI). The global application of EBSAs scientific criteria is a challenging scientific and technical task (Ardron et al. 2009; Druel 2012).

In Nagoya 2010 (CBD COP 10), the Parties decided that the process to describe marine areas meeting the EBSA criteria was set out through regional workshops, held between governmental and non-governmental representatives as well as regional initiatives like the FAO, IMO or regional fisheries management organisations (RFMOs). The CBD Secretariat was tasked to establish a CBD repository and an information sharing mechanism. Those marine areas which meet the EBSA criteria as described by regional workshops need to be confirmed by the CBD Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) and finally endorsed and supported by a subsequent COP (e.g. CBD Decision X/29). The information on EBSAs endorsed by the CBD COP is made available for the UNGA and relevant competent authorities (von Nordheim and Wollny-Goerke 2013).

Since 2010, there has been substantial progress in the description of EBSAs. By the end of 2016, 12 of said Regional Workshops were held. Each workshop was tasked to describe areas meeting the scientific criteria for EBSAs or other relevant, similar criteria based on the best available scientific information. A high number of EBSAs has been reported to date to the CBD COP, some even *within* territorial or EEZ waters of Contracting Parties, resulting in a total of 280 EBSAs being recognised and covering about 19,3% of marine waters in a wide range of regions in the world's oceans (see http://www.cbd.int/ebsa/; UNEP 2016; Fig. 46.2). However, it has to be stressed that from the beginning of the process it was repetitively made clear that the status of an EBSA for a specific marine area does not mean that it is automatically a MPA and protected by any legal mechanism (see also Dunn et al. 2014; Bax et al. 2015).

An independent international scientific partnership, the **G**lobal **O**ceans **B**iodiversity **I**nitiative (GOBI), strives to advance the scientific basis for the

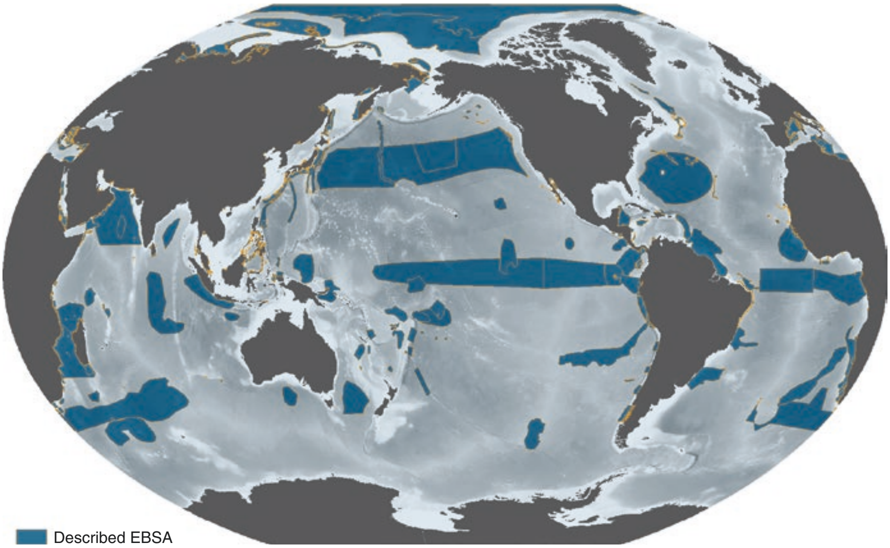


Fig. 46.2 Ecologically and Biologically Significant Areas (EBSAs) of the world's oceans by 2017.

conservation of marine biodiversity plays a key role in the EBSA process, providing guidance, data, tools and methodologies (see also www.gobi.org). GOBI representatives have participated in all regional workshops. They assisted the State Parties and NGOs, identified gaps and ensured consistency within the application of the scientific criteria (Johnson 2016).

46.3.2 From EBSAs to MPAs Accepted Worldwide

In the last years, three parallel levels to address MPA issues have developed: the EBSA identification process as described above, the process of implementing MPAs within the framework of Regional Sea Conventions (see below) and the process of implementing protected areas by states in their territorial waters or EEZs, which is sometimes initiated due to international directives (e.g. the Habitats-, Birds-, and Marine Strategy Framework Directives in European waters).

Regarding the CBD's 10%-target, we have to realise that up to-date only few of the Contracting Parties of the CBD implemented sufficent MPAs in their EEZ or territorial marine waters and have reached the 10%-target (von Nordheim et al. 2011; IUCN and UNEP-WCMC 2013).

By 2017, only 5,7% of the marine regions of the world were protected as an MPA under a protection regime according to IUCN criteria (https://www.cbd.int/pa/

UN-Ocean-Conference/flyer-en.pdf). In 2017 the world data base of MPAs reported that 14,4% of marine areas under national juristdiction were protected globally. Areas Beyond National Jurisdiction (ABNJ) are clearly further away from achieving the 10%-target.

As indicated above, a final designation of EBSAs or part of them as marine protected areas is not guaranteed "automatically" and it is a difficult and long-lasting process, depending on the political will and commitment of the international community. Currently there are promising signs for a possible agreement in the frame of the United Nations Convention on the Law of the Sea (UNCLOS) to ensure the protection and sustainable use of biodiversity in ABNJ. As a first step in 2015, the UNGA has adopted a resolution on the development of a legally-binding agreement under UNCLOS on the conservation and sustainable use of marine biological diversity in ABNJ. (UNGA Res/69/292, 2015). A preparatory committee (BBNJ) has worked on it and will report to the General Assembly by the end of 2017. UNGA may than decide whether and when to convene an intergovernmental conference to negotiate the agreement. According to Johnson (2016) it seems realistic that consensus at the UN to negotiate a legally binding agreement to protect biodiversity for Areas Beyond National Jurisdiction will be reached as a positive move, however, any Implementing Agreement will likely take years to be formally adopted.

46.4 MPA Networks Within the Regional Seas Conventions—Some Examples

In the 1970s the United Nations Environmental Programme (UNEP) established the Regional Seas Programme. Until now UNEP Regional Seas Programmes with various Action Plans were set up in 18 marine regions of the world, within 12 of these parties have adopted a legally-binding Convention. The first Regional Seas Convention under the umbrella of UNEP was the Barcelona Convention in 1976 (see below). Outside the UNEP process, some further conventions were set up, e.g. in the North-East-Atlantic, in Arctic and Antarctic regions.

Most of the Regional Seas Conventions for European waters, which will be the focus of the following sections, were originally set up to protect marine regions from environmental hazards such as contaminants and nutrients as well as other pollutions (e.g. by oil or waste). Bit by bit the scope of these conventions like the Oslo-Paris-Convention (OSPAR) of 1992, the Helsinki Convention (HELCOM) of 1992 and also the Barcelona Convention was widened to also address marine nature conservation objectives. The amendments include e.g. assessment and monitoring of human activities and their impacts on marine biodiversity as well as the possibility to establish marine protected areas or recovery plans for threatened species and habitats. Marine nature conservation therefore gradually became an integral part of most Regional Sea Conventions.

This process was marked by certain milestones which can be considered as a basis for establishing MPAs and MPA networks within the maritime areas of the Regional Seas Conventions in Europe:

- The HELCOM Recommendation 15/5 of 1994 recommending that Contracting Parties of the Helsinki Convention take all appropriate measures to establish a system of Coastal and Marine Baltic Sea Protected Areas (BSPA);
- The adoption of an Action Plan for the Protection of the Marine Environment and the Sustainable Development of the Coastal Areas of the Mediterranean in the frame of the Barcelona Convention in 1995;
- The OSPAR Ministerial Meeting 1998 in Sintra/Portugal when the OSPAR Ministers adopted a new Annex V to the convention comprehensively covering marine biodiversity aspects and agreed to promote the establishing of a network of MPAs in the OSPAR maritime area;
- The first (and only) joint meeting of the HELCOM and OSPAR Commissions in Bremen 2003, when a joint work programme on Marine Protected Areas was agreed (OSPAR 2003b, Recommendation 2003/3). This intended network of MPAs in the HELCOM and OSPAR maritime regions should be ecological coherent by 2012 and well-managed by 2016. It was the first common programme for these regional seas conventions.

Parallel to the MPA process under the European Regional Seas Conventions, three important Directives entered into force on EU-level:

- The Habitats Directive (1992)
- The Birds Directive (1979, amended in 2009)
- The Marine Strategy Framework Directive (MSFD 2008).

When the Habitats- and Birds- Directives entered into force the EU member states committed themselves to establishing a joint network of protected areas, which will form the Natura 2000 network. Many MPAs were established in European countries were nominated and later designated as Natura 2000 sites. As such they were often integrated in the MPA networks of the Regional Seas Conventions. This process is enhanced by several relevant provisions of the more recent MSFD.

46.4.1 MPA regime of the OSPAR Convention

There has been substantial progress in designation and implementation of MPAs in the OSPAR maritime area within in the last years (Fig. 46.3). For instance, in 2014 alone, 77 MPAs were added to the OSPAR network, covering about 90,000km^2. By the end of 2016, 448 MPAs had been designated resulting in 5,9% of the whole OSPAR maritime area being protected. Most of these are located in territorial waters or the EEZ of parties. However, the 10%-target has not been reached, yet, even if OSPAR developed groundbreaking activities compared to other marine regions of the World. 10 MPAs are in Areas beyond National Jurisdiction, covering about 9%

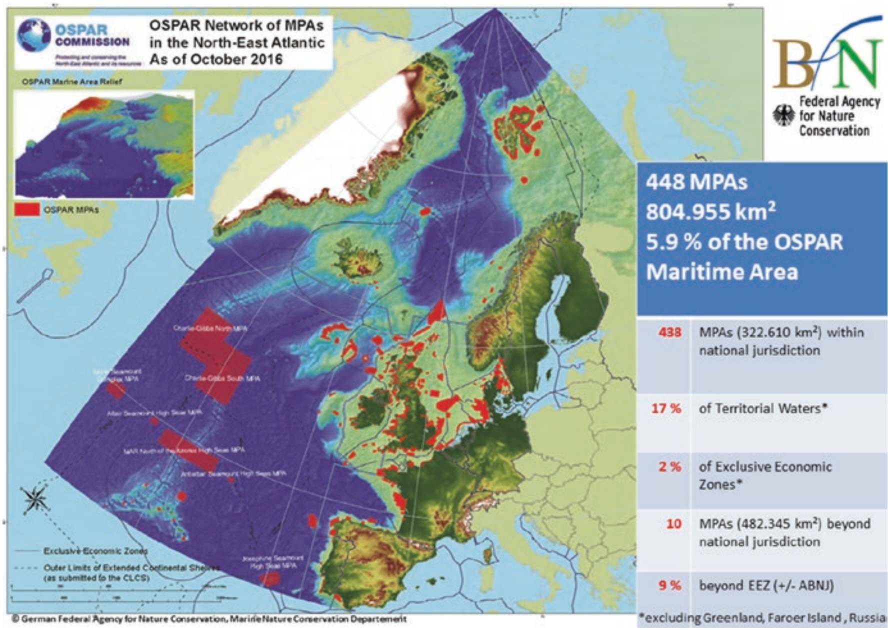


Fig. 46.3 OSPAR MPA network. Map designed by BfN 2016

of this important zone (O'Leary et al. 2012; OSPAR 2016). Especially the MPAs in ABNJ around the Mid-Atlantic Ridge play a model role in the international context. (See also www.charlie-gibbs.org).

It can be stated that the OSPAR MPAs form a network that shows first signs of sufficient ecological coherence. However, regarding the different marine regions within the network, the representativity is not satisfactory as there are still gaps (OSPAR 2016). It is obvious from Fig. 46.3 that in coming years the focus has to be on those regions, which are not sufficiently represented, like the arctic waters.

Concerning the degree of effective management measures in MPAs, OSPAR member states are already on different levels with their progress in implementing management plans. A number of MPAs are subject to general or specific management regulations, including conservation objectives and management plans, but for many sites, management regimes are still under preparation and effective implementation needs to be established (Von Nordheim et al. 2016).

46.4.2 MPA Regime of the Helsinki Convention

The first coastal and marine Baltic Sea Protected Areas (BSPAs) were established in 1994 (HELCOM 1994). Continuous progress in the designation and implementation of BSPAs and of the Natura 2000 network has in the meantime resulted in a

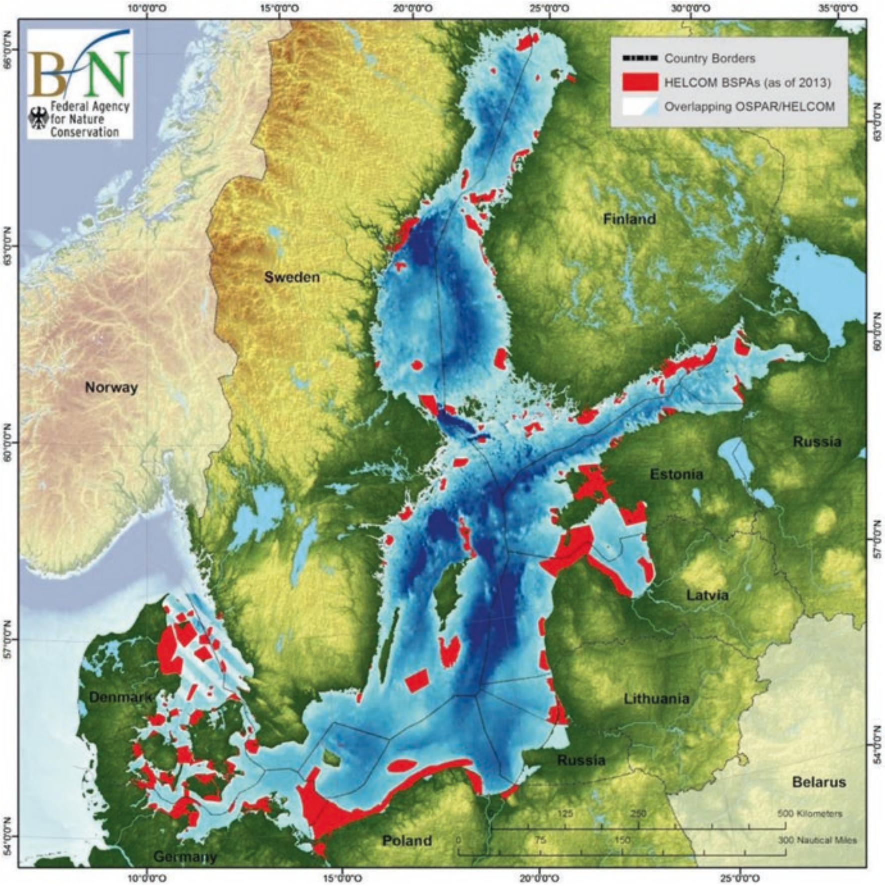


Fig. 46.4 HELCOM MPA network. Map designed by BfN 2013

comprehensive network of BSPAs (Fig. 46.4). The network aims to protect marine and coastal habitats and species specific to the Baltic Sea. By 2013 64% of Natura 2000 sites in the Baltic Sea had also been designated as HELCOM BSPAs following a detailed list of selection criteria similar to OSPAR (see http://www.helcom.fi/action-areas/marine-protected-areas/HELCOM-MPAs-and-Natura-2000-areas/). Meanwhile, the HELCOM Recommendation 15/5 was renewed in 2014 and the BSPAs are now renamed HELCOM MPAs (HELCOM 2014) according to the internationally more commonly used term.

Between 2009 and 2016 the improvement of the MPA regime has been substantial as site numbers have nearly doubled and the CBD- 10%-target has already been reached in 2010. In 2015, 11.7% of the HELCOM maritime area was covered by MPAs, encompassing a total number of 174 MPAs.

However, the 10%-target has not been achieved in all Contracting Parties' waters and in all subregions. There is still a strong bias towards nearshore waters with few sites in the EEZs and there is an unequal distribution of MPAs across the Baltic Sea. Additionally, the area of many HELCOM MPAs is below the recommended minimum size of 3000 ha (HELCOM 2010). Although good progress has been made, the network cannot be considered as being coherent by 2015.

A conclusion of the HELCOM Ministerial Meeting in 2013 was to set up effective management plans for all "old" areas by 2015. For new areas, management plans have to be in place 5 years after establishment. The achievement of this target does not seem too far off if considering the pure data only: 65% of the MPAs have a management plan in force, 26% have a plan in preparation and only 9% have no management plan. Nevertheless some activities with a relatively high impact on marine ecosystems such as construction of cables and pipelines, dredging, constructions of wind farms, extraction of resources, need permissions in quite a high number of areas; but only in a few areas, these activities are restricted or forbidden (HELCOM 2013). This is the same with respect to fisheries. Therefore, there is no guarantee for an effective protection of the marine ecosystem even in an MPA and there is still a strong need for implementation of effective management plans within the HELCOM maritime area (Von Nordheim et al. 2016).

46.4.3 Barcelona Convention

Following the Protocol concerning Specially Protected Areas and Biological Diversity in the Mediterranean (SPA/BD Protocol of 1995), contracting parties of the Barcelona Convention started several initiatives to establish a network of MPAs in the Mediterranean Sea under the umbrella of UNEP that led to the list of Specially Protected Areas of Mediterranean Importance (SPAMI List).

Within the framework of the "Barcelona Protocol" Italy, France and Monaco established in 1999 the Pelagos Sanctuary for the protection of marine mammals in international waters of the north western Mediterranean Sea (Notobartolo et al. 2008; Fig. 46.5). It entered into force in 2002 and is implemented as a trilateral SPAMI. This MPA encompasses nearly 87,500 km^2 with about 53% of that area located in ABNJ. Therefore, it may be considered as globally first MPA which included high seas sections. Consequently, it plays a key role for the further designation process of MPAs and in the ongoing considerations on possible implementation of several EBSAs in the Mediterranean Sea as SPAMIs (UNEP 2012; Fig. 46.2). However, until now, it remains the only MPA with such a high proportion of "high seas" waters in the Mediterranean Sea.

Since the 19th meeting of the Barcelona Convention and its protocols, the SPAMI List includes 34 sites with different protection regimes (February 2016, http://www.rac-spa.org/spami). Most of them are located in the western part of the Mediterranean;

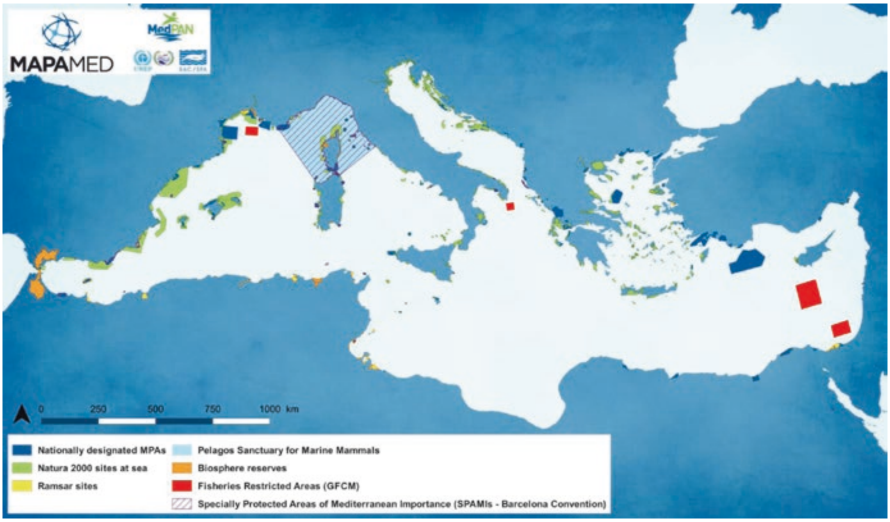


Fig. 46.5 Overview of the Mediterranean MPA system as in March 2016**.** Released by MedPan, UNEP/MAP/RAC-SPA, March 2016

only few of them are found in the eastern part. Currently, the ecological coherence of the network cannot be considered as sufficient. Management measures are still very complicated and limited due to ongoing fisheries or shipping in many MPAs (see also Gabrie et al. 2012).

The latest overview of the Mediterranean MPA system was published by MedPan as MAPAMED, a database on sites of interest for the conservation of marine environment in the Mediterranean Sea (Fig. 46.5).

46.4.4 MPA Regime Under CCAMLR

The Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) entered into force in 1982 and covers the conservation of Antarctic marine life in the Southern Ocean. CCAMLR includes MPAs as one instrument of its marine spatial planning to complement a variety of management tools such as fishing quota and gear restrictions. It is stated that MPAs have a variety of forms and the precise level of protection afforded to any specific area depends on the characteristics and qualities that require protection (https://www.ccamlr.org/en/science/marine-protected-areas-mpas, February 2016).

The first MPA in ABNJ - the South Orkney Islands Southern Shelf MPA - encompasses a large area of 94,000 km^2 and extends across large areas of open oceans in ABNJ, including the front systems “Antarctic convergence” and “Weddell front”. It was adopted in 2009 by CCAMLR and entered into force in May 2010 in the same year when OSPAR established the world’s first ABNJ MPA network (see above).

One of the most remarkable management measures is that all fisheries activities are excluded. In 2016, the so far world largest MPA, the Ross Sea Region MPA was adopted under CCAMLR and enters into force on December 1st 2017. The area covered amounts to 1.55 million km2 of which 72% is fully protected (fishing is forbidden) while fishing for scientific research is permitted in the remaining sections.

Furthermore, all 25 Contracting Parties agreed on establishing a representative network of MPAs in the Antarctic waters by 2012, a commitment which is not implemented to date. However, in the meantime, large marine reserves have been established in the CCAMLR Convention Area for sites within national jurisdiction (HIMI, South Georgia, Prince Edward and Marion Islands). Current work towards the establishment of MPAs in ABNJ in nine planning domains in the CCAMLR Convention Area is ongoing. There has been extensive discussion of MPAs in the Scientific Committee and the Commission in recent years (CCAMLR 2011). Different proposals have been submitted (East Antarctic) or are in preparation (Weddell Sea and the Antarctic Peninsula) (see also https://www.ccamlr.org/en/science/marine-protected-areas-mpas). Under the Protocol on Environmental Protection to the Antarctic Treaty, so-called Antarctic Specially Protected Areas (ASPA) and Antarctic Specially Managed Areas (ASMA) can be designated which can also include small near shore sites.

46.5 MPA Regime of a Nation State (Example: Germany)

By 2016 Germany has established a comprehensive system of marine Natura 2000 sites by its federal states and the Federal Government so that 43% of the North Sea and 51% of the Baltic Sea under German jurisdiction are now protected as MPAs (Fig. 46.6) most of them are also part of the OSPAR and HELCOM MPA networks (see http://www.bfn.de/0314_daten-meeresflaeche+M52087573ab0.html, 2016).

10 of these sites are located in the German EEZ of the North Sea and Baltic Sea and are administered by the Federal Government (BfN). They were nominated to the EU Commission as Natura 2000 sites in May 2004, covering more than 10,000 km^2 which amounts up to 32% of its EEZ (von Nordheim et al. 2006; Krause et al. 2011).

The relevant selection criteria for the identification and designation of the EEZ-sites were a relatively limited set of species and habitats according to the short marine features list of the EU-Habitats and Birds Directives (EU 1992, 2009): such as marine mammals like harbour porpoises (*Phocoena phocoena*) and grey seals (*Halichoerus grypus*), some anadromous migratory fish species such as sea lamprey (*Petromyzon marinus*), twaite shad (*Allosa fallax*) or sturgeon (*Acipenser sp.*) and vulnerable habitats like sandbanks and reefs (Figs. 46.7 and 46.8) as well as a wide range of sea bird species.

As indicated before, MPAs can be affected by a number of human activities. Particularly fisheries activities in various forms are a strong impacting factor in German MPAs (Pusch and Pedersen 2010). Consequently ecologically sound fish-

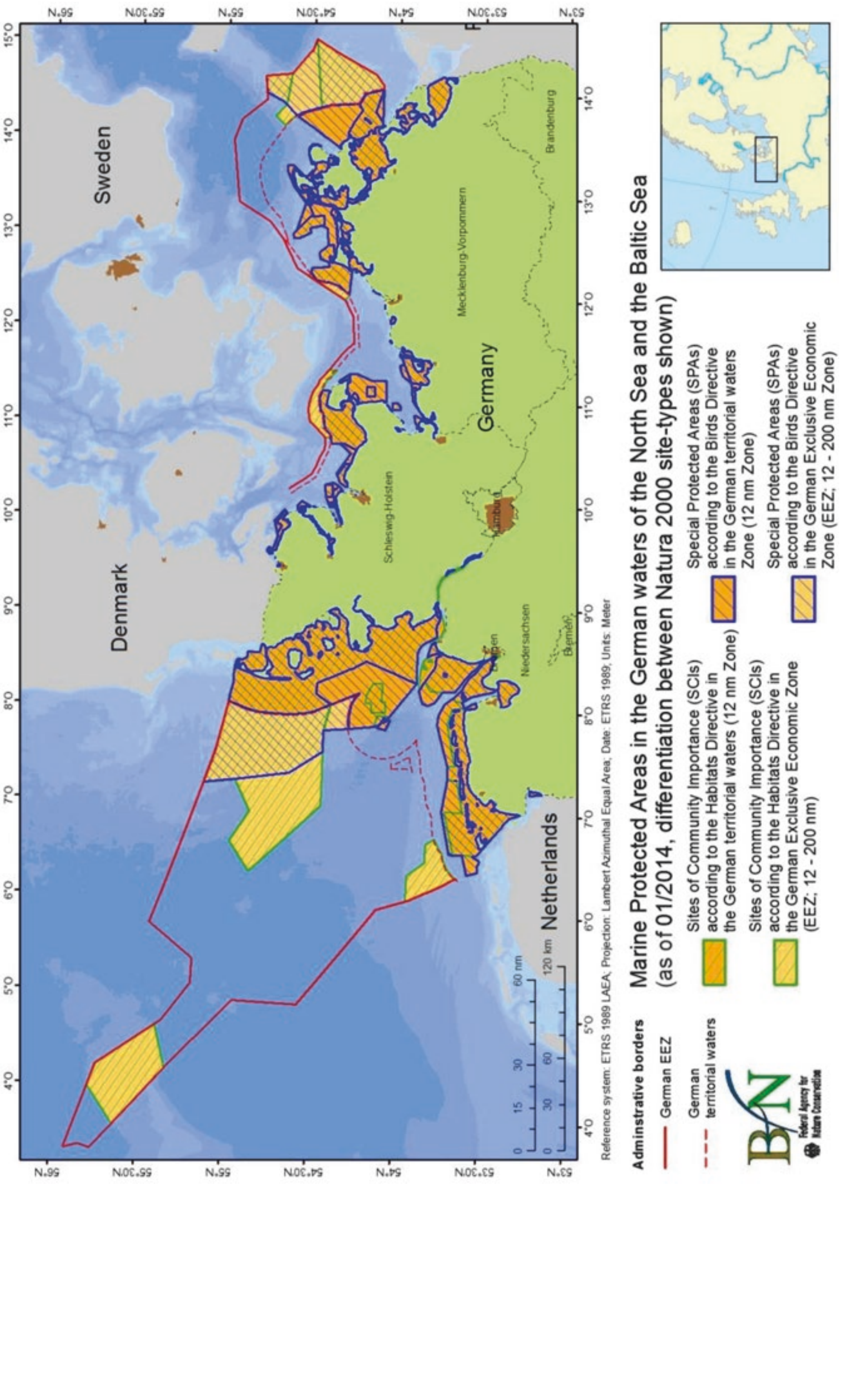


Fig. 46.6 MPAs in German waters of the North Sea and the Baltic Sea.

Fig. 46.7 Reef at the MPA Kadet Trench in the Baltic Sea with mussels (*Mytulis edulis*), large algae sugar kelp (*Laminaria saccharina*) and red algae. Photo: Hübner/Krause, BfN

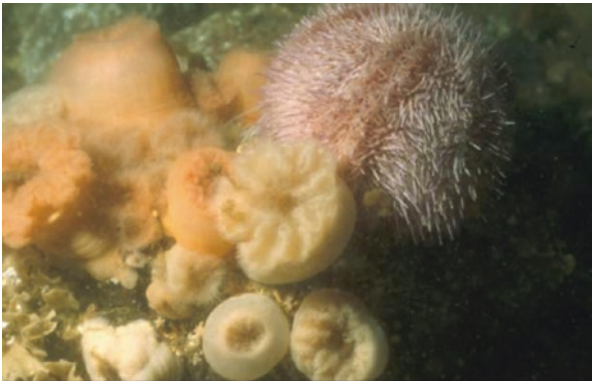


Fig. 46.8 Plumose anemones (*Metridium senile*) and common sea urchin (*Echinus esculentes*) on a reef in the North Sea (Sylt Outer Reef). Photo: Hübner/Krause, BfN

eries management, especially in marine protected areas, is an important instrument to protect marine biodiversity as well as commercially used fish stocks. In this context, measures have to be established to protect sensitive habitats like reefs and sandbanks from the negative effects of bottom-trawling fisheries. To ensure effective protection of threatened species such as the harbour porpoise and several seabird species, also gillnet fisheries have to be restricted temporarily or completely in certain areas. According to EU fishery regulation mechanisms, Germany as EU member state can establish fishery management measures for the German MPAs only in a multi-step and long-term process. This includes formulating a "joint declaration" based on consultations with neighbouring countries and finally inviting the EU Commission to issues respective fisheries measures for the German MPAs binding fishing fleet of neighbouring states.

At the same time, the development of national ordinances for Natura 2000 sites in the EEZ is pressing and is due to be finalised in 2017. Germany started the process on the respective ordinances within government and with public participation. Parallel to the process of developing ordinances, work on management plans for each area is ongoing.

46.6 Outlook—Requirements for a Well-managed, Ecologically Coherent and Representative MPA Network

MPAs are generally accepted as a powerful tool for enhancing marine biodiversity conservation and an inevitable component of effective marine spatial planning which intents to address protection of the carrying capacity of marine ecosystems.

Nevertheless, we are still far away from a global representative, ecologically coherent and well-managed network.

One basic requirement for achieving and fulfilling the "representativity criterion" for MPAs is the development of a bioregionalisation concept on a global or regional scale. Several regions and countries have successfully applied this approach such as Australia, the Mediterranean Sea, HELCOM, OSPAR (Dinter 2001) or the European Union and selected a relevant number of MPA sites for certain bioregions. Although protection of a representative amount of areas by MPAs in all bioregions is not achieved so far on a global scale, there are promising signs for good representativity under some Regional Seas Conventions.

Taking a closer look on the requirements for the criterion "well-managed", the picture is quite diverse. There is no common definition what a "well-managed" MPA or network of MPAs would constitute of although it seems to be easily defined as the opposite of a "paper park". There are some good examples for MPAs being well-managed in coastal zones or within the EEZ of some countries, sometimes addressing only a single human pressure as a starting point (Quigley et al. 2016). Expert working groups of conventions such as HELCOM or as OSPAR with its Intersessional Correspondence Group on MPAs are working intensively on criteria for the assessment of the effectiveness of management of protected areas, for getting a realistic view on the effectiveness of different management measures taken and of relevant plans.

For ABNJ MPAs there is an inevitable need for joint or cooperative management plans, including other institutions with global competence such as the International Seabed Authority (ISA), the International Maritime Organisation (IMO) but also regional fisheries management organisations (RFMOs) like the NEAFC, NAFO, NASCO, or ICCAT. To protect successfully areas in ABNJ, the authorities or Regional Sea Conventions have to work with agreements like a Memorandum of Understanding or collective arrangements on ABMT in MPAs (von Nordheim and Wollny-Goerke 2013).

A good example for such regionally agreed cooperation is to be found in the ABNJ of the OSPAR maritime area. Here, the competent RFMO “North East Atlantic Fisheries Commission” (NEAFC) has set up for years temporally closures for bottom trawling fisheries in sensitive areas e.g. with seamounts, cold water corals or endangered fish species and marine mammals in several OSPAR MPAs.

The third and often postulated requirement for a MPA network namely to be ecologically coherent, proves to be quite difficult to be defined and assessed.

Consequently a number of approaches exist from very general, but practical (Ardron 2008; OSPAR 2013) to more detailed single-feature driven attempts (e.g. HELCOM 2010). None of these seem to be capable so far of addressing all levels of ecological coherence and interactions or interdependence of the conservation features of MPAs in an envisaged network of MPAs and substantial further work and research on this questions is needed.

In conclusion, substantial progress in MPA establishment was made in the last 15 years, which could eventually lead to ecologically coherent networks of MPAs around the globe. To meet the WSSD and the CBD’s vision of a 10% coverage of the global oceans with MPAs by 2020, it is vital that the EBSAs process and the endorsement of further EBSAs by the CBD COP is strengthened to reach a better level of representativity and ecological coherence of MPAs in ALL different regions of the world wide oceans.

This development needs to be urgently complemented by a successful outcome of the current negotiations of UN bodies hopefully resulting in a legally-binding agreement under UNCLOS. The ultimate result has to guarantee sufficient protection as well as sustainable use of marine biodiversity in ABNJ additionally to parallel processes in waters under national jurisdiction.

Acknowledgements I wish to thank particularly Katrin Wollny-Goerke for collection of background information and supporting the compilation and Nina Schröder for improving the English of the manuscript. Further my thanks got to all colleagues who supplied infos, maps and photographs.

References

Agardy, T. & Staub, F. (2006) Marine protected areas and MPA networks: Educational module. Network of Conservation Educators and Practitioners (NCEP)

Ardron JA (2008) Three initial OSPAR tests of ecological coherence: heuristics in a data-limited situation. ICES J MarSci 65:1527–1533

Ardron, J., Dunn, D., Corrigan, C., Gjerde, K., Halpin, P., Rice, J., Vanden Berghe, E. & Vierros, M. (2009) Defining ecologically or biologically significant areas in the open oceans and deep seas: Analysis, tools, resources and illustrations. A Report of the Global Ocean Biodiversity Initiative (GOBI). Ottawa, Canada

Ban NC, Bax NJ, Gjerde KM et al (2013) Systematic conservation planning: A better recipe for managing the high seas for biodiversity conservation and sustainable use. Cons Lett 7:41–54

Bax NJ, Cleary J, Donnelly B, Dunn DC, Dunstan PK, Fuller M, Halpin PN (2015) Results and implications of the first global effort to identify ecologically or biologically significant marine areas. Conserv Biol 30:571–581. http://onlinelibrary.wiley.com/doi/10.1111/cobi.12649/epdf

CBD (2008). Decision IX/20: Section 18 and Annex 1.
CBD (2010a) Decision X/2 and Annex. The strategic plan for biodiversity 2011-2020 and the Aichi biodiversity targets
CBD (2010b) Decision X/29: Sections 4, 32, 37, 41, 42
CCAMLR (2011) Report of the thirtieth Meeting of the Commission https://www.ccamlr.org/en/system/files/e-cc-xxx.pdf
Dinter W (2001) Biogeography of the OSPAR Maritime Area. Landwirtschaftsverlag, Münster
Druel, E. (2012) Ecologically or Biologically Significant Marine Areas (EBSAs): the identification process under the Convention on Biological Diversity (CB) and possible ways forward (No. 17/12). IDDRI Working Paper, pp 1–24
Dunn D, Ardron J, Bax N, Bernal P, Cleary J, Cresswell I, Donnelly B, Dunstan P, Gjerde K, Johnson D, Kaschner K, Lascelles B, von Nordheim H, Rice J, Wood L, Halpin P (2014) The convention on biological diversity's ecologically or biologically significant areas: origins, development and current status. Mar Policy 49:137–145
EU Commission (1992) Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora (The Habitats Directive)
EU-Commission (2009) Council Directive 2009/147/EC on the conservation of wild birds (The Birds Directive)
Gabrié C, Lagabrielle E, Bissery C, Crochelet E, Meola B, Webster C, Claudet J, Chassanite A, Marinesque S, Robert P, Goutx M, Quod C (2012) The status of marine protected areas in the Mediterranean Sea. MedPAN & RAC/SPA, Marseille
Gjerde KM (2012) Challenges to Protecting the Marine Environment beyond National Jurisdiction. Int J Mar Coast Law 27:839–847
Halpern BS, Walbridge S, Selkoe KA, Kappel CV, Micheli F, D'Agrosa C, Bruno JF, Casey KS, Ebert C, Fox HE, Fujita R, Heinemann D, Lenihan HS, Madin EM, Perry MT, Selig ER, Spalding M, Steneck R, Watson R (2008) A global map of human impact on marine ecosystems. Science 319:948–952
HELCOM (1994) Recommendation 15/5
HELCOM (2010) Towards an ecologically coherent network of well-managed Marine Protected Areas. Baltic Sea Environment Proceedings 124A. Helsinki Commission, Helsinki
HELCOM (2013) Overview of the status of the network of Baltic Sea marine protected areas. Helsinki, Helsinki Commission
HELCOM (2014) Recommendation 35/1 (replacing Rec. 15/5 of 1994)
IUCN and UNEP-WCMC (2013) The World Database on Protected Areas (WDPA). UNEP-WCMC, Cambridge
IUCN-WCPA (2008) Establishing Resilient Marine Protected Area Networks—Making it Happen. IUCN-WCPA, Washington, DC
Johnson D (2016) Global Ocean Process of Identifying Ecologically and Biologically Significant Areas (EBSAs)—what now, what next? In: Nordheim H, Wollny-Goerke K (eds) Progress in marine conservation in Europe 2015:Proceedings of the symposium, BfN-Skripten 451:22–28
Krause J, Wollny-Goerke K, Boller F, Hauswirth M, Heinicke K, Herrmann C, Körber P, Narberhaus I, Richter-Kemmermann A (2011) Die deutschen Meeresnaturschutzgebiete in Nord- und Ostsee. Themenheft Meeresnaturschutz. Nat Landschaft 86:397–409
Mora C, Andrefouet S, Costello MJ, Kranenburg C, Rollo A, Veron J, Gaston KJ, Myers RA (2006) Coral reefs and the global network of marine protected areas. Science 312:1750–1751
Notarbartolo di Sciara G, Agardy T, Hyrenbach D, Scovazzi T, Van Klaveren P (2008) The Pelagos Sanctuary for Mediterranean marine mammals. Aquat Conserv Mar Freshwat Ecosyst 18:367–391
O'Leary BC, Brown RL, Johnson DE, von Nordheim H, Ardron J, Packeiser T (2012) The first network of marine protected areas (MPAs) in the high seas: the process, the challenges and where next. Mar Policy 36:598–605
OSPAR (2003a) First joint ministerial meeting of the Helsinki and OSPAR commissions (JMM)—Record of the meeting, Annex 5: Statement on the Ecosystem Approach to the Management of Human Activities

OSPAR (2003b) First joint ministerial meeting of the Helsinki and OSPAR commissions (JMM)—Record of the meeting: Recommendation 2003/3

OSPAR (2013) An assessment of the ecological coherence of the OSPAR network of marine protected areas in 2012. OSPAR Commission, London

OSPAR (2016) 2015 Status of the OSPAR Network of Marine Protected Areas. OPSAR Commission, London

Parks JE, Pomeroy RS, Philibotte J (2006) Experiences and lessons learned from evaluating the management effectiveness of marine protected areas in Southeast Asia and the Pacific Islands. CBD/IUCN International Workshop for Better Management of Protected Areas.

Pusch C, Pedersen SA (eds) (2010) Environmental sound fisheries management in marine protected areas (EMPAS) in Germany. Naturschutz und Biologische Vielfalt, 92 pp.

Quigley M (2016) Managing fishing in MPAs: making a start. In: Nordheim H, Wollny-Goerke K (eds) Progress in marine conservation in Europe 2015: Proceedings of the symposium, BfN-Skripten 451:76–81

Thiel H (2003) Approaches to the Establishment of Protected Areas on the High Seas. In: Kirchner A (ed) International Maritime Environmental Law. Kluwer Law International, The Hague, 169–192

Thiel H, Koslow A (eds) (2001) Managing Risk to Biodiversity and the Environment on the High Sea, Including Tools such as Marine Protected Areas: Scientific Requirenments and Legal Aspects, BfN-Skripten 43. German Federal Agency for Nature Conservation, Bonn

UN (1982) United Nations Convention on the Law of the Sea (UNCLOS)

UN (1992) United Nation conference on environment and development (Convention on Biological Diversity): Agenda 21. Rio de Janeiro, Brazil

UN (2002) Report of the World Summit of Sustainable Development—A/CONF.100/20. Johannesburg, South Africa

UN (2015) UN General Assembly resolution—Res/69/292

UNEP (2012) Synthesis report on the work carried out regarding the description of EBSAs in the Mediterranean—UNEP/CBD/SBSTTA/16/INF/8

UNEP (2016) Progress report on describing areas meeting the criteria for ecologically and biologically significant marine areas - UNEP/CBD/SBSTTA/20/3

Von Nordheim H, Wollny-Goerke K (2013) Marine biodiversity and networks of Marine Protected Areas—towards a global network of MPAs in Areas Beyond National Jurisdiction. In: von Norheim H, Maschner K, Wollny-Goerke K (eds) Progress in marine conservation in Europe 2012. BfN-Skripten 339:25–37

Von Nordheim H, Boedeker D, Krause JC (eds) (2006) Progress in Marine Conservation in Europe—Natura 2000 sites in German Offshore Waters. Springer, Berlin/Heidelberg

Von Nordheim H, Packeiser T, Durussel C (2011) Auf dem Weg zu einem weltweiten Netzwerk von Meeresschutzgebieten. Themenheft Meeresnaturschutz: Nat Landschaft 86:382–387

Von Nordheim H, Wollny-Goerke K, Schröder N (2016) The MPA networks of HELCOM and OSPAR by 2015. In: Nordheim H, Wollny-Goerke K (eds) Progress in marine conservation in Europe 2015: Proceedings of the symposium, BfN-Skripten 451:29–38

Links

http://www.bfn.de/0314_daten-meeresflaeche+M52087573ab0.html. (Retrieved February 2016)
http://www.bfn.de/0314_meeresschutzgebiete+M52087573ab0.html. (Retrieved February 2016)
http://www.cbd.int/ebsa/. (Retrieved April 2016)
https://www.ccamlr.org/en/conservation-and-management/conservation-measures. (Retrieved February 2016)
http://www.charlie-gibbs.org/. (Retrieved February 2016)
http://www.gobi.org. (Retrieved February 2016)
http://www.helcom.fi/action-areas/marine-protected-areas/HELCOM-MPAs-and-Natura-2000-areas. (Retrieved February 2016)
https://www.cbd.int/pa/UN-Ocean-Conference/flyer-en.pdf
http://www.rac-spa.org/spami. (Retrieved February 2016)

Chapter 47
Marine Environmental Protection and Climate Change

Birgit Peters

Abstract The rules governing marine environmental protection and climate change are diverse and range from direct regulatory approaches addressing the effects of climate change on the marine environment to rules targeting their mitigation. Nonetheless, it is remarkable that most rules addressing marine environmental protection and climate change, especially the most recent, tackle this issue indirectly, from the viewpoint of marine environmental protection. This chapter illustrates this "environmental protection approach" by assessing current and emerging regulations targeting marine climate change, as well as some of its limitations. Discussing the rules addressing the major causes of climate change, as well as those mitigating its effects, the chapter argues that climate change has become a major and cross cutting issue of the international rules addressing environmental protection. While this may be a viable and legitimate way to address the major effects of climate change, it is still questionable whether the established framework is far reaching enough to address the root causes of climate change and its impacts on the global marine environment.

Keywords Climate change • Regulatory approaches • Marine environmental protection • Mitigation

47.1 Introduction

The effects of climate change on the marine environment are immensely diverse and extensive. It is virtually impossible to describe their full extent. This chapter can give just a few impressions. On one hand, the oceans act as the world's largest carbon sink (Bothe 2011: 32). On the other, climate change is the major cause of the current rise in ocean temperatures and sea water levels (Intergovernmental Panel on Climate

---

B. Peters
University of Rostock, Rostock, Germany
e-mail: birgit.peters@uni-rostock.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_47

Change [IPCC] (IPCC 2014: 451; Doney et al. 2012: 12). These two major effects have many side effects in a host of different areas. Rising sea levels have and will lead to problems of marine delimitation and may eventually result in the disappearance of the current territory of certain small island states and to loss of their jurisdiction (Rayfuse 2012: 152; Stephens 2015: 788). The rise in ocean temperatures affects O_2 concentrations in seawater (IPCC 2014: 451), contributing to a reduction in O_2 concentrations in deeper layers. It influences seawater exchange between different layers, altering sea currents and eventually wind and weather conditions at the sea surface (Reeve et al. 2012: 266; Doney et al. 2012: 12; Wernberg et al. 2011: 11). The absorption of CO_2 by the oceans (driven by the rise of atmospheric CO_2-concentrations) alters water pH and leads to the so-called acidification of the oceans (Stephens 2015: 780; Schellnhuber et al. 2013: 47). Marine organisms which produce calcareous skeletal structures are highly sensitive to ocean acidification (Chap. 19). This is true for example for certain planktonic algae which are an important part of the ocean food-web (Fabry et al. 2008). Increase in sea temperatures is the main cause for mass coral bleaching. The reefs turn white because algae hosted by the coral die. Moreover, due to changes in seawater carbon chemistry, the corals ability to build carbonate structures is disturbed (Harley et al. 2006: 231). These are only three specific examples of impacts on marine biodiversity which results from climate change (Doney et al. 2012: 11ff.) (Chap. 18 and Chap. 19). Although little is known about how marine species respond to multiple stressors (Harley et al. 2006: 236), it is clear that climate change contributes to the disappearance or significant alteration of certain marine habitats and the species dependent on them (IPCC 2014: 451). It also causes marine species to shift their distributions and abundances (IPCC 2014: 451; Harley et al. 2006: 233). For example, salmon already have migrated further north into the northern Atlantic and Arctic Sea in search of colder temperatures (IPCC 2014: 295).

As climate change impacts a multitude of areas of the marine environment, many aspects still require further detailed study (Gattuso et al. 2015: aac4722-3-4). Accordingly, the international regulatory framework covering or intended to cover the broader field of marine climate change—whether treaty or customary—is fragmented. Regulations address many different subject areas. Marine climate change has been tackled in forums as diverse as the United Nations Framework Convention on Climate Change (United Nations Framework Convention on Climate Change 1994, UNFCCC), the International Maritime Organization (IMO) (in amendments to the 1972/1973 International Convention on the Prevention of Pollution from Ships (MARPOL) and 1947 International Convention for the Safety of Life at Sea (SOLAS) conventions, the 1982 United Nations Convention on the Law of the Sea (UNCLOS) and the 1993 Convention on Biological Diversity (CBD), just to name the most prominent examples.

Despite the obvious differences in regulatory approach, it is remarkable that the rules addressing marine environmental protection and climate change, especially the most recent, tackle this issue indirectly, from the viewpoint of marine environmental protection. Considering this regulatory framework, it seems clear that climate change has become a cross-cutting issue. Yet, despite global regulations to reduce carbon emissions, not many rules directly target climate change at sea, establishing emissions targets or similar frameworks. Apart from state conferences, the IMO, which assembles private and state actors, stands out as a major actor driving the regulatory developments on the protection of the marine environment.

This chapter illustrates this "environmental protection approach" which characterizes the area of marine environmental governance and climate change by assessing current and emerging regulations targeting marine climate change, as well as some of the limitations of this approach. In order to identify which rules address climate change directly, and which tackle climate change as part of marine environmental protection, I rely on the categories of article 3 para. 3 of the UNFCCC, which distinguishes rules which address the major *causes* of climate change (Sect. 47.2) from those geared to *mitigate its effects* (Sect. 47.3). The chapter considers rules in these two categories by area of underlying issue. When discussing measures directly combatting climate change, it deals with the rules for reduction of greenhouse gas emissions in the UNFCCC and IMO frameworks (Sect. 47.2.1) and under UNCLOS prohibitions of marine pollution (Sect. 47.2.2). I discuss the rules governing general biodiversity (Sect. 47.3.1), regional governance Schemes (Sect. 47.3.2), as well as Arctic and Antarctic biodiversity (Sect. 47.3.3) in addressing indirect marine climate change governance. In the final part I highlight some of the limitations of this current trend to govern climate change through environmental law and draw some conclusions (Sect. 47.4).

On such a broad topic, I can only assess a fraction of the emerging subjects. I therefore concentrate on some recent regulatory trends in the law governing marine environmental protection and climate change (from about 2010 onwards). I do not discuss the exposure of small island states and other states to the rise in sea level (Rayfuse 2009: 1, 2012: 149). Such questions may be answered with reference to general international law and the general rules of the law of the sea, and except for the fact that they change the territorial scope of application of certain conventions that apply to this field, they are less related to the aspect of marine environmental protection. Similarly, the chapter does not address measures concerning fisheries management. Though fish stocks are also affected by rising sea temperatures, which cause changes in distribution and abundance (Ainsworth et al. 2011: 1220; Cheung et al. 2009: 241; Cheung et al. 2010: 28), solutions for fisheries affected by climate change primarily require reconsideration of the territorial application of current governance schemes and if necessary, conclusions on related measures. This is addressed by the chapter on fisheries management in this book (Chap. 33).

47.2 Direct Climate Governance

Emissions of CO_2 and other greenhouse gases responsible for climate change originate from a number of sources, industrial and residual, onshore and offshore, and marine traffic also contributes its share. Globally, marine traffic continues to grow (Karim 2015: 106). Ships were responsible for about 3.1% of global emissions of greenhouse gases in the period of 2007–2012 (IMO 2014). Nonetheless, the

UNFCCC, its Kyoto protocol and also the recent Paris Agreement, only provide a few programmatic guidelines on state commitment in the area of the marine environment (Bodansky 2015: 291). Binding legal rules concerning marine climate change have mostly been adopted in the area of marine pollution, most importantly in the IMO's overall framework on marine pollution. In light of this development, a relatively new approach advocates classifying CO_2 and other greenhouse gas emissions at sea as marine pollution under the 1982 United Nations Convention on the Law of the Sea (UNCLOS). Climate change has thus become a cross-cutting theme in the area of marine environmental protection.

47.2.1 Promoting Greenhouse Gas Emissions Reduction at Sea: The UNFCCC and the IMO Regime

As a general instrument concerned with the worldwide reduction of greenhouse-gas emissions, the UNFCCC addresses the specificities of marine climate change in a limited number of areas. Its preamble highlights the effects of climate change on the marine environment. It emphasizes the importance of marine ecosystems as carbon sinks, warns against the adverse effects of climate change and underscores rising sea-levels as one of the immediate effects of climate change on the marine environment. Moreover, article 4 of the UNFCCC, which establishes the primary commitments of the parties to the convention, urges states to cooperate to promote conservation of oceans as sinks, and to consider marine ecosystems a primary commitment of the parties (Art. 4 (d) UNFCCC). Yet, contrary to the general commitments of the parties to adopt measures to mitigate climate change by reducing their emissions according to their individual emissions reduction targets (Art. 4 (a) UNFCCC), the commitments of the parties concerning the marine environment are not accompanied by individual reduction commitments or measures. The Kyoto protocol, which substantiates individual commitments of states under Art. 4 UNFCCC, primarily foresees a collective solution for the issues arising in the area of marine climate change: it establishes a duty of states with registered individual reduction targets, to "pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels"… "working through the International Maritime Organization" (Art. 2 para. 2 Kyoto Protocol). Also the recent Paris Agreement focuses on this collective solution. Even though the agreement lacks special reference to the marine environment, except for its preamble, which recognizes the "importance of ensuring the integrity of all ecosystems, including the oceans" (UNGA 2015?, Annex, preamble), it authorizes UN organizations and specialized agencies to support the efforts of the parties toward the implementation of mitigation and adaptation measures to climate change (Art. 7 para. 7 Paris Agreement).

Kyoto's collective solution for the area of the marine environment proved relatively successful. Since the early 2000s, the IMO has targeted greenhouse gas emissions from ships. In 2005, the Organization addressed the emission of nitrogen oxide and sulphur oxides, as well as certain ozone-depleting substances, such as halons, by establishing emission thresholds in the regulations of Annex VI to MARPOL. These came into force in 2010 (IMO 2015). To ensure compliance with these standards, the organization established a certificate and survey system. Flag states must survey ships at regular intervals and issue a certificate if the ship complies with the standards set by the Annex (regulation 6 para. 1, MARPOL Annex VI). Port states may check that ships comply with certificate standards (regulation 10, MARPOL Annex VI).

However, the 2005 amendments of Annex VI MARPOL did not address the reduction of CO_2 emissions. Though it is possible to formulate procedural obligations on the reduction of CO_2 by states, as I demonstrate later, the IMO considers this primarily a global problem, since emissions cannot be attributed to a single state or emitter (IMO 2015). So in order to target CO_2 reductions in international shipping, the IMO recently made further amendments to the MARPOL Annex VI regulations, establishing a mandatory Ship Energy Efficiency Management Plan, as well as an Energy Efficiency Design Index. This was much to the regret of some developing states, who claimed that these universally applicable rules do not consider the principle of common but differentiated responsibilities that rule in the area of climate change law (Karim 2015: 108; Kopela 2013). Quite to the contrary, however, the amendments were accompanied by a resolution on technical cooperation and technology transfer, and thus took note of the common but differentiated responsibilities of developing states (IMO 2011). Though not ratified by all member states, they came into force on 1 January 2013 by way of IMO's tacit acceptance procedure (IMO 2013). All ships must carry the Plan on board, whereas the Index applies to the construction of new ships. It sets a minimum energy efficiency level per tonne mile as a target for different ship types and leaves the decision on how to design new ships to meet the target to industry. Together, the Index and the Plan should lead to a 13–23% reduction in CO_2 emissions by ships as compared to 2011 (Bazari and Longva 2011: 4).

Concerning the immediate reduction of greenhouse gases by ships, the provisions of Annex VI MARPOL appear to have established a viable international framework that even applies to states, such as the USA, who did not sign the Kyoto Protocol. Although the initial mandate of the IMO to deal with the effects of climate change on the marine environment may be derived from UNFCCC's Kyoto Protocol, it builds on the pollution provisions of MARPOL as its common basis. Thus, even in the area of direct marine climate change governance, the issues are primarily addressed via the law on the marine environment.

47.2.2 CO_2 Emissions as Pollution of the Seas Under UNCLOS and Other Conventions Prohibiting Pollution of the Marine Environment

A similar environmental law approach emerges from discussions on regulation of the effects of climate change on the marine environment under the regime of UNCLOS. Here, a number of authors advocate the application of UNCLOS's pollution provisions to the context of marine climate change (Boyle 2012: 831; Doelle

2007: 319). The suggestion is not unattractive since the International Tribunal for the Law of the Sea is competent to decide conflicts over the obligations contained in UNCLOS and could provide an effective dispute settlement mechanism (Boyle 2012: 837), thus ensuring enforcement of the respective UNCLOS provisions.

The UNCLOS provides a few broad provisions prohibiting marine pollution. Article 192 UNCLOS establishes a general obligation of UNCLOS member states to protect the marine environment from pollution. According to article 194 para. 1 of UNCLOS, this obligation extends to pollution from any source, especially pollution from substances (emitted from land-based sources) into the atmosphere (Art. 194 para. 1 (a) UNCLOS). Pollution is defined in article 1 para. 4 UNCLOS as the introduction of substances or "energy", which is likely to cause harm to marine living resources, into the marine environment by humans. Considering the effects of CO_2 and other greenhouse gas emissions on the oceans (warming and acidification), they may well be considered a 'substance' or even 'energy' in the light of the foregoing articles, causing pollution of the oceans in the sense of article 194 para. 1 (a) UNCLOS (Boyle 2012: 833; Doelle 2007: 323).

Even considering this broader interpretation of the prohibition contained in article 194 UNCLOS, the resulting obligations of the parties, in particular their characterization as obligations of result, or obligations of conduct, remain unclear. Doelle suggests that article 194 para. 1 (a) UNCLOS creates an obligation of result, meaning that states are liable for every emission of CO_2 into the oceans, whether below or above the agreed cap levels of the UNFCCC and its Kyoto protocol (Doelle 2007: 325). Yet their individual liability would depend on their emissions relative to other emitting states (Doelle 2007: 325). Boyle, on the other hand, suggests that article 194 para. 1 (a) UNCLOS defines an obligation of conduct, which is oriented towards, but not ultimately dependent on, the established and negotiated climate change framework. He argues that pursuant to article 194 para. 1 (a) UNCLOS, states have a general duty to regulate and control CO_2 uptake by the seas (Boyle 2012: 833). States also have a corresponding procedural duty to stabilize emissions in view of the overall provisions of the UNFCCC (Boyle 2012: 834). Boyle contends that article 194 para. 1. (a) UNCLOS expresses a duty to mitigate the effects of CO_2 uptake by oceans, which include environmental impact assessments and best available practices. However, this duty does not extend to the observation of absulte emissions targets such as those agreed in the Kyoto Protocol, or lately the Paris agreement. As the International Court of Justice pointed out in the Pulp Mills Case, only environmental standards of a customary nature or those agreed between the parties can be used to further determine the nature of procedural environmental obligations. The UNFCCC and its Kyoto Protocol however, were neither representative of an emission standard agreed between the parties of UNCLOS, nor could they yet be regarded to have crystallized in to a standard of customary international law (Boyle 2012: 836).

It is difficult to follow Doelle's reasoning that article 194 para. 1 (a) UNCLOS creates an obligation of result for CO_2 emissions. Already the wording of article 194 UNCLOS, which leaves concrete measures for combatting marine pollution to the discretion of the parties, suggests that the obligations are obligations of conduct, where parties to UNCLOS have the primary obligation of adopting measures to prevent pollution from the sources mentioned in the article. Article 194 UNCLOS therefore creates a procedural obligation to combat further uptake of CO_2 and other greenhouse gasses by oceans and the marine environment. It requires states to adopt all possible means to reach the emissions targets of the UNFCCC and its Kyoto protocol, though according to case law of the ICJ, those standards may only be a general guideline and cannot be considered standards agreed between the parties to UNCLOS.

If CO_2 emissions are regarded as pollution under UNCLOS, it is also generally possible and plausible to interpret similar provisions of other international conventions, such as article 3 and 5 of the OSPAR Convention, to include a prohibition to pollute the marine environment with CO_2 from land- or marine-based sources. Article 1 para. d of the OSPAR Convention defines pollution in line with UNCLOS as "the introduction by man, directly or indirectly, of substances or energy into the maritime area which results, or is likely to result, in hazards to human health, harm to living resources and marine ecosystems, damage to amenities or interference with other legitimate uses of the sea." Accordingly, introduction of CO_2 into the marine environment may be considered pollution under the OSPAR Convention in the same circumstances as under UNCLOS.

47.3 Indirect Climate Governance: Protecting Marine Biodiversity from the Adverse Effects of Climate Change

Whereas the previous part discussed the rules which address marine climate change directly, by imposing emission reduction targets or similar regulations, I now turn to rules which indirectly target the effects of climate change on the marine environment. Usually, those rules have the general objective of protecting the marine environment from any sort of pollution or negative influence. Accordingly, climate changes is regulated as one of several environmental threats and set up general protection schemes to protect the marine environment from these threats. For example, the protected areas regime of the CBD and other regional conventions addresses the particular vulnerability and sensitivity of the marine environment to the effects of climate change. Similarly, recent regulatory efforts of the IMO and other regional regimes aim at protecting the marine environment of the Arctic and Antarctic.

47.3.1 Protection of Marine Biodiversity Under the CBD and Other Conventions of Global Reach

Based on the principle that biodiversity is a common concern of mankind (CBD, preamble), the CBD is aimed at the protection of all biodiversity. There is no particular focus on the marine environment. Nonetheless, the CBD provides important tools for the protection of marine biodiversity from the adverse effects of climate change. In particular, protected areas (Art. 8 (a) CBD) are generally regarded as the most common (Sands 2003: 503), and in the area of the marine environment, as the most effective (Nordtvedt Reeve et al. 2012: 265) means of addressing the protection of marine biological diversity. This applies both to marine areas within and beyond national jurisdiction. Protected areas in the latter have been especially subject to discussion in recent years, as they are regarded as the only way to preserve particularly sensitive high-sea areas, and above all their biodiversity, from further deterioration (Scott and Van der Zwaag 2015: 748, 749; Drankier 2012: 431; Gjerde and Rulska-Domino 2012: 354; Nordtvedt Reeve et al. 2012: 266). The UN General Assembly has also made efforts to this effect and initiated an open ended ad-hoc working group on the protection of marine areas beyond national jurisdiction. Its discussions have progressed to initiating a process toward the adoption of an international instrument under the auspices of UNCLOS (cf. Open Ended, Ad-Hoc Working Group 2015).

Regarding the establishment of marine protected areas under the CBD, in its strategic plan for biodiversity 2011–2020 (CoP 2010a), the Conference of the Parties to the CBD established that 10% of marine and coastal areas within and beyond national jurisdiction be designated as protected areas (CoP 2010), yet, without agreeing on a particular timeframe within which this target be realized. For marine areas beyond national jurisdiction, the Conference of the Parties to CBD approved criteria for "ecologically or biologically significant areas" in open waters and deep sea habitats (EBSA) (CoP 2010, annex I) and for networks of marine protected areas (CoP 2010, annex II). The criteria developed to determine EBSA build on references such as the uniqueness and rarity of the area, their importance for threatened habitats, or their vulnerability or sensitivity to external influences (CoP 2010, annex I). The criteria for the determination of networks of protected areas, in particular, are also intended for application within national jurisdictions, in combination with the respective national criteria (CoP 2010).

Although the CBD thus provides an extensive framework for the establishment of marine protected areas, the institution of a marine protected area in an individual case may still vary according to the rules formulated by international and regional agreements on the preservation and protection of marine biodiversity in the sea area in question (Gjerde and Rulska-Domino 2012: 360). Another international system that envisages establishment of marine protected areas is that established for the conventions of the IMO. In a decision of 1 December 2005, the IMO adopted guidelines on the identification of *Particularly Sensitive Sea Areas*, defining them as areas "that need[…] special protection through action by the IMO because of …[their] significance for recognized ecological, socio-economic, or scientific attributes where such attributes may be vulnerable to damage by international shipping activities" (IMO? 2005, Annex). Once designated, particularly sensitive sea areas trigger particular protection measures by states party to the IMO and its conventions. For example, the IMO can decide that particularly sensitive sea areas must be regarded as special areas under MARPOL, or as SO_x emission control areas, with the consequence that stricter regulations apply, such as those concerning discharge of ballast water, oil or other substances, or those concerning the determination of shipping routes (MARPOL, PROTOCOL 1, SOLAS). Until now, the organization has designated about 15 areas as particularly sensitive sea areas; among them are several marine areas particularly affected by the adverse effects of climate change, such as the Great Barrier Reef and the Wadden Sea.

47.3.2 Regional Protection of Marine Biodiversity

Besides the CBD and IMO regulations, marine protected areas to protect the marine environment from the adverse effects of climate change may also be established under a number of regional conventions. The designation of marine protected areas is foreseen under the Convention for the Conservation and Sustainable Use of the Wider Caribbean Region and its Protocol for Specially Protected Areas and Wildlife (SPAW Protocol), as well as under the 1976 Convention for the Protection of the Mediterranean Sea Against Pollution (Barcelona Convention) and its Protocol on Biodiversity and Specially Protected Areas.

The OSPAR convention also envisages establishment of marine protected areas. Annex V of the convention establishes the procedural duty of the parties to protect the marine environment, marine ecosystems and biodiversity in particular, from the adverse effects of human activities, by taking the "necessary measures" (Art. 2 (a), annex V). To meet this obligation, parties to the OSPAR convention are required under article 3 para. 1. (b), ii of annex V to establish a system of institutional protection in accordance with international law. During the meeting of the OSPAR commission in Bremen (2003), recommendation 3/2003 was adopted. This recommendation indicates that the obligation can be met by designation of marine protected areas having the purpose of protecting species and ecosystems and preventing their further degradation (Recommendation 3/2003, para. 2.1). Although the convention regime only provides for a limited scope of protection, as the OSPAR convention commends states to ensure compliance with possibly conflicting obligations under the UNCLOS, or the IMO conventions (Matz-Lück and Fuchs 2012: 539), the regime has successfully established its first protection areas: as of today, six marine protected areas in the high seas have been established. Other conventions, those concerned with the polar regions in particular, envisage protected areas to ensure protection of the marine environment from the adverse effects of climate change. This is illustrated in the next section.

47.3.3 Protecting Polar Biodiversity

The polar regions are probably the regions of the Earth most heavily and visibly affected by the adverse effects of climate change (Rayfuse 2007: 196; 2008: 3). Certain polar marine species are at risk to disappear in the very near future. Notably, most polar bear populations are expected to be extinct in the Artic within 30 years

(ACIA Report 2004; Stirling and Derocher 2012: 2694–2706). Melting of the polar ice caps also opens these regions to global shipping and resource extraction. Though the latter is generally prohibited under article X of the Antarctic Treaty of 1959, the Arctic, lacking any such global agreement prohibiting these activities, is of particular interest to neighbouring states. It is estimated to possess large reserves of oil, gas and other resources (CBD Report 2011). Extraction, shipping and other activities pose continuous threats for existing ecosystems in the Arctic, but also in the Antarctic regions, and require appropriate regulation and management. Since these new activities and environmental threats will increase in the context of climate change, the need for environmental regulation is obvious.

The CBD and UNCLOS provide general and specific regulations dealing with marine biodiversity in ice covered areas. In addition to articles 192 ff. UNCLOS, already mentioned, article 234 UNCLOS allows coastal states with an exclusive economic zone adjacent ice covered areas to take measures to protect and preserve the ecological balance in those areas. The article thus contemplates adoption of regional management regimes, following articles 16 and 69 et seq. UNCLOS. The Convention on the Conservation of Antarctic Marine Living Resources of 1982 (CAMLR), which applies a strict management system to *all* marine living resources in the area beyond the 60°-south parallel, is one such large regime. Under CBD, the usual protection measures apply, such as the establishment of protected areas (see Sect. 47.3.1, above). However, attempts have been made to address the particular sensitivity of the Arctic marine environment under this convention. In 2011, the Subsidiary Body on Scientific, Technical and Technological Advice of CBD met with the Arctic Council, a regional organisation which comprises the Arctic five (Russia, Canada, USA, Denmark and Norway) as well as the Faroe Islands, Finland and Sweden. The Council coordinates cooperation of the Arctic states on matters concerning climate change, biodiversity, and preservation/protection of the Arctic marine environment and peoples (Artic Council 2011). Both treaty bodies signed a memorandum of understanding in which they emphasised the importance of the Arctic Council's working group on Arctic fauna and flora as a knowledge resource for CBD (ibid.). However, beyond this facutal contribution of the Council to the collection of biodiversity data to the CBD, the cooperation between the Arctic Council and the CBD treaty organs has not yet extended into a legal cooperation, i.e. joint decision-making or regulation.

The most recent regulations concerning the preservation and protection of the marine environment of the Arctic and Antarctic from the effects of climate change have been adopted in the context of the IMO. In November 2014 and May 2015, the IMO adopted the International Code for Ships Operating in Polar Waters, the so called Polar Code, which succeeds the hitherto voluntary Guidelines for Ships Operating in Ice-Covered Waters (2011) and makes binding amendments to the MARPOL and SOLAS conventions. The code is expected to come into force in 2017. While the amendments to SOLAS mostly concern the manning and equipment of ships operating in polar waters, the amendments to MARPOL include particular environmental regulations, such as guidelines for the discharge of oil, noxious liquid substances, garbage and ballast water (Polar Code 2014, Chaps. 2–5). They acknowledge the particular sensitivity of the marine environment in the polar regions as well as the fact that these regions take longer to recover from existing pollution (para. 3.1. Polar Code 2014) The code therefore counts as another example of an environmental regulation addressing aspects of the effects of climate change on the marine environment.

At regional level, the regulatory activities of the Arctic Council are noteworthy, since other regional regimes, like EU regulations or the OSPAR convention apply only to limited geographical parts of the Arctic. In 2013, the Arctic Council published the Arctic biodiversity assessment, which assesses present status and future development scenarios of the Arctic (Arctic Council 2014). In the same year, the Council adopted the Agreement on Cooperation on Marine Oil Pollution, which establishes an emergency and rescue system between Arctic neighbours and a system of mutual assistance in cases of oil spills. As one of the first binding agreements of the Council, it shows that the states are paying greater attention to marine environmental issues resulting from climate change. However, as the agreement shows, the steps taken are somewhat limited. Protection and preservation of the Arctic marine environment is mostly sought through environmental protection provisions, which address the prevention of harm from large-scale environmental disasters. No agreements have yet addressed the harmful effects of activities conducted regularly in that region. Moreover, the states no longer pursue overarching solutions, as discussed in the 1990s and 2000s, when the players still promoted adoption of a treaty similar to the Antarctic treaty (EU Parliament 2008; Sands 2003: 731; Verhaag 2003: 555). However, a new attempt toward a more coherent protection was recently made by the European Parliament, which on 16 March 2017 adopted a resolution promoting an integrated policy for the Arctic (European Parliament, 2017).

47.4 Conclusions

In considering some of the more recent regulations that apply to emerging management issues in the area of marine environmental protection and climate change, this overview reveals that regulatory attempts to address this topic of global importance have been made in many forums and have involved many actors. It is striking that most of them concentrate on the area of environmental law. This is true for the general regulations addressing marine climate change, such as pollution prevention provisions under the UNCLOS, the IMO conventions and the definition of protected areas under the CBD, as well as for the specific regulations addressing climate change in the Arctic and Antarctic. Thus, climate change has become a central issue area which needs addressing by global marine environmental regulation.

The IMO stands out as a major actor driving the current developments. Exploiting its tacit consent procedure, the organization tackles the effects of climate change and preservation of the marine environment efficiently by adopting new amendments to the MARPOL and SOLAS conventions. Regional actors such as the Arctic Council have also begun to address the effects of climate change on the marine environment. As the Arctic example showed, marine climate change may lead to greater cooperation between existing organizations, such as the cooperation agreement between the Body on Scientific, Technical and Technological Advice of CBD and the biodiversity working group of the Arctic Council (Rothwell et al. 2015: 893; Gjerde et al. 2010: 11).

The attempts to address climate change in the area of the marine environment via environmental provisions may be an effective and above all viable supplemental attempt to regulate climate change (in addition to the implementation of the new greenhouse gas reduction instrument adopted at Paris). They show that climate change has become a cross-cutting issue which cannot be excluded from any regulation to do with the marine environment. Nevertheless, it is still questionable whether the measures adopted in the area of marine pollution and protection will be sufficient to address the myriads of different effects of climate change on the marine environment. Considering the current pace at which marine environments are deteriorating, it is legitimate to think that they may only be properly addressed by combatting the root causes of climate change, i.e. emission of greenhouse gases. Hopefully, the new accord reached at Paris will be able to contribute to this battle. Indirect environmental protection measures alone are still a meagre contribution to what is necessary to protect our oceans from the adverse effects of climate change.

References

1973 International Convention for the Prevention of Pollution from Ships, United Nations Treaty Series, 1340, 184 (1973)

1974 International Convention for the Safety of Life at Sea (SOLAS), United Nations Treaty Series, 1184, 1185, 1372 (1974)

1982 United Nations Convention on the Law of the Sea, United Nations, Treaty Series, 1833, 3 (1982)

1992 Convention on the Protection of the Marine Environment in the North-East Atlantic, United Nations, Treaty Series 2354, 67 (1992)

1993 Convention on Biological Diversity, United Nations, Treaty Series, 1760, 79 (1993)

1994 United Nations Framework Convention on Climate Change, United Nations, Treaty Series, 30822 (1994)

2011 Amendments to the Annex of the Protocol of 1997 to Amend the International Convention for the Prevention of Pollution From Ships, 1973, As Modified by the Protocol of 1978 Relating Thereto, MEPC Res. 203(62) (15 July) (2011)

2014 International Code for Ships Operating in Polar Waters, Polar Code, (21 November) (2014)

Ainsworth CH, Samhouri JF, Busch DS, Cheung WWL, Dunne J, Okey TA (2011) Potential impacts of climate change on Northeast Pacific marine foodwebs and fisheries. ICES J Mar Sci 68(6):1217–1229

Arctic Council (2004) Impacts of a warming Arctic: Arctic climate impact assessment (ACIA) overview report. http://www.amap.no/documents/doc/impacts-of-a-warming-arctic-2004/786

Arctic Council (2011) CAFF works with the CBD on Arctic biodiversity (Press release). https://www.arctic-council.org/index.php/en/our-work2/8-news-andevents/77-caff-works-with-the-cbd-on-arctic-biodiversity-2

Arctic Council (2014) Arctic biodiversity assessment now available (Press release). https://www.arctic-council.org/index.php/en/our-work2/8-news-andevents/196-arctic-biodiversity-assessment-now-available

Bazari Z, Longva T (2011) Assessment of IMO mandated energy efficiency measures from international shipping. Oslo, London

Bodansky D (2015) Climate change—transnational legal order or disorder. In: Schaffer G, Halliday TC (eds) Transnational legal orders. Cambridge University Press, Cambridge, pp 287–308
Bothe M (2011) Measures to fight climate change—a role for the law of the sea? In: Hestermeyer H, Matz-Lück N, Seibert-Fohr A, Vöneky S (eds) Law of the sea in dialogue. Springer, Heidelberg, pp 31–45
Boyle A (2012) Law of the sea perspectives on climate change. Int J Mar Coastal Law 27:831–838
Cheung WWL, Lam VWY, Sarmiento JL, Kearney K, Watson R, Pauly D (2009) Projecting global marine biodiversity impacts under climate change scenarios. Fish Fish 10(3):235–251
Cheung WWL, Lam VWY, Sarmiento JL, Kearney K, Watson REG, Zeller D, Pauly D (2010) Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. Glob Chang Biol 16(1):24–35
Conference of the Parties of the Convention on Biodiversity (2010a) Decision X/2, Strategic Plan for Biodiversity, 2011–2020. Nagoya, Japan
Conference of the Parties of the Convention on Biodiversity (2010b) Decision X/33, Biodiversity and Climate Change. Nagoya, Japan
Doelle M (2007) Climate change and the use of the dispute settlement regime of the law of the sea convention. Ocean Dev Int Law 37(3–4):319–337
Doney, S. C., Ruckelshaus, M., Duffy, J. E., Barry, J. P., Chan, F., English, C. A. & Talley, L. D. (2012). Climate change impacts on marine ecosystems. Annu Rev Mar Sci, 4, 11–37.
Drankier P (2012) Marine genetic resources in areas beyond national jurisdiction. Int J Mar Coastal Law 27(2):375–434
European Parliament (2008) Decision of the european parliament on the international treaty on the protection of the arctic. Strassbourg
European Parliament (2017) Integrated European Union policy for the Arctic (Doc. No. 2016/2228(INI))
Fabry VJ, Seibel BA, Feely RA, Orr JC (2008) Impacts of ocean acidification on marine fauna and ecosystem processes. ICES J Mar Sci 65:414–432
Gattuso J-P, Magnan A, Billé R, Cheung WWL, Howes EL, Joos F, Turley C (2015) Contrasting futures for ocean and society from different anthropogenic CO2 emissions scenarios. Science 349:6243
Gjerde KM, Ardron J, Gotheil S, Hanich Q, Simard F, Warner P, Vestergaard O (2010) Modalities for advancing cross-sectoral cooperation in managing marine areas beyond national jurisdiction. Report for UNEP's 12th Global Meeting of the Regional Seas Conventions and Action Plans, 2010
Gjerde KM, Rulska-Domino A (2012) Marine protected areas beyond national jurisdiction: some practical perspectives for moving ahead. Int J Mar Coastal Law 27(2):351–373
Harley CDG, Randall Hughes A, Hultgren KM, Miner BG, Sorte CJB, Thornber CS, Williams SL (2006) The impacts of climate change in coastal marine systems. Ecol Lett 9(2):228–241
International Panel on Climate Change (2014) Climate change 2014: impacts, adaptation and vulnerability: regional aspects. Cambridge University Press, Cambridge
International Maritime Organization (n.d.) Air pollution, energy efficiency and greenhouse gas emissions (Press release). http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Default.aspx
International Maritime Organization (2014) Third IMO greenhouse gas study 2014. Retrieved from Suffolk, UK: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/ThirdGreenhouseGasStudy/GHG3ExecutiveSummaryandReport.pdf
Karim MS (2015) Prevention of pollution of the marine environment from vessels—the potential and limitations of the International Maritime Organization. Springer, Heidelberg
Kopela S (2013) Climate change and the International Maritime Organization: another breakthrough at the marine environment protection committee? ASIL Insights 17(24)
Matz-Lück N, Fuchs J (2012) Die Ausweisung maritimer Schutzgebiete in hoheitsfreien Räumen am Beispiel des OSPAR Abkommens. ZUR—Zeitschrift für Umweltrecht:532–543
Open ended Ad-hoc Working Group to Study Issues Relating to the Conservation and Sustainable Use of Marine Biological Diversity Beyond Areas of National Jurisdiction (2015) Letter to the General Assembly. UN Doc. A/69/780

Rayfuse R (2007) Melting moments: The future of polar oceans governance in a warming world. Rev Euro Commun Int Environ Law 16(2):196–216

Rayfuse R (2008) Protecting marine biodiversity in polar areas beyond national jurisdiction. Rev Euro Commun Int Environ Law 17(1):3–13

Rayfuse RG (2009) W(h)ither Tuvalu? International law and disappearing states. (April 1, 2009). UNSW Law Research Paper (2009-9)

Rayfuse RG (2010) International law and disappearing states: utilising maritime entitlements to overcome the statehood dilemma. UNSW Law Research Paper(2010-52)

Rayfuse R (2012) Climate change and the law of the sea. In: Rayfuse R, Scott SV (eds) International law in the era of climate change. Edward Elgar, Cheltenham, pp 147–174

Reeve LRN, Rulska-Domino A, Gjerde KM (2012) The future of high seas marine protected areas. Ocean Yearbook Online 26(1):265–289

Regulations to improve the energy efficiency of international shipping enter into force (2013) (Press release). http://www.imo.org/en/MediaCentre/PressBriefings/Pages/01-MARPOL-EEDI.aspx-VciXFHgViR0.

Rothwell DJ, Oude Elferink A, Scott K, Stephens T (2015) Charting the future for the law of the sea. In: Rothwell D, Oude Elferink AG, Scott KN, Stephens T (eds) The Oxford handbook of the law of the sea. Oxford University Press, Oxford, pp 887–892

Sands P (2003) Principles of international environmental law, 2nd edn. Cambridge University Press, Cambridge

Schellnhuber HJ, Messner D, Leggewie C, Leinfelder R, Nakicenovic N, Rahmstorf S, Scubert R (2013) Welt im Wandel—Menscheitserbe Meer. WBGU, Berlin

Scott K, Vander Zwaag DL (2015) Polar oceans and law of the sea. In: Rothwell D, Oude Elferink AG, Scott KN, Stephens T (eds) The Oxford handbook of the law of the sea. Oxford University Press, Oxford, pp 724–751

Stephens T (2015) Warming waters and souring seas. In: Rothwell D (ed) The Oxford handbook on the law of the sea. Oxford University Press, Oxford, pp 777–797

Stirling L, Derocher AE (2012) Effects of climate warming on polar bears: a review of the evidence. Glob Chang Biol 18:2694–2706

Verhaag MA (2003) It is not too late: The need for a comprehensive international treaty to protect the Arctic environment. Georgetown Int Environ Law Rev 15(4):555

Wernberg T, Russell BD, Moore PJ, Ling SD, Smale DA, Campbell A, Connell SD (2011) Impacts of climate change in a global hotspot for temperate marine biodiversity and ocean warming. J Exp Mar Biol Ecol 400(1):7–16

Chapter 48
Management of Non-indigenous Species and Invasive Alien Species

Wolfgang Köck and Bjørn-Oliver Magsig

Abstract When seeking to manage the risks to marine ecosystems and other marine assets arising from the introduction of invasive alien species by human activities, there are two challenges to be surmounted: first, how to avoid the unintentional introduction of non-indigenous species and, second, how to prevent the intentional introduction of such species which, according to both scientific knowledge and practical experience, are "invasive".

This contribution to the Handbook outlines the legal framework for dealing with the complex challenge to the marine environment posed by non-indigenous species. The chapter focuses on two main vectors—aquaculture and ballast water—and summarizes recent developments at the international level, with a particular focus on the Ballast Water Management Convention. In doing so, it identifies gaps and inconsistencies at the various regulatory levels and illustrates potential development options for the future legal framework. Given the fact that, in almost all cases, the establishment of invasive species is irreversible, the precautionary and the preventive principle must play a key role in managing the impacts of non-indigenous species on the marine environment.

In addition to looking at the specific regulations, strategies and plans designed to protect the marine environment from the risks associated with the introduction of non-indigenous species, the article also deals with the general legal provisions regarding IAS at the level of the Convention on Biological Diversity and, in particular, at the EU level. With the adoption of Regulation (EU) No 1143/2014 of 22 October 2014, a foundational legal instrument now exists at EU level for dealing with IAS. Its most important achievement is to establish a legally binding list of IAS based on risk assessments; this list is to be continuously developed further, its purpose being effectively to prevent the intentional introduction of IAS.

W. Köck (✉)
Helmholtz Centre for Environmental Research, Leipzig, Germany
e-mail: wolfgang.koeck@ufz.de

B.-O. Magsig
School of Law, University College Cork, Cork, Ireland

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_48

Keywords Non-indigenous species • Alien species • Invasive alien species • Aquaculture • Ballast water • Intentional introduction • Unintentional introduction • Three-stage hierarchical approach • Precautionary principle • Prevention • IAS list • Environmental Risk Assessment

48.1 Introduction

Non-indigenous, or alien, species are those which, as a result of human action, have succeeded in extending beyond their natural range and establishing themselves on new terrain (Kowarik 2010: 13; Kuhlenkamp and Kind 2016). Marine ecosystems are significantly affected by non-indigenous species that have been introduced either intentionally or unintentionally by humans (Kuhlenkamp and Kind 2016). The main causes of introduction are as follows (Kuhlenkamp and Kind 2016; Kowarik 2010: 355f.; Hewitt et.al. 2009: 117ff.; Leppäskoski et al. 2002: 3):

- the unintentional introduction of species through ballast water from ships and the accumulation of matter on ships' hulls (fouling),
- oceanic regions that are no longer separated due to the creation of water corridors, including shipping channels in particular, which enable marine species to penetrate into new habitats, and
- deliberate releases of species, especially through the importation of marine species for aquacultures and aquariums.

Studies for Europe show that up until 2012 some 1230 marine alien species had been introduced, and that an astonishing 57% of these species have managed to develop stable populations without external influence (Kuhlenkamp and Kind 2016). Successfully established populations in Europe are to be found especially in the Mediterranean region, although climate change has also improved conditions for establishment in the cooler climes of the North Sea area (Galil et.al. 2007: 64ff.; Lonhart 2009: 65; SRU 2012: 276). In its 2010 status report the OSPAR Commission (a body formed out of the OSPAR Convention) speaks of more than 160 non-indigenous species that have been introduced into the OSPAR (North Atlantic) area (OSPAR Commission 2010a: 118).

The introduction of non-indigenous, or alien, species by human activities can have adverse impacts on (marine) ecosystems and on other natural assets, such as ecosystem services, when they display "invasive" characteristics—in other words, when they are capable of spreading aggressively at the expense of native species, triggering changes in the functional processes of ecosystems, or exerting constraints on original communities. It is in this context that experts speak of "invasive alien species" (IAS) (Kuhlenkamp and Kind 2016). This concept has been taken up in international agreements including, especially, the Convention on Biological Diversity (henceforth CBD), and in other major legal regulations, such as Regulation (EU) No 1143/2014 on the prevention and management of the introduction and spread of invasive alien species (henceforth EU-IAS Regulation). Art. 3 (3) of the

EU-IAS Regulation now contains a definition established—for the first time—by EU legislation directly: "'invasive alien species' means an alien species whose introduction or spread has been found to threaten or adversely impact upon biodiversity and related ecosystem services."

IAS are considered to be one of the most significant threats to biodiversity worldwide (Kowarik 2010: 375; Klingenstein et.al. 2005: 14). This gives rise to the need for action on nature conservation in order to preserve biological diversity and its natural dynamic (Klingenstein et.al. 2005: 6) and to protect other important public assets such as ecosystem services.

In the following sections of this chapter we address the requirements for managing IAS and the challenges arising from these (Sect. 48.2), before providing information about the most significant institutional waymarks and pieces of legislation aimed at addressing the IAS problem (Sect. 48.3), along with the key steering instruments and strategies used to do so (Sect. 48.4). The chapter closes with a brief section assessing what has been achieved and giving an indication of future prospects and next steps (Sect. 48.5). Since the task of protecting the oceans from the risks posed by IAS is an international one, the analysis focuses on global actions but also highlights European activities as an example, given that they draw upon global and EU approaches and those found in regional formulations of international law.

48.2 Management Requirements and Challenges

Averting or reducing the risks arising for marine ecosystems and other marine assets from the introduction of non-indigenous species requires two kinds of management measures (Köck 2004: 114f., 121). It is necessary to ensure:

- that, as far as is possible using reasonable means, the unintentional introduction of non-indigenous species does not occur, and
- that the intentional introduction of non-indigenous species identified as "invasive" does not occur (IAS).

These management tasks are already set out in the "Guiding Principles for the Prevention, Introduction and Mitigation of Impacts of alien species that threaten ecosystems, habitats or species" adopted in 2002 by the Conference of the Parties (COP) on the basis of Art. 8 (h) of the CBD (COP 2002: Principles No. 7, 10, 11). (While not legally binding, these Guiding Principles are nonetheless highly significant in practical terms.) Having recognized these tasks as valid, the parties to the CBD have reached agreement on a "three-stage hierarchical approach" (COP 2002: Principle No. 2) and on giving priority to preventive measures: "Priority should be given to preventing the introduction of invasive alien species, between and within States. If an invasive alien species has been introduced, early detection and rapid action are crucial to prevent its establishment. The preferred response is often to eradicate the organisms as soon as possible (principle 13). In the event that eradication is not feasible or resources are not available for its eradication, containment (principle 14) and long-term control measures (principle 15) should be implemented."

In order to implement the preventive strategy, the actors require knowledge that is relevant to practical management measures on the following issues at least:

- the entry pathways of non-indigenous species (vectors): along what (non-natural) pathways do non-indigenous species find their way into new habitats?
- appropriate measures for reducing or averting risk: what can be done in practical terms to reduce or completely eradicate the risk of introduction on the entry pathways identified? Taking account of the importance of human activity, which measures are acceptable and appropriate for achieving societal well-being?
- identifying IAS when non-indigenous species are to be introduced deliberately into new habitats for economic reasons.

Accordingly, the first challenge involves guaranteeing that appropriate knowledge is generated, that is, ensuring that entry pathways are identified along with suitable measures for reducing the risks from introduction. This requires not just setting up and securing funding for scientific programmes (COP 2002: Principle No. 5) but also generating knowledge about acceptable options for action that is tailored to each industrial sector. With regard to marine ecosystems and marine ecosystem services, the main issue here is to do with options for shipping (e.g. dealing with ballast water), the management of ocean shipping routes (e.g. environmental impact assessments for new channel projects) and the management of aquacultures along coastlines.

More complex than this, though, is the challenge of identifying IAS, because this is a matter of assessing by anticipation whether or not a non-indigenous species will develop invasive characteristics in its intended new location. This demands the use of corresponding assessment instruments (risk analyses) but also—in view of government agencies' authority to intervene—the option of applying the precautionary principle if existing knowledge about risks is not yet certain (COP 2002: Principles No. 1 and 10). Further, the socio-economic benefits of introduction should not be ignored when it comes to deciding whether the intentional introduction of IAS can be considered acceptable in isolated cases. In other words, it is also a matter of considering under what circumstances IAS may be introduced as an exception. This issue is addressed explicitly in the EU-IAS Regulation (see below Sect. 48.3.5; Köck 2015: 78).

In addition to generating knowledge, a further challenge consists in giving the actors the necessary knowledge to reduce the risks of introduction (COP 2002: Principle No. 6), ensuring there is a legal framework that places the key actors identified as such under obligation to implement measures for averting or reducing risks and to set up effective monitoring instruments. With particular regard to the intentional introduction of non-indigenous species, it is crucial to establish (border) controls and approval procedures (COP 2002: Principle No. 7) and to provide the relevant agencies with IAS lists based on current scientific and practical knowledge as criteria for control.

Last but not least, a number of requirements exist with regard to the practical, operative level. Marine ecosystems and marine ecosystem services can only be protected if there is an effective international framework for action. Management strategies aimed solely at the national level are doomed to failure because of their much too limited range.

48.3 Existing International Legal and Institutional Framework

"In accordance with customary international law, States have a duty to prevent, reduce and control environmental harm and a duty to cooperate to mitigate transboundary environmental risks" (Riley 2009: 200). These general obligations can also be meaningful in the context of averting the risks posed by IAS, but they are ineffective in terms of specificity and enforcement. It is for this reason that treaties have been forged at the global level which specifically address these risks and the obligations arising from them. Of major significance in the early days of these efforts was the CBD, adopted in 1992 (see below, Sect. 48.3.1). Going back further, there is also the UN Convention on the Law of the Sea (UNCLOS) from 1982, which contains a provision for dealing with non-indigenous species (see Sect. 48.3.2). At the level of so-called soft law, regional marine conservation agreements contain specific goals and measures aimed at combating IAS (see Sect. 48.3.3). The International Maritime Organisation's (IMO) Ballast Water Management Convention is of huge practical significance in the context of protecting marine ecosystems from the risks posed by IAS because it regulates a key entry pathway directly (see below, Sect. 48.3.4). The most important piece of EU legislation for managing the risks posed by IAS is the aforementioned EU-IAS Regulation from 2014 (see below, Sect. 48.3.5.1). It covers the entire sovereign territory of the EU, including coastal waters, thereby affording protection to marine ecosystems in coastal regions. Another EU regulation aimed at protecting Europe's marine environment is the Marine Strategy Framework Directive, which sets protection and conservation targets and commits EU Member States to setting up programmes and plans to achieve them (see below, Sect. 48.3.5.2).

The following section analyses the international legal response to the challenge of non-indigenous species in the marine environment. While the threat has been a subject of scientific research for more than 50 years and has been recognized in several conventions and treaties, the risk of the spread of invasive alien species has continued to grow worldwide.

48.3.1 Convention on Biological Diversity (CBD)

At national level the problem of non-indigenous species has been a part of nature conservation policy and law for several decades, albeit the focus here has been principally on terrestrial ecosystems (e.g in Germany: Köck 2004: 116ff.). At the global level the 1992 CBD is the foundational piece of legislation containing obligations to combat or reduce the risks posed by IAS and has led to a revision of national and regional strategies. Art. 8 (h) CBD requires of the parties "as far as possible and as appropriate" to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species". It also commits the parties in Art. 6 (a) to "develop national strategies, plans or programmes for the conservation and sustainable use of biological diversity or adapt for this purpose existing strategies, plans or programmes". What the CBD has not brought forth to date are farther reaching, practical obligations—for example, in the form of an independent IAS protocol. The institutions created by the CBD, especially the Conference of the Parties (COP) (Art. 23 CBD), have, however, adopted a range of non-binding ("soft law") but, in practical terms, important resolutions regarding how to manage the IAS issue; in particular, they have clarified a number of conceptual issues (COP 2002), developed a set of "Guiding Principles" for dealing with IAS (COP 2002) (Holljesiefken 2007: 67ff.), and formulated targets. In the "Aichi Biodiversity Targets" from 2010, for example, target 9 states: "By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment."

It can be noted, in summary, that the CBD grants the parties to it a wide range of options for dealing with IAS and relies primarily on the states to implement their own strategic plans but to heed the Guiding Principles in doing so. In addition, the COPs provide a forum for communicating and conveying information about practical further steps. While generally applicable to the marine environment (Article 22(2) CBD; see Wolfrum and Matz-Lück 2000), the CBD contains no *specific* stipulations with regard to the protection of marine ecosystems. Due to the lack of legally binding measures at the international level and the lack of common implementation standards, the wide scope given to states to implement the voluntary measures will most likely lead to inconsistencies in terms of how the transboundary problem of marine invasive species is addressed by individual countries (Bostrom 2009: 880). Hence, while in theory having the prevention approach and the precautionary principle at heart, the CBD by itself does little to advance consistent international technological standards and performance benchmarks regarding the prevention, control or eradication of non-indigenous species which threaten marine ecosystems.

48.3.2 Global Marine Conventions

Arguably one of the most important international environmental agreements is the 1982 United Nations Convention on the Law of the Sea (UNCLOS) (Birnie et al. 2009: 3), coined the 'constitution for the oceans' by Tommy T.B. Koh, President of the Third United Nations Conference on the Law of the Sea. The fact that even states which have not ratified UNCLOS, such as the United States, comply with it for the most part underlines the international legal clout of the Convention.

According to Article 196(1) on the use of technologies and the introduction of alien or new species, states 'shall take all measures necessary to prevent, reduce and control pollution of the marine environment resulting from the use of technologies under their jurisdiction or control, or the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment, which may cause significant and harmful changes thereto'. While the introduction of an article dedicated to alien species is to be welcomed, the precise interpretation of the provision is still being debated. The main question is whether the introduction of potentially harmful alien species constitutes 'pollution' of the marine environment or whether it should be classified as some other form of environmental harm (Firestone and Corbett 2005: 303) Zink 2016: 123ff). Article 1 (4) of UNCLOS defines "pollution of the marine environment" as "the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, […] impairment of quality for use of sea water and reduction of amenities;". If we were to place alien species within the category of pollution, it would certainly impose stricter legal obligations and responsibilities upon states, such as ensuring that species which may cause harm do not spread beyond areas of national jurisdiction (Article 194(2) UNCLOS), or being liable for transboundary invasions of such species (Article 235 UNCLOS).

However, since UNCLOS fails to link the problem of non-indigenous species specifically to the articles regarding pollution, it does not trigger concrete legal obligations for the adoption of uniform and rigorous rules concerning the management of non-indigenous marine species (Bostrom 2009: 881; Holljesiefken 2007: 106).

Furthermore, two other important global marine conventions, the International Convention for the Prevention of Pollution from Ships of 1973, as modified by the Protocol of 1978 (hereinafter MARPOL 73/78), and the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (hereinafter London Convention), do not cover living organisms at all, and thus do not address the challenges posed by non-indigenous species at all (Holljesiefken 2007: 106).

48.3.3 Regional Sea Conventions

While regional conventions are playing an increasingly important role in international environmental law, provisions on marine invasive species are scarce. The Convention on the Protection of the Marine Environment of the Baltic Sea Area (hereinafter Helsinki Convention), for example, is aimed at the "ecological restoration of the Baltic Sea, ensuring the possibility of self-regeneration of the marine environment and preservation of its ecological balance" (Preamble of Helsinki Convention). Of particular relevance here is Article 5 on harmful substances, which obliges the parties to "undertake to prevent and eliminate pollution of the marine environment of the Baltic Sea Area caused by harmful substances from all sources

[…]". In addition, Article 15 on nature conservation and biodiversity requires them to "individually and jointly take all appropriate measures with respect to the Baltic Sea Area and its coastal ecosystems influenced by the Baltic Sea to conserve natural habitats and biological diversity and to protect ecological processes." However, the text of the Helsinki Convention, when viewed in isolation, fails to introduce concrete measures concerning invasive species.

Similarly, the Convention for the Protection of the Marine Environment of the North-East Atlantic (hereinafter OSPAR) does not contain specific regulations on IAS, but requires member states to "take all possible steps to prevent and eliminate pollution" and "take the necessary measures to protect the maritime area against the adverse effects of human activities so as to safeguard human health and to conserve marine ecosystems and, when practicable, restore marine areas which have been adversely affected" (Article 2(1)(a) OSPAR).

In order to spell out these rather broad provisions, both the governing body of the Helsinki Convention, HELCOM, and the OSPAR Commission have issued several documents and policy papers to address the very particular risks and challenges of managing invasive species. These include, for example, the HELCOM Guide to Alien Species and Ballast Water Management in the Baltic Sea (HELCOM 2014). Furthermore, the two commissions have worked jointly on harmonizing their procedures and have developed an online risk assessment tool for alien species transfers via the ballast water of commercial ships (http://jointbwmexemptions.org/ballast_water_RA/apex/f?p=100:LOGIN:15542751493980:::::).

48.3.4 Ballast Water Management Convention

In order to address some of the apparent shortcomings of the international legal framework on the management of marine invasive alien species, the International Maritime Organization (IMO) has developed several mechanisms to tackle the introduction of non-indigenous species through ballast water. An important step in this endeavour was the adoption of the Guidelines for the Control and Management of Ships' Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens (1997). The measures recommended by the IMO include actions to minimize the uptake of organisms by avoiding areas known to contain harmful organisms, cleaning ballast tanks, and avoiding unnecessary discharges of ballast water (IMO 1997, paras 9.1.1–9.1.3). However, due to the fact that these were voluntary guidelines, compliance was very low (Bostrom 2009: 883). Acknowledging the shortcomings, the IMO's Marine Environmental Protection Committee (MEPC) drafted the text for the International Convention for the Control and Management of Ships' Ballast Water and Sediments (the Ballast Water Management Convention), which was adopted in February 2004 and is due to enter into force on 8 September 2017.

The Ballast Water Management Convention is the first international agreement that seeks to "prevent, minimize and ultimately eliminate the transfer of harmful aquatic organisms and pathogens through the control and management of ships' ballast water and sediments". It is based to a large extent on the precautionary approach and is influenced by the debate on Article 196(1) of UNCLOS. In order to achieve broader implementation, the Convention applies not only to the flag-bearing ships of contracting parties but also to ships "which operate under the authority of a Party" (Article 3(1))—i.e. vessels which operate within the territorial waters of a particular state and are thus subject to its laws.

In order to achieve its goal, the Ballast Water Management Convention sets out specific requirements for discharges of ballast water, including ballast water exchange procedures. For example, the Convention calls upon ships to conduct a ballast water exchange with a rate of effectiveness of at least 95% (Annex D-1, para 1); this should, whenever possible, be conducted at least 200 miles offshore and at a depth of at least 200 m (Annex B-4, para 1.1). In addition, the Convention sets binding performance standards which regulate the number of organisms allowed in ballast water discharges and limits the concentrations of "human health related" microbes, or indicator microbes (Annex D-2, paras 1 and 2).

Annex D-3 further stipulates that all treatment technologies are subject to IMO's approval. Interesting here is the distinction between technologies that employ an "active substance," and those that do not (Annex D-3, para 2). An active substance is defined as "a substance or organism, including a virus or a fungus, that has a general or specific action on or against Harmful Aquatic Organisms and Pathogens" (Annex A-1, para 7). If a system uses active substances, it must comply with additional requirements before being approved, in order to ensure "that the use of the [active substance] poses no harm to the environment." Importantly, the performance standards do not permit the grandfathering of older vessels, and thus entire fleets are required to shift technologies or management practices within the specified time schedule (Bostrom 2009: 886).

In order to ensure a high level of compliance, the Convention creates a legal obligation for ships to retain detailed records of the vessel's ballast water operations (Annex B-2) and for each vessel to develop a ballast water management plan describing how the provisions will be implemented (Annex B-1). Furthermore, inspections of a ship's ballast water certificate may be conducted and samples of its ballast water taken (Article 9). In case a vessel violates the Convention's provisions, the Convention authorizes the state to take several actions—including bringing proceedings in its own court (Article 8(2)) and prohibiting the ship from discharging ballast water (Article 10(3)). Several provisions of the Ballast Water Management Convention refer to guidelines to be developed by the IMO and reviewed by the MEPC, which allows for timely updates as new knowledge becomes available. Several of such guidelines have since been developed and adopted, including guidelines for ballast water sampling (G2) (resolution MEPC.173(58)); guidelines for ballast water management and development of ballast water management plans (G4) (resolution MEPC.127(53)); guidelines for ballast water exchange (G6) (resolution MEPC.124(53)); and guidelines on designation of areas for ballast water exchange (G14) (resolution MEPC.151(55)).

The Ballast Water Management Convention, in conjunction with the various other efforts by the IMO, might be able to drive technology adoption as well as strengthen enforcement by setting clear goals for the treatment of ballast water. This would certainly constitute an improvement to the current international legal regime, which is far from comprehensive.

48.3.5 Specific European Regulations and Directives

48.3.5.1 EU-IAS Regulation

The EU-IAS Regulation from 2014 is the EU's foundational piece of legislation for the management of IAS. It imposes a ban on importing, keeping, breeding, purchasing, using, exchanging and releasing certain (listed) species (Art. 7). It also contains further obligations to do with identifying pathways of introduction (Art. 13), setting up surveillance systems (Art.14 ff.) and eradicating not yet established IAS "of Union concern" (Art. 17 ff.), along with the necessary requirements for applying the programme to combat and monitor IAS in practice (definition of terms and compilation of lists—Art. 3 ff.).

The most important instrument to be implemented by the new regulation is a legally binding "List of invasive alien species of Union concern" (hereinafter EU-IAS list) to which the bans and extended obligations refer (Art. 4). The phrase "of Union concern" does not mean that the species identified need to be "invasive" in the entire EU but merely that its "adverse impact has been deemed such as to require concerted action at Union level" (Art. 3(3)). This criterion is likely to be met regularly in the case of marine IAS.

It is the European Commission that is responsible for compiling the EU-IAS list. It makes its decision in the legal form of implementing regulations (Art. 4(1)) and is supported in this by a "Scientific Forum" consisting of representatives from the scientific community who can be appointed by the EU Member States.

The EU-IAS Regulation defines the material criteria for including species in the list of Union concern. The decision must be backed up by, among other things, scientific research; here, uncertainties can be dealt with by applying the precautionary principle (Köck 2015: 166f). The decision must also be taken on the basis of a risk assessment, involving consideration of not just the risks but also the benefits of introduction (Art. 5 (h)) (Köck 2015: 168). In the summer of 2016 the EU Commission adopted an initial list containing 37 species (Commission Implementing Regulation (EU) 2016/1141 of 13 July 2016), which meet the material criteria and to which the new prohibitions apply (Köck 2016). Thus far, however, this list contains few species of relevance to marine ecosystems.

48.3.5.2 EU Marine Strategy Framework Directive

The EU's Marine Strategy Framework Directive (hereinafter MSFD) commits the Member States to develop strategies and programmes in order toa) protect and preserve the marine environment, prevent its deterioration or, where practicable, restore marine ecosystems in areas where they have been adversely affected; andb) prevent and reduce inputs in the marine environment, with a view to phasing out pollution (…), so as to ensure that there are no significant impacts on or risks to marine biodiversity, marine ecosystems, human health or legitimate uses of the sea (Art. 1, (2)).

The strategies to be developed by the Member States are committed to the goal of achieving or maintaining good environmental status in the marine environment by 2020 (Art. 1 MSFD) (Markus et al. 2011: 59–90; Markus 2013)). In doing so, the Member States must also take account of risks that may arise from biological disturbance. In this connection the MSFD mentions, among others, the "introduction of non-indigenous species and translocations" (Annex III, Table 2). The Member States were to devise the strategies and requisite assessments for taking stock and evaluating by 2012 and the programmes of measures by 2015. Germany, which devised its strategy and programme of measures on schedule, can be mentioned as an example in this context. In terms of the objectives, it is guided by the IAS targets of OSPAR and HELCON: endeavour to limit the introduction of non-indigenous species by human activities to levels that do not adversely alter the ecosystems (BMUB 2016: 10; OSPAR-Commission 2010b: 7). In the part of the programme detailing the measures, however, the sole references are to those contained in the IMO Ballast Water Management Convention, the regulation (EC) concerning the use of alien and locally absent species in aquaculture, and the EU-IAS Regulation (BMUB 2016: 29), so that the MSFD currently offers no farther-reaching suggestions for dealing with non-indigenous species (NIS) and IAS.

48.3.5.3 Regulation (EC) Concerning Use of Alien and Locally Absent Species in Aquaculture

The EC had created a special piece of legislation for dealing with NIS in aquacultures in 2007, referring to the CBD in doing so. Regulation (EC) No 708/2007 of 11 June 2007 concerning the use of alien and locally absent species in aquaculture (hereinafter Aquaculture Regulation) stipulates, among other things, that aquaculture operators intending to undertake the introduction of an alien species or the translocation of a locally absent species (…) shall apply for a permit from the competent authority of the receiving Member State. The requirement of a permit does not apply to all species listed in Annex IV (such as the Pacific cupped oyster, Japanese or Manila clam, arctic char and various freshwater fish) (Art. 2 (5)). The permit procedure is conducted on the basis of an Environmental Risk Assessment (Art. 9) whose individual steps are regulated in Annex II. The permit may be granted only in cases where the risk assessment, including any mitigation measures, show a low risk to the environment (Art. 9 (4)). Art. 9 (4) also stipulates explicitly that the precautionary principle is to be applied whenever this judgement cannot be made with the necessary certainty.

At EU level, then, an effective management mechanism for the vector of aquacultures has been available for some 10 years, albeit it does not correspond in every respect to the regulatory approach taken by the EU-IAS Regulation. The key issue in an Environmental Risk Assessment—unlike in risk assessments within the EU-IAS Regulation—is not benefit. Considerations of benefit play a role only in relation to the species listed in Annex IV. The Aquaculture Regulation provides no special procedure, however, for including species in the Annex IV list.

48.4 Concluding Remarks and Further Perspectives

The study has shown that, beginning with the CBD, a wide range of management approaches have been developed for dealing with NIS and IAS in the context of protecting marine ecosystems and ecosystem services. For the most part, these approaches rest upon strategies and programmes (of measures) which generally have been derived from qualitative targets and key institutional decisions enshrined in international agreements. One example worth mentioning is the important work of the CBD Conference of the Parties aimed at developing an IAS management strategy. Another is the work of the commissions established through regional marine protection treaties, such as the OSPAR Commission and the strategy it oversees, which also addresses NIS and IAS management measures. The development of appropriate strategies and programmes is also a key feature of the IMO's Ballast Water Management Convention, perhaps the most important agreement aimed at protecting marine ecosystems from the risks posed by NIS and IAS.

The international agreements as well as regional legal provisions, such as EU laws on the IAS issue, are not merely limited to proscribing the development of strategies and programmes, however; in many cases they also regulate specific instruments, such as permit requirements (e.g. EC-Aquaculture Regulation), risk assessments (EC-Aquaculture Regulation; EU-IAS Regulation), and technical standards aimed at protecting marine ecosystems (IMO Ballast Water Management Convention).

In all these cases, priority has been given to a management approach that focuses on prevention and thereby includes the precautionary principle, while also taking account of costs and benefits (see especially the EU-IAS Regulation). So far there is little information available about the success of these measures—due in part to the fact that some important regulations have only recently been adopted (such as the EU-IAS Regulation) or else are soon to come into force (IMO-Ballast Water Management Convention).

Of particular interest for the further development of mechanisms to protect marine ecosystems from the risks posed by NIS and IAS is European legislation, because it has established some important and exemplary priority issues, with regard to both the effectiveness of regulations and to the regulatory approach. Worthy of mention in this connection are the Aquaculture Regulation and the EU-IAS Regulation with its binding list of IAS of Union concern and the establishment of procedures for developing this list further.

Whether or not it is possible to protect marine ecosystems effectively from the risks posed by NIS and IAS depends not only on further introductions being prevented, however. It is also dependent on the international community taking effective measures to tackle climate change.

References

1996 Protocol to the convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (7 November 1996; entered into force on 24 March 2006) reprinted in 36 ILM 1 (1997)

Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB) (ed) (2016) MSRL-Maßnahmenprogramm zum Meeresschutz der deutschen Nord- und Ostsee

Convention on Biological Diversity (5 June 1992; entered into force on 29 December 1993) 1760 UNTS 79; reprinted in 31 ILM 818 (1992)

Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (13 November 1972; entered into force on 30 August 1975) 26 UST 2403, 1046 UNTS 120; reprinted in 11 ILM 1294 (1972)

Convention on the Protection of the Marine Environment of the Baltic Sea Area (9 April 1992; entered into force on 17 January 2000) 1507 UNTS 167; reprinted in 13 ILM 546 (1974)

Convention for the Protection of the Marine Environment of the North-East Atlantic (22 September 1992; entered into force on 25 March 1998) 2354 UNTS 67; reprinted in 32 ILM 1069 (1993)

COP (2002) Guiding principles for the prevention, introduction and mitigation of impacts of alien species that threaten Ecosystems, Habitats or Species

HELCOM, HELCOM Guide to Alien Species and Ballast Water Management in the Baltic Sea (2014)

International Convention for the Control and Management of Ship's Ballast Water and Sediments (16 January 2004; will enter into force 8 2017) IMO Doc. BWM/CONF/36; reprinted in 18 ATNIF (2005)

International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978 (17 February 1973; entered into force on 2 October 1983) 34 UST 3407; 1340 UNTS 184; TIAS No. 10,561; reprinted in 12 ILM 1319 (1973)

International Maritime Organization (1997) Guidelines for the control and management of ships' ballast water to minimize the transfer of harmful aquatic organisms and pathogens, Resolution A, 868(20)

OSPAR Commission (2010a) Quality status report 2010

OSPAR Commission (2010b) The North-East Atlantic Environment Strategy 2010-2020

United Nations Convention on the Law of the Sea (10 December 1982; entered into force on 16 November 1994) 1833 UNTS 3; reprinted in 21 ILM 1261) (1982)

Birnie P, Boyle A, Redgwell C (2009) International law and the environment, 3rd edn. Oxford University Press, Oxford

Bostrom S (2009) Halting the hitchhikers: challenges and opportunities for controlling ballast water discharges and aquatic invasive species. Environ Law 39(3):867–914

Firestone J, Corbett JJ (2005) Coastal and port environments: international legal and policy responses to reduce ballast water introductions of potentially invasive species. Ocean Dev Int Law 36(3):291–316. doi:10.1080/00908320591004469

Galil BS, Nehring S, Panov V (2007) Waterways as invasion highways—impact of climate change and globalization. In: Nentwig W (ed) Biological invasions. Springer, Berlin, pp 59–74

Hewitt C, Gollasch S, Minchin D (2009) The Vessel as a vector: biofouling, ballast water and sediments. In: Rilov G, Crooks JA (eds) Biological invasions in marine ecosystems. Springer, Berlin, pp 117–131

Holljesiefken A (2007) Die rechtliche Regulierung invasiver gebietsfremder Arten in Deutschland: Bestandsaufnahme und Bewertung. Springer, Berlin
Jastremski WM (2002) A proposed international framework convention on bioinvasive species. In: Susskind L, Moomaw W, Gallagher K (eds) Transboundary environmental negotiation: new approaches to global cooperation. Jossey-Bass, San Francisco, pp 361–375
Klingenstein F, Kornacker PM, Martens H, Schippmann U (2005) Gebietsfremde Arten. Positionspapier des Bundesamtes für Naturschutz, BfN-Skripten Nr 128
Köck W (2004) Invasive gebietsfremde Arten. In: Wolff N, Köck W (eds) 10 Jahre Übereinkommen über die biologische Vielfalt. Nomos, Baden-Baden, pp 107–125
Köck W (2015) The eu regulation on invasive alien species. J Euro Environ Plan Law 12:157–173
Köck W (2016) Comment on sec 40 of the Federal Nature Protection Act. In: Schlacke S (ed) Gemeinschaftskommentar zum Bundesnaturschutzgesetz, 2nd edn. Heymanns, Köln. (in print)
Kowarik (2010) Biologische Invasionen: Neophyten und Neozoen in Mitteleuropa, (2 ed)
Kuhlenkamp R, Kind B (2016) Introduction of non-indigenous species (in this book)
Leppäskoski E, Gollasch S, Olenin S (2002) Alien species in European waters. In: Leppäskoski E, Gollasch S, Olenin S (eds) Invasive aquatic species of Europe distribution, impacts and management. Kluwer Academics, Dordrecht, pp 1–6
Lonhart SI (2009) Natural and climate change mediated invasions. In: Rilov G, Crooks JA (eds) Biological invasions in marine ecosystems. Springer, Berlin, pp 57–69
Riley S (2009) Preventing transboundary harm from invasive alien species. RECIEL 18(2):198–210
Markus T (2013) Changing the base: legal implications of scientific criteria and methodological standards on what constitutes good marine environmental status. In: Transnational Environmental Law, Page 1 of 21, 2012 Cambridge University Press. doi:10.1017/S2047102512000088
Markus T, Schlacke S, Maier N (2011) Legal implementation of integrated ocean policies: the EU Marine Strategy Framework Directive. Int J Mar Coastal Law 26:59–90
SRU—Rat von Sachverständigen für Umweltfragen (2012): Umweltgutachten 2012.
Wolfrum R, Matz-Lück N (2000) The interplay of the United Nations Convention on the Law of the Sea and the Convention on Biological Diversity. In: Frowein JA, Wolfrum R (eds) Max Planck Yearbook of United Nations Law, vol 4. Kluwer Law International, The Hague, pp 445–480
Zink AR (2016) Das Ballastwasser-Übereinkommen der internationalen Seeschifffahrtsorganisation. Nomos, Baden-Baden

Chapter 49
Integrating Sectoral Ocean Policies

Markus Salomon and Miriam Dross

Abstract Oceans and seas are adversely affected by a large number of anthropogenic pressures. The need to better integrate the policies of different sectors, which impact the oceans is generally seen. Different countries strive to implement a more integrated approach for the management and protection of their marine areas. Important tools which can support this process are marine spatial planning and marine protected areas. If a single administrative body is made responsible for the entire task of sustainable marine use and conservation, this could help to bundle responsibilities. Existing approaches often do not meet expectations. Reasons for this are diverse, ranging from insufficient governmental and scientific resources, lack of political will or a federal political system that complicates cooperation and coordination.

Keywords Integrating ocean policies • Ecosystem approach • Protection of marine biodiversity • Marine protected areas • Maritime spatial planning

49.1 Introduction

Oceans and seas are adversely affected by a large number of anthropogenic pressures. A wide range of economic actors is responsible for negative impacts on the marine environment. These impacts are caused by typical maritime activities such as fishing, shipping and oil and gas-drilling as well as land-based activities such as agriculture, industries and traffic (see Chaps. 4 to 17 of this book). These undertakings are subject to many different regulations and policies, ranging from local to international level. However, they are seldom coordinated in order to reduce impacts on the oceans and to achieve a consistent policy approach.

M. Salomon (✉) • M. Dross
German Advisory Council on the Environment, Berlin, Germany
e-mail: markus.salomon@umweltrat.de; miriam.dross@umweltrat.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_49

This is due to the fact that policies are mainly structured by sectors such as agriculture and fishing, transport, economic affairs and energy as opposed to the media that are affected by human activities such as soil, air, and oceans. The coordination of these policies represents an important challenge, because sectoral based policies are often blind for ecosystem requirements. When different sectors contribute to a problem, adopting a sectoral based approach inevitably leads to the outcome that cumulative burdens are not taken into account, because the sector policy economic interests of the relevant sectoral actors are dominant in the decision making process (Markus Chap. 28).

The importance of an integrated coastal and ocean management was prominently singled out 1992 by Chap. 17 of the Agenda 21 of the UN Conference on Environment and Development (United Nations 1992). Chap. 17 outlines that the marine environment forms an integrated whole that is an essential component of the global life-support system and a positive asset that presents opportunities for sustainable development. It explains that this requires new approaches to marine and coastal area management and development, at the national, sub-regional, regional and global levels and that these approaches need to be integrated. Programme areas therefore include, among others, integrated management and sustainable development of coastal areas and strengthening international, including regional, cooperation and coordination.

There exists no generally agreed definition of integrated ocean management. However, integrated ocean management can be described as the task to plan and manage human activities impacting the oceans in a comprehensive fashion while considering all factors necessary for the conservation and sustainable use of marine resources and the shared use of ocean space. As opposed to a single act, this represents a continuous and dynamic process by which decisions are made (Cicin-Sain and Knecht 1998). To ensure continuity, decisions of all sectors and all levels of government should be harmonised and made consistent with the ocean and coastal policies in force. The process should be designed to overcome fragmentation which is inherent in the sectoral management approach as described above.

This is no small task: In an article in 1980, Underdal outlined three requirements that an integrated policy must meet: comprehensiveness in the input phase, aggregation when processing inputs, and consistency of outputs (Underdal 1980: 159 ff.). Comprehensiveness in the input phase refers to the need to collect and make use of an array of different data ranging from biodiversity and pollution to spectral activities and mitigation. An integrated approach is only realistic, when sufficient data is available. Aggregation when processing inputs requires not only funding and personnel but also a mandate. Typically, this only takes place if a ministry or an agency has an obligation to do so. Finally, consistency of outputs is crucial. Consistency of outputs necessitates that no single economic interest prevails and that marine protection considerations are sufficiently taken into account.

In this chapter, short case studies will illustrate different approaches to integrating ocean policies in Australia, the EU and Canada, as they have made attempts to introduce integrated management of ocean policy under different political backdrops respectively: Australia as a federal state, Canada as a centralised one and the EU as an intergovernmental or supranational entity.

49.2 The Ecosystem Approach as a Management Guideline

In addition to integrating marine protection in various departmental policies and ensuring transboundary coordination, a comprehensive view of the sea as a natural region and of its uses is of great importance for effective marine protection. This position underlies the application of the ecosystem approach to marine policy. There exist a number of different definitions of the ecosystem approach in the context of marine management (Farmer et al. 2012; COMPASS 2005). The one defined in the framework of the Convention on Biological Diversity (CBD) and agreed on by 196 contracting states is well recognised on the global level. According to Art. 2 of the CBD, 'ecosystem means a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit'. Decision V/6 of the Fifth Conference of the Parties in Nairobi in 2000 further describes the ecosystem approach as 'a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way', which 'requires adaptive management to deal with the complex and dynamic nature of ecosystems and the absence of complete knowledge or understanding of their functioning' (CBD, COP 5, Decision V/6). The annexes to the decision explain in greater detail the governing principles of the ecosystem approach. They point out that the objectives of management of land, water and living resources are a matter of societal choice. Different sectors of society view ecosystems in terms of their own economic, cultural and societal needs and interests. The conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be seen as a primary target of the ecosystem approach.

The functioning of ecosystems as well as their resilience depends on a dynamic relationship within species, among species and between species and their abiotic environment, as well as the physical and chemical interactions within the environment. The conservation and, where appropriate, restoration of these interactions and processes is of greater significance for the long-term maintenance of biological diversity as opposed to the mere protection of species.

The ecosystem approach thrives to reach a balance of the three objectives of the CBD: conservation, sustainable use, and fair and equitable sharing of the benefits arising out of the utilisation of genetic resources. Appropriate scientific methodologies should be applied, focused on levels of biological organisation, which encompass the essential structure, processes, functions and interactions among organisms and their environment. In this respect, it is vital to note that humans are regarded as part of the ecosystem.

The ecosystem approach also has to be regarded as a process which involves moving progressively closer to the actual goal in the light of the changing body of knowledge (OSPAR Commission 2010). For this reason, practical implementation can only take place on a step-by-step or staggered basis. Important aspects of this process are the establishment and coordination of ecological criteria and objectives and the associated indicators, the further development of management and research, and the constant updating of knowledge about ecosystems and the pressures they are subject to.

49.3 Australia's Integrated Ocean Policy

Australia's marine jurisdiction extends to around 2.56 million square kilometres, nearly twice the size of the Australian landmass and islands, and represents (including the extended continental shelf) 3.8% of the world's oceans (State of the Environment Committee 2011: 378). Australia started to address the question of ocean governance early on. The first integrated strategy, named *Australia's Ocean Policy*, was released in 1998 (Commonwealth of Australia 1998a), completed by a second volume called *Specific Sectoral Measures* (Commonwealth of Australia 1998b). At the time, the policy was recognised as setting an international benchmark in taking an integrated approach (National Environmental Law Association 2014: 1).

The goal of the Ocean Policy was to set in place the framework for integrated and ecosystem based planning and management for all of Australia's marine jurisdictions (Commonwealth of Australia 1998a: 2). It was also meant to exercise and protect Australia's rights and jurisdiction over offshore areas, including offshore resources and to meet Australia's international obligations under the United Nations Convention on the Law of the Sea and other international treaties. Furthermore, it was intended to increase understanding and enhance protection of Australia's marine biological diversity, the ocean environment and its resources, and to ensure ocean uses were ecologically sustainable. Also, its goal was to establish integrated oceans planning and management arrangements (Commonwealth of Australia 1998a: 4).

To achieve this, new institutions were established: first, the National Oceans Ministerial Board, which comprised of the ministers responsible for the environment (Chair), industry, resources, fisheries, science, tourism and shipping, was created to oversee the Regional Marine Planning process (Commonwealth of Australia 1998a: 15). Second, the National Oceans Office (NOO) was set up as an independent agency without power to override decisions from other agencies. It was placed in Tasmania, away from the government in Canberra. In addition, Regional Marine Steering Committees and a National Oceans Advisory Group were established (Vince et al. 2015). The advisory group comprised key stakeholders that included marine sectors, industries, indigenous groups and academics.

While in the beginning, many attempts were made to include states and stakeholders in the development of the strategy, subsequently the central government became the main driver of the initiative and the federal states were left out. This resulted in the fact that the vast majority of the coastal zone, which is under jurisdiction of the states, was not included in the strategy (Vince et al. 2015).

At the same time as the Oceans Policy, a network of marine protected areas was developed (ANZECC 1998). This process directly involved the states and the Commonwealth, developed criteria and provided relevant information such as maps of conservation assets.

The Ocean Policy foresaw the need to establish regional marine plans that were to be developed in the process (Commonwealth of Australia 1998a). These plans were to be established in seven regions that were selected based on the concept of large marine ecosystems.

Even though the government provided 50 million AUS$, only one regional marine plan was completed, the one for the South East bioregion of Australia, which was released in 2004. The overall implementation of the Ocean's Policy process was delayed due to a number of factors, including the complexity of the marine uses involved, the difficult decision making process within the government and problems in the sectors concerned. Departments within the government were not given additional resources to support the Ocean Policy. They were also reluctant to concede any part of their ocean-related responsibilities to the National Oceans Office (Bateman and Bergin 2009). At the state level, the federal states and the Northern territory were reluctant to support the Ocean's Policy. Furthermore the process lacked sufficient scientific input, especially with regard to integrating the biophysical, economic and social dimension of ocean management in a coherent framework (Vince et al. 2015). A review of the Ocean Policy's process in 2002 resulted in major changes, including the dissolution of the initial institutions. The National Oceans Office was absorbed into the Environmental Department. The regional marine plans were discontinued.

Instead, marine planning would be done under the *Environment Protection and Biodiversity Conservation Act* 1999. The government allocated more than 37 million Australian dollars to develop Marine Bioregional Plans. Marine Bioregional Plans were established for the South West, North West, North, and Temperate East (Australian Government 2014). As opposed to the regional marine plans, the bioregional plans centred on environmental conditions and conservation of marine species and formed the basis for a network of marine protected areas (National Representative System of Marine Protected Areas, NRSMPAs) and left economic and social aspects mostly aside. The plans were intended to support consistent decision-making and efficient administration under the Commonwealth environmental legislation with respect to Commonwealth marine areas. The final plans for the four regions, which are not legislative instruments but guidance documents, were only issued in 2012. During this time, the states gradually disengaged from the Ocean Policy. The Great Barrier Reef Marine Park was not part of the Commonwealth marine reserves process and is managed under its own jurisdiction and legislation.

In conclusion, Australia's Ocean Policy has not achieved the high expectations originally set for it (Bateman and Bergin 2009). In comparison with the vision of an integrated oceans policy, the "final set of Marine Bioregional Plans are a pale shadow of the intended scope of marine planning" (Vince et al. 2015). A major shortcoming was that the process did not strive to include both the national and the state level. Since Australia's coastal zones are under jurisdiction of the states, numerous major challenges could not be addressed. While the initial initiative of the Ocean Policy came from the cabinet, the ownership of the process later moved to the environmental ministry, which led to a narrower focus of the policy. Also, the decision to locate the National Oceans Office in Tasmania, far away from the political centre, was seen to contribute to the failure of the policy (Hu 2012). Australia's Ocean Policy exemplifies the challenges of implementing integrated oceans management (Vince et al. 2015) and it illustrates that integration is a very complex task, especially within a federal system with a strong central government.

49.4 Canada's Ocean Policy

Canada has coasts on three different oceans and the world longest coastline. Canada's Oceans Act came into force in 1997, thus making it one of the leading countries in integrated ocean management at the time. The Oceans Act empowers the Minister of Fisheries and Ocean to develop and implement an oceans management strategy based on the principles of sustainable development, integrated management of activities in marine waters and the precautionary approach. The oceans strategy was released in 2002 under the lead of the Department of Fisheries and Oceans (DFO) (Government of Canada 2002). The DFO Minister was encharged to facilitate the development of the national oceans strategy in collaboration with other federal departments having oceans responsibility, the provinces, territories, indigenous organisations, coastal communities and further stakeholders. In this process, the Minister did not receive additional competencies to override decisions by other stakeholders. The main goal of the strategy was seen in the coordination of all engaged in ocean matters (McDorman and Chirop 2012). The oceans strategy was subsequently followed by the oceans action plan, published in 2005 (Government of Canada 2005). The government created the so called Oceans Branch within the DFO as the lead agency to facilitate the implementation of the strategy (Bailey et al. 2016).

The oceans strategy placed a focus on "large ocean management areas" (LOMAs) of which five were chosen for the first phase of implementing the action plan: Placentia Bay and the Grand Banks, the Scotian Shelf, the Gulf of St. Lawrence, the Beaufort Sea, and the Pacific North Coast (Government of Canada 2002). For each area, a science and management framework was to be established in order to coordinate different uses. Although different results were foreseen for each of the priority areas, the oceans strategy strived for two fundamental outcomes in all of them. First, an open and collaborative oceans governance and management arrangement amongst governments at all levels, with stakeholders directly affected by those government decisions, and with citizens and interested parties who have an interest in decisions affecting that oceans area was to be established. Second, that integrated management was to be founded on ecosystem-based approaches to science and management to provide for more informed and comprehensive advice in support of oceans decision-making (Government of Canada 2005). Since its adoption, only one of five management plans has been endorsed by the Fisheries Department (Bailey et al. 2016).

The Oceans Act gives the DFO the responsibility to lead and coordinate the development and implementation of a system of marine protected areas. In order to avoid overlaps, a strategy regarding marine protected areas was issued in 2005. As a signatory to the Convention on Biological Diversity, Canada has committed to establishing a network of marine protected areas (MPA) that effectively conserves at least 10% of coastal and marine areas by 2020. This is not the case: Canada's Pacific MPAs cover approximately 1% of Canadian Pacific waters. Results showed that 90% of existing MPAs were intended to exclude commercial fishing, yet only 2.5% fully or partially meet this goal, therefore management intent was not achieved. Further, existing MPAs are small, 75% less than 10 km^2 in size, but are reasonably spaced, from 1 to 50 km apart (Robba et al. 2015). The Auditor General of Canada therefore concluded in 2002 that the plan to establish a network of MPAs has failed.

Another indication that the Canadian ocean policy has—at least in parts—failed is the number of commercially important fish stocks, which are still at risk (Environment and Climate Change Canada 2016). One reason is that the Species at Risk Act 2002, which is Canada's primary legislative tool to protect species at risk, was not properly implemented especially in the context of the protection of marine species. Scientists have criticised that this is primarily due to a lack of political will (Bailey et al. 2016). Another criticism is that the government does not effectively support a science based management of Canadian marine waters. This is shown, for example, by the fact that in recent years the funds for ocean research have been gradually reduced.

The evaluations of Canada's integrated oceans policy are deviating. Some claim that the Oceans Act has had important results both in terms of concrete actions as well as in processes (McDorman and Chirop 2012). Others maintain that even though Canada has developed legislation and policies to effectively protect its oceans, these have been weakened and not fully implemented (Bailey et al. 2016). This view is supported by the lack of concrete outcomes of the policy, the insufficient number of MPAs, the modest implementation of the Species at Risk Act, and the reduced funding for ocean research.

49.5 The Approach of the European Union

The European coastline is approximately 66,000 km long, bordering the Atlantic Ocean, Mediterranean Sea, Black Sea, North Sea and Baltic Sea. Most EU Member States are coastal states. Although ocean policies have gained increasingly in significance in the last years, they are not a central focus of EU policies. The EU ocean policy is unique because it is an intergovernmental approach. The competences of the EU to regulate human activities in the context of seas and oceans are not comparable with those of a federal state. With the exception of fisheries policy, the EU shares competences with Member States to regulate pressures on the marine environment (Salomon et al. 2014; Markus 2009). Integrating ocean policies in Europe is based on two different pillars: an ongoing process for an integrated maritime policy and a framework directive for the protection of European seas.

The political process towards an integrated European maritime policy started in 2006 and was initiated by the six Directorates-General for Maritime Affairs and Fisheries, the Environment, Enterprise and Industry, Transport, Energy, Regional Policy and Research (European Commission 2006). For this process, a green and a blue paper were published with a focus of the following five aspects: use of the seas, the quality of life in coastal regions, tools for managing relations with the oceans, governance, and Europe's maritime heritage and maritime identity. The idea behind the integrated maritime policy was to find the right balance between the economic, social and environmental dimensions of sustainable development. The focus of the two mentioned documents was on use aspects. The actual outcome of this process is pretty much a summary of existing activities and suggestions for concepts for better pooling and provision of data (European Commission 2012). Furthermore, EU Member States are encouraged to develop their own national integrated maritime policy. What is (still) missing are specific suggestions on how a better integration of hitherto fragmented European policies relating to the seas can be realised (Salomon and Dross 2013). The mentioned documents merely point out that the creation of a maritime identity could improve cooperation and coordination between the political sectors. It has to be seen if further development of the integrated maritime policy in the future will give impulses for better integration.

Very significant for an integrated approach in the management of European seas is the Marine Strategy Framework Directive 2008/56/EC (MSFD) which was adopted in 2008. With this directive, for the first time a comprehensive approach (in the sense that it covers the entire spectrum of marine pollution) on the protection of the marine environment in Europe was established. The MSFD is the central tool currently being used to shape marine protection at EU level. The purpose of the directive is to achieve 'good environmental status' in Europe's marine waters by the year 2020. Good environmental status is defined as: "the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for uses and activities by current and future generations". In this context, the MSFD makes reference to the ecosystem approach. The directive provides a framework within which the Member States are required to develop and implement strategies for protecting their marine waters. The MSFD should be implemented stepwise following a set timetable (Fig. 49.1).

The MSFD requires the Member States of a marine region or sub-region to cooperate with each other in developing their marine protection strategies. Furthermore, the effective involvement of all interested parties is to be ensured

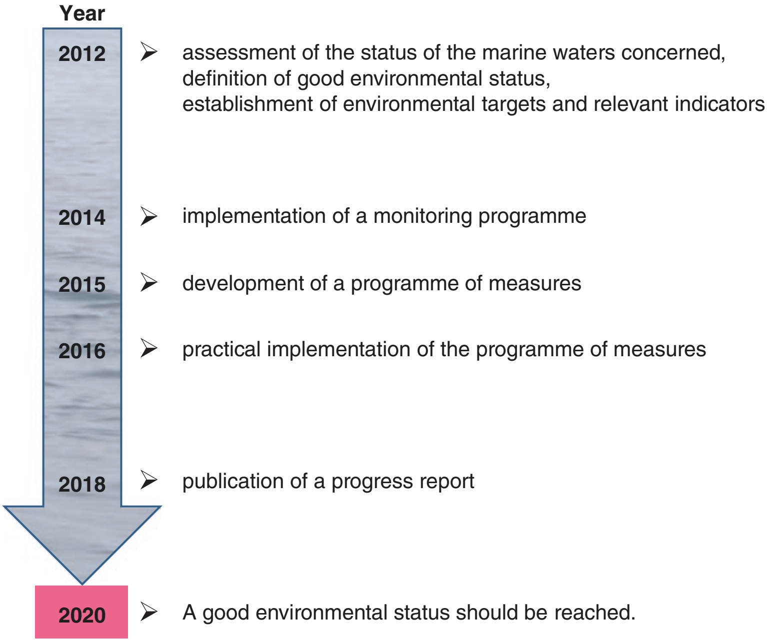


Fig. 49.1 Implementation process of the EU marine strategy framework directive

during each procedural step of implementing the strategy (Fletcher 2007). The Member States are also called upon to take into account existing EU legislation on marine protection in their programmes of measures as well as other relevant environmental standards.

The first three steps of the MSFD implementation process have been already finalised. At present the Member States are responsible for putting their programmes of measures into practice (Fig. 49.1).

The overall responsibility for implementing the MSFD by developing a protection strategy for European waters lies largely in the hands of the Member States (Salomon and Dross 2013). However, the leeway of Member States in implementing marine protection concepts to achieve good environmental status is limited because the sectors particularly relevant for marine protection, such as fisheries, shipping and agriculture, are strongly regulated at international and European level. There are a number of European policies and regulations that influence the protection of marine waters and do not fall under the regime of the MSFD (Bigagli 2015). One important example is the Common Fisheries Policy (CFP) which aims at the sustainable exploitation of marine biological resources. The EU holds the exclusive competence to regulate the conservation of marine biological resources in European waters (Markus et al. 2011). Nevertheless, the EU has until now been unable to implement a fisheries management system that guarantees a sustainable use of its marine biological resources, which is mainly due to the influence of short-term industrial interests (Salomon et al. 2014).

If in the process of implementing the MSFD a Member State identifies an environmental problem for which it has no competence to take action, it is required to inform the European Commission and other relevant organisations and request for them to take action. This indirect route is one opportunity to initiate changes to the relevant policies via the MSFD. The other one is to establish ambitious environmental protection targets in the implementation process of the directive. These targets can be a driver for the integration of marine environment protection issues in other policies. Overall, the two mentioned pathways and the fact that the directive addresses all forms of marine pollution are in the spotlight if one is to speak of an integrative character of the MSFD.

Europe is on its way to develop a more integrated approach in the management and protection of its seas. This can be seen, for example, in the fact that until now 6% of European seas are designated as MPAs (EEA 2015). But this network of MPAs is still not effectively managed. Whether the European approach will be successful is a question that can only be answered in the future. This is highly dependent on the ability and willpower of the Member States to integrate responsible sectors in ambitious protection plans. Besides that, it is necessary to provide the required resources and to further develop relevant European policies in accordance with the targets of the MSFD.

49.6 Conclusions

There seems to be a general consensus that an integrated approach is necessary for ocean management. However, in practice, attempts to establish such an approach have been met with difficulties. In fact, there are a number of barriers and obstacles for a successful implementation of such a policy as can be seen in the three case studies described above.

McDorman and Chirop point out that national ocean policymaking cannot be a single path, structure or instrument, because in reality the state and its citizens interact with the oceans in a multitude of different manners (McDorman and Chirop 2012). On the other hand, a more integrated ocean management is necessary to establish a decision making structure that pays sufficient consideration to marine conservation and ecosystem protection as well as provides opportunities for the sustainable maritime uses. Accordingly, one goal of such a policy is to improve coordination and cooperation in ocean management. More precisely, all sector policies that influence ocean management have to be coordinated to some degree.

From the marine protection perspective, an integrated approach means mainly to give environmental aspects more weight in and guidance to sectoral policies. However, attempts to do so are often met with opposition. The strong political influence of the marine economic sectors (fishing, shipping, and mining) especially plays a crucial role here. If there is a lack of political will on the government level, these obstacles cannot be overcome.

Furthermore, a number of attempts to establish an integrated oceans policy suffered from limitations in sufficient governmental and scientific resources. Scientific resources are of particular importance, because scientific input provides ocean management with legitimacy and data. They are also a prerequisite for the ecosystem-based management of oceans and seas.

In general, a country with a federal system or multilevel political system generally suffers more from difficulties to implement an integrated ocean policy. This is due to their complex internal decision-making structure and litigation (Hu 2012).

One possibility to overcome the mentioned shortcomings might be to establish an administrative body that takes responsibility for the entire area of sustainable marine use and conservation of the national marine area. One example for such an institution is the United States National Oceanic and Atmospheric Administration (NOAA), the federal agency responsible for conservation and management of US coastal and marine ecosystems and resources (NOAA n.d.). The establishment of such an authority can be an opportunity to strengthen marine policy and marine conservation. An important feature of the NOAA is that management and conservation tasks are bundled under one roof, which can improve coordination and cooperation. Furthermore, such an agency can represent all interests in marine protection and can better communicate them to the public.

Marine protected areas and maritime spatial planning or multi-use planning are important tools in the context of an integrated ocean policy in order to direct the spatial distribution of the different human activities in the usage of marine resources, in particular to protect sensitive ecosystems, habitats or species (Chaps. 46 and 54) (Ban et al. 2014). Whether marine spatial planning can really reach its steering potential is highly dependent on the way it is implemented. The targets of MPAs are often being missed because of the absence of appropriate management plans. This is mainly because the administration responsible for the implementation of MPAs has insufficient authorisation to regulate sectoral interests such as fishing or shipping.

The idea that all relevant levels of government can be involved in one management plan for a single marine region or national marine area is compelling. The crucial question remains if it is better to invest in the development of a strategy for an integrated ocean policy, or to accept the status quo and to put all efforts into the development of measures to protect the marine environment from pressures from single sectors.

References

ANZECC, Australian and New Zealand Environment and Conservation Council Task Force on Marine Protected Areas (1998) Guidelines for establishing the national representative system of marine protected areas. Environment Australia, Canberra

Australian Government Department of Environment (2014) Marine bioregional plans. Australian Government Department of Environment. https://www.environment.gov.au/marine/marine-bioregional-plans. Accessed 18 Feb 2016

Bailey M, Favaro B, Otto SP, Charles A, Devillers R, Metaxas A, Tyedmers P, Ban NC, Mason T, Hoover C, Duck TJ, Fanning L, Milley C, Cisneros-Montemayor AM, Pauly D, Cheung WWL, Cullis-Suzuki S, Teh L, Sumaila UR (2016) Canada at a crossroad: the imperative for realigning ocean policy with ocean science. Mar Policy 63:53–60

Ban NC, Maxwell SM, Dunn DC, Hobday AJ, Bax NJ, Ardron J, Gjerde KM, Game ET, Devillers R, Kaplan DM, Dunstan PK, Halpin PN, Pressey RL (2014) Better integration of sectoral planning and management approaches for the interlinked ecology of the open oceans. Mar Policy 49:127–136

Bateman S, Bergin A (2009) Sea change: advancing Australia's ocean interests. The Australian Strategic Policy Institute, Caberra

Bigagli E (2015) The EU legal framework for the management of marine complex social–ecological systems. Mar Policy 54:44–51

Cicin-Sain B, Knecht R (1998) Integtraged ocean and coastal management. Island Press, Washington, DC

COMPASS (2005) COMPASS scientific consensus statement on marine ecosystem-based management. 21 March 2005

Commonwealth of Australia (1998a) Australia's Ocean policy. Environment Australia, Canberra

Commonwealth of Australia (1998b) Australia's Ocean Policy. Specific sectoral measures. Environment Australia, Canberra

European Environment Agency (EEA) (2015) Marine protected areas in Europe's seas—An overview and perspectives for the future. EEA report. European Environment Agency, Kopenahgen

Environment and Climate Change Canada (2016) Canadian environmental sustainability indicators: status of major fish stocks

European Commission (2006) Green Paper—towards a future maritime policy for the union: a European vision for the oceans and seas. European Commission, Brussels

European Commission (2012) Progress of the EU's integrated maritime policy—report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. European Commission, Brussels

Farmer A, Mee L, Langmead O, Cooper P, Kannen A, Kershaw P, Cherrier V (2012) The ecosystem approach in marine management. EU FP7 KNOWSEAS Project

Fletcher S (2007) Converting science to policy through stakeholder involvement: an analysis of the European marine strategy directive. Mar Pollut Bulletin 54(12):1881–1886. doi:10.1016/j.marpolbul.2007.08.004

Government of Canada (2002) Canada's oceans strategy our oceans, our future

Government of Canada (2005) Canada's oceans. Action plan for present and future generations

Hu N-TA (2012) Integrated oceans policymaking: an ongoing process or a forgotten concept? Coastal Manage 40:107–118

Markus T, Schlacke S, Maier N (2011) Legal implementation of integrated ocean policies: the EU´s marine strategy framework directive. Int J Mar Coastal Law 26(1):59–90

Markus T (2009) European fisheries law—from promotion to management. Europa Law Publishing, Groningen

McDorman TL, Chirop A (2012) Canada's oceans policy framework: an overview. Coastal Manage 40:133–144

National Environmental Law Association (2014) NELA's proposed national oceans policy

NOAA (National Oceanic and Atmospheric Adminstration) (n.d.) Our mission and vison. http://www.noaa.gov/our-mission-and-vision. Accessed 5 Apr 2016

OSPAR Commission (2010) The North-East Atlantic Environment Strategy—Strategy of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic 2010–2020. OSPAR Agreement 2010-3. OSPAR Commission, London

Robba CK, Bodtkera KM, Wrighta K (2015) Marine protected areas in the Canadian Pacific: do they fulfill network criteria? Coastal Manage 43(3):253–269

Salomon M, Dross M (2013) Challenges in cross-sectoral marine protection in Europe. Marine Policy 42:142–149
Salomon M, Markus T, Dross M (2014) Masterstroke or paper tiger—the reform of the EU´s Common Fisheries Policy. Marine Policy 47:76–84
State of the Environment Committee (2011) Australia state of the environment 2011 Independent report to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities. Canberra
Underdal A (1980) Integrated marine policy: what? why? how? Marine Policy 4(3):159–169
United Nations (1992) United Nations Conference on Environment & Development Rio de Janerio, Brazil, 3 to 14 June 1992 Agenda 21. United Nations, Rio de Janerio
Vince J, Smith ADM, Sainsbury K, Cresswell I, Smith DC, Haward M (2015) Australia's oceans policy: past; present and future. Marine Policy 57(1):1–8

Chapter 50
Marine Scientific Research

Anna-Maria Hubert

Abstract Though not necessarily the case, there is increasing recognition that some marine scientific research activities may have adverse effects on the environment. This chapter examines recent developments in regulatory and management measures aimed at the environmentally sustainable conduct of marine scientific research. It begins by laying out the central management challenge of this emerging issue, which entails striking an appropriate balance between the promotion of marine scientific research to advance understanding of the marine environment and minimising environmental impacts of research in light of uncertainties. The next section provides an overview of the legal framework laid down in Parts XIII and XII of the 1982 United Nations Convention on the Law of the Sea (UNCLOS), which govern marine scientific research and protection and preservation of the marine environment respectively. It then describes progressive developments in law and policy, outlining sources of emerging norms and standards and analysing the content and scope of principles and best practices that are taking hold in this area. Finally, it analyses the effectiveness of current measures and points out some next steps for developments in this field.

Keywords Marine scientific research • Law of the sea • Marine environmental protection • Marine regulation • Marine management • Precautionary principle

A.-M. Hubert
Faculty of Law, University of Calgary, Calgary, Canada

Faculty of Law, University of Bremen, Bremen, Germany

Institute for Science, Innovation and Society (InSIS), University of Oxford, Oxford, UK
e-mail: annamaria.hubert@ucalgary.ca

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_50

50.1 Challenges on the Road to Environmentally Sustainable Marine Scientific Research

The central management challenge in ensuring environmentally sustainable research practices involves striking an appropriate balance between the promotion of marine scientific research and the adoption of necessary restrictions on research activities that have the potential to cause environmental harm. This challenge is compounded by the fact that this balancing must often be carried out under conditions of scientific uncertainty about the impacts of research activities on marine ecosystems, habitats and species.

As a general proposition, marine scientific research should be encouraged in order enhance understanding of the marine environment. This notion is backed-up by the legal framework in the 1982 United Nations Convention on the Law of the Sea (UNCLOS), according to which marine scientific research should be promoted generally, and to advance evidence-based governance in particular sectors, such as fisheries and seabed mining. Against this backdrop, regulatory and management measures directed at the environmentally sustainable conduct of marine scientific research should reflect legal obligations to promote research and be based on the best available scientific information.

On the other hand, there is increasing recognition that some marine scientific research activities may also have adverse effects on the environment. In general, the potential for research to cause damage is low relative to other common uses of the oceans (Benn et al. 2010). Where there are plausible concerns, however, marine regulation and management schemes should factor in potential impacts from the conduct of marine scientific research, and institute measures to ensure that research activities are conducted in an environmentally responsible manner.

Science-specific impacts on the marine environment can be categorized as physical, acoustical, chemical, or accidental in nature (Breslin et al. 2007). Physical effects may arise from sampling and the use of drilling technologies, explosives, and other specialized scientific equipment (e.g., piloted or remotely operated vehicles). Such disturbances can harm marine habitats or species, and damage structural features of marine ecosystems (Leary 2006: 189; Gjerde 2008: 35). Other physical impacts include harm to marine species caused by exposure to heat and light from scientific instruments (UNGA 2005, paras. 174–75). Acoustical impacts include potential harm to marine life from the introduction of sound for underwater imaging purposes (Dotinga and Elferink 2000; Markus and Silva-Sanchez, Ch. 7.12). Chemical impacts may result from the use of chemical tracers and disposable devices containing hazardous materials (Breslin et al. 2007). Finally, accidental impacts from marine research operations include biological contamination (e.g., introduction of alien species or pathogens that alter local community structure and potentially cause extinctions of native species) (Leary 2006: 189; Gjerde 2008: 35; UNGA 2005, para. 174).

Another way to distinguish the environmental impacts of marine research activities is in terms of research design. This encompasses, for example, the experimental manipulation of marine systems and processes to advance basic understanding of such phenomena or for applied purposes (Verlaan 2007). Perturbation experiments are controversial, and raise concerns about the risks and uncertainties of intentionally 'meddling with nature' (Smetacek and Naqvi 2008: 3947). For example, ocean fertilization experiments directly alter marine ecosystems by introducing nutrients such as iron, phosphorous, and nitrogen to artificially stimulate phytoplankton blooms that are expected to eventually sink, locking fixed atmospheric carbon dioxide in the deep sea for long-time scales (Buesseler and Boyd 2003). Although these studies may yield important new insights into the structure and functioning of marine ecosystems and potentially offer a method for offsetting rising global carbon dioxide emissions, there are widespread concerns about side effects (Buesseler et al. 2008).

This chapter considers the specific regulatory and management challenges in achieving an appropriate balance between promoting research and minimising its environmental impact. It begins with an overview of the international legal framework established in UNCLOS. It then goes on to describe the elaboration of this legal framework through the development of best practices at various levels. Finally, it provides a brief assessment of management results to date and outlines policy recommendations for how the existing approach could be improved upon.

50.2 International Legal Framework in the UNCLOS

The preamble of UNCLOS declares the intention to establish a legal order for the seas and oceans to promote 'the study, protection and preservation of the marine environment'. With these objectives in mind, UNCLOS as the *de facto* 'constitution of the oceans' provides the starting point for analysing progressive developments in law and policy relating to the environmentally responsible conduct of marine scientific research. When considering the environmental implications of research activities, the regime for the conduct of marine scientific research in Part XIII of UNCLOS must be read in the context of the Convention as a whole, and specifically Part XII for the protection and preservation of the marine environment. This section outlines the relevant provisions in these two parts in order to clarify the applicable legal framework that applies at the international level.

50.2.1 Regime for Marine Scientific Research in Part XIII of UNCLOS

The core provisions of the international legal framework for the conduct of marine scientific research are found in Part XIII of UNCLOS. It addresses general principles, international cooperation and the promotion of marine scientific research, specific rules on the conduct of research activities in different maritime zones, the use of scientific research installations and equipment, and responsibility and liability.

Part XIII begins by establishing the right of all States and competent international organisations to conduct marine scientific research (Art. 238 UNCLOS). This right is paired with a positive obligation to promote and facilitate the development and conduct of marine scientific research (Art. 239 UNCLOS), and other obligations relating to international cooperation on research. In particular, States and international organisations are to promote international cooperation in marine scientific research for peaceful purposes generally (Art. 242 UNCLOS), and specifically by concluding agreements to create favourable conditions for the conduct of marine scientific research and to integrate the efforts of scientists in studying the essence of marine phenomena and processes (Art. 243 UNCLOS), as well as through the publication and dissemination of information and knowledge (Art 244 UNCLOS).

General principles for the conduct of marine scientific research include that research be conducted for peaceful purposes and that it not unjustifiably interfere with other legitimate uses of the oceans (Art. 240 UNCLOS). The principle in Article 240(d) is particularly germane to the issue of the sustainable conduct of marine scientific research. It requires that research be conducted in compliance with all relevant regulations for the protection and preservation of the marine environment. This principle employs mandatory language, and its scope is not limited to the provisions of Part XII of UNCLOS. Rather, it extends to all environmental protection regulations 'adopted in conformity with the Convention', including those adopted in other regional and international treaties and domestic legislation. The principle in paragraph (b) further requires that marine scientific research be conducted with appropriate scientific methods and means compatible with UNCLOS. The term 'appropriate' is undefined in UNCLOS, but according to its ordinary meaning captures those methods or means that are suitable or proper in the circumstances. This language also invites an evolutionary interpretation that takes into account advances in best practices and standards for research to ensure that it is conducted sustainably.

Marine scientific research is also governed spatially according to the zonal-approach adopted in UNCLOS. Generally speaking, coastal State control over marine scientific research diminishes moving seaward from the baseline. Conversely, researching States have the greatest freedom on the high seas.

Nearest to the baseline, the coastal State by virtue of its sovereignty has the exclusive right to regulate, authorise and conduct marine scientific research in the territorial sea (Art. 245 UNCLOS). As a consequence, a researching State requires the express consent of the coastal State to conduct marine scientific research in territorial waters, and must comply with any conditions imposed, including any conditions imposed on the grounds of environmental protection (Art. 245 UNCLOS).

Beyond the territorial sea lies the exclusive economic zone (EEZ) in which the coastal State enjoys sovereign rights over the living and non-living natural resources, and jurisdiction over installations and structures, marine scientific research, and protection of the marine environment (Art. 56 UNCLOS). Part XIII establishes a detailed consent regime for marine scientific research that takes place in the water column or on continental shelf within the 200 nautical mile limit. The basis of this regime is the right of coastal States, in the exercise of their jurisdiction, to regulate, authorise and conduct marine scientific research in these areas (Art. 246(1) UNCLOS). Foreign researching States must have the consent of the coastal State to conduct marine research in the EEZ (Art. 246(2) UNCLOS).

However, the Convention incorporates a presumption that 'in normal circumstances' coastal States must grant their consent for projects carried out 'in accordance with the Convention exclusively for peaceful purposes and in order to increase scientific knowledge of the marine environment for the benefit of mankind' (Art. 246(3) UNCLOS). The coastal State only enjoys a discretionary power to refuse its consent to research projects that touch on certain recognized state interests enumerated in Article 246(5) of UNCLOS. Subparagraph 5(b) provides 'the most explicit legal basis' for a refusal of consent if a research project involves drilling into the continental shelf, the use of explosives or the introduction of harmful substances into the marine environment (Ribeiro 2010: 204). However, list does not capture all environmental risks associated with the conduct of marine research, such as sound and light emissions. Beyond the four exceptions set out in Article 246(5), the DOALOS Revised Guide on the marine scientific research regime refers to other 'exceptional situations' in which the coastal State may refuse its consent to a research project in its EEZ or on it continental shelf (DOLAS 2010: 42). This refers to circumstances in which it is clear – based on the information required by Article 248 – that a research project is not carried out in accordance with the Convention. Article 248 relates to the duty of the researching State to provide information to the coastal State including the nature and objectives of the project, methods and means used, and precise location of the proposed project. This information is useful for determining whether and the extent to which a proposed research activity will have adverse effects on the marine environment in advance of it being carried out.

UNCLOS also seeks to safeguard access to the EEZ and continental shelf for scientists by ensuring consistency, transparency and predictability in the consent process. Coastal states are required to establish rules and procedures for ensuring that consent will be granted within a reasonable time (Art. 246(3) UNCLOS). Consent is implied if the coastal state does not respond after four months of notification of the proposed project (Art. 252 UNCLOS).

Marine scientific research conducted on the high seas is governed by the principle of the freedom of scientific research in accordance with the freedom regime that governs the ocean commons (Art. 87 UNCLOS). All States and competent international organisations have the right to right, in conformity with the UNCLOS, to conduct marine scientific research in the water column beyond the limits of the EEZ (Art. 257 UNCLOS). This qualification that marine research be conducted 'in conformity with the Convention' incorporates the obligations laid down in Part XII for the protection and preservation of the marine environment (Nordquist et al. 1991, para. 257.6(a)).

The right to conduct marine scientific research also extends to research conducted in the Area (Art. 256 UNCLOS), defined as the seabed and ocean floor and subsoil, beyond the limits of national jurisdiction (Art 1(1) UNCLOS). This right is to be exercised in conformity with Part XI to the extent that those provisions are applicable. Article 143 in Part XI lays down specific requirements that reflect the general principles of the regime for the Area as the common heritage of mankind. The International Seabed Authority (ISA) has the competence *inter alia* to carry out research, promote and encourage the conduct of marine scientific research in the Area, and coordinate and disseminate the results of such research and analysis when available (Art 143(2) UNCLOS).

50.2.2 Regime for the Protection and Preservation of the Marine Environment in Part XII of UNCLOS

Part XII of UNCLOS is dedicated to environmental protection. Article 192 declares the general duty of all States to protect and preserve the marine environment. In the recent *South China Sea* award on the merits, the arbitral tribunal confirmed that although this obligation is phrased in general terms, it nonetheless imposes a binding legal obligation upon States. The legal nature of this obligation is one of due diligence (South China Sea Award, PCA 2016, para. 941). The tribunal further pointed out that '[t]he content of the general obligation in Article 192 is further detailed in the subsequent provisions of Part XII, including Article 194, as well as by reference to specific obligations set out in other international agreements, as envisaged in Article 237 of the Convention' (South China Sea Award, PCA 2016, para. 942).

Owing to the time of its adoption, however, the language of Part XII focuses on the prevention, reduction and control of marine pollution. According to Article 194(1), States must take 'all measures consistent with [the] Convention that are necessary to prevent, reduce and control pollution of the marine environment from any source, using for this purpose the best practicable means at their disposal and in accordance with their capabilities, and they shall endeavour to harmonize their policies in this connection'. Marine pollution is defined as the introduction by man, directly or indirectly, of substances or energy into the marine environment which results or is likely to result in harm to the marine environment (Art. 1(1, 4) UNCLOS). This definition incorporates an 'evolutionary phraseology' which extends the term to new concerns that were not contemplated at the time of the adoption of the Convention (Boyle 2005: 569). As such, it may cover some marine research methods, such as those involving the use of harmful chemical or radioactive tracers, or the use of equipment or autonomous or manned vehicles that introduce light or sound into the marine environment to the extent that these are likely to cause harm to the marine environment (ISOM 2007).

Article 194 imposes a due diligence obligation of conduct to prevent marine pollution regardless of source. States are not strictly liable for harms inflicted, but rather are only required to take all appropriate measures to prevent damage which results or is likely to result from the conduct of marine scientific research (Seabed Mining Advisory Opinion, ITLOS Seabed Disputes Chamber 2011, paras. 110, 131). In terms of its content, due diligence is a 'variable' standard of conduct that evades precise definition. In determining the degree of care required, several factors are typically considered, such as 'the size of the operation; its location, special climate conditions, materials used in the activity, and whether the conclusions drawn from the application of these factors in a specific case are reasonable' (ILC Draft Articles of Prevention 2001: 154) In short, due diligence is a flexible, fact-sensitive norm that can be usefully applied in the context of many different circumstances. The content of due diligence is also defined with reference to other provisions of UNCLOS, and by other legal developments in the international sphere. In the case of marine scientific research, it is likely to encompass duties to apply the precautionary approach and use best environmental practices (Seabed Mining Advisory Opinion, ITLOS Seabed Disputes Chamber 2011, para. 122), as well as to carry out environmental assessment and monitoring (Arts. 206 and 204 UNCLOS).

In defining the relevant standard, the Chamber pointed out that a higher level of vigilant care is mandated for riskier activities (Seabed Mining Advisory Opinion, ITLOS Seabed Disputes Chamber 2011, para. 117). In applying this proportionality test to conduct of marine scientific research, it is likely that standard of due diligence would be lower for research activities, which are generally considered to have a lower impact on the marine environment in relation to full-scale ocean uses.

The Seabed Disputes Chamber also noted that the required level of diligence may also 'change over time as measures considered sufficiently diligent at a certain moment may become not diligent enough in light, for instance, of new scientific or technical knowledge' (Seabed Mining Advisory Opinion, ITLOS Seabed Disputes Chamber 2011, paras. 111–7). The application of an evolving standard of care means that although evidence concerning the potential risks of a more novel research activity may initially be limited, as scientific knowledge about the negative impacts of the activity accumulates, more vigorous efforts would be required of a State to satisfy its standard of care.

The duty in UNCLOS to take appropriate measures to prevent or minimize marine pollution is addressed solely at States. However, marine research activities are frequently carried out by private actors, such as scientific institutions and individual scientists. Due diligence also encompasses the responsibility of States over private individuals or entities in regulating and monitoring activities under their jurisdiction or control to prevent or minimise damage by marine pollution (South China Sea Award, PCA 2016, para. 944).

Other provisions are also relevant to marine research activities, including the:

- Duty to take necessary measures to protect and preserve rare or fragile ecosystems as well as the habitat of depleted, threatened or endangered species and other forms of marine life (Art. 194(5) UNCLOS).
- Duty not to transfer damage or hazards or transform one type of pollution into another (Art. 195 UNCLOS).
- Duty to take all measures necessary to prevent, reduce and control pollution of the marine environment resulting from the use of technologies or the intentional or accidental introduction of new or alien species (Art. 196 UNCLOS).
- Duty to monitor the risks or effects of pollution (Art. 204 UNCLOS).
- Duty to assess the potential effects of activities (Art. 206 UNCLOS).
- Duties relating to responsibility and liability for environmental damage (Art. 235 UNCLOS).

Part XII of UNCLOS does not just address the risks of marine scientific research, but also recognizes that measures for the protection of the marine environment must be evidence-based and informed by state of the art science. States are obligated to cooperate to promote studies, undertake research programmes and encourage the exchange of information and data acquired about pollution of the marine environment (Art. 200 UNCLOS). The information generated from this process is to be used to support the establishment of international rules, standards and recommended practices and procedures for addressing marine pollution (Art. 201 UNCLOS). As noted above, scientific knowledge also informs the scope and content of the obligations of States' due diligence obligations to prevent or minimize marine pollution.

50.2.3 Relationship Between Parts XIII and XII of the UNCLOS

UNCLOS provides a constitutional framework to guide legal and policy developments related to marine research activities with potential impacts on the marine environment. Parts XIII and XII of the Convention establish a general system of governance, laying down principles and rules relating to the promotion of marine scientific research and the prevention of environmental harm. However, they do not provide detailed measures to regulate conduct. Specific guidance is being developed in other contexts to fill the gaps in the existing regime. Over time, the norm-building processes at various levels and synergies between them may contribute to the progressive development of the international law of the sea. The next section of this chapter describes recent developments in the creation of norms and standards for the sustainable management of marine scientific research.

50.3 Sources of Norms and Standards for the Sustainable Regulation and Management of Marine Scientific Research

The past decade has seen a wave of instruments and measures directed at the environmentally sustainable conduct of marine scientific research. Legal and policy developments in this area are occurring at all levels and are being promulgated by both State and private actors. Instruments aimed at the sustainable conduct of marine scientific research may address governments or address scientists directly.[1] The regulatory scope of these instruments and measures may cover marine scientific research generally, or govern research conducted at specific sites (e.g., marine protected areas), research carried out in particular sectors (e.g., deep seabed mining), or target research of a particular kind (e.g., deep sea research). Some of these instruments are legally binding in nature, though the vast majority are not. Despite their

[1] The latter distinguishes them from international treaties, including UNCLOS, which generally regulate the conduct of States Parties who then are responsible for the actions of private actors under their jurisdiction and control.

'soft' legal character, however, these may be normative in their effects and serve as 'harbingers of legal progression' by reinforcing, interpreting and amplifying the relevant provision of UNCLOS (see Friedrich 2010, para. 1). As demonstrated below, for example, codes of conduct can gain legal force through implementation into national or supranational law (Friedrich 2010, para. 26).

50.3.1 Norms and Standards Developed by Private Actors

Most of the early legal and policy developments in this area can be traced to private codes of conduct created by scientists and research institutions themselves. As such, they can be loosely categorised as a form of self-regulation. These instruments include the 2006 InterRidge Statement of Commitment to Responsible Research Practices at Deep-Sea Hydrothermal Vents (InterRidge 2006) and the 2007 Code of Conduct for Marine Scientific Research Vessels developed by the International Research Ship Operators' Meeting (ISOM 2007).

50.3.2 Regional Regulatory and Management Measures

Norms and standards for the promotion of environmentally sustainable research practices are also being developed at the regional level. These instruments take the form of public codes of conduct developed to provide guidance to States Parties. One example is the 2008 OSPAR Code of Conduct for Responsible Marine Research in the Deep Seas and High Seas of the OSPAR Maritime Area, which was developed within the work programme of the OSPAR Biodiversity Committee by an intercessional correspondence group on marine protected areas working in consultation with deep-sea scientists and experts (OSPAR Commission 2008). The Organisation of the Eastern Caribbean States (OECS) has also developed a comprehensive draft Code of Conduct for Responsible Marine Research, which is addressed at both marine scientists wishing to engage in research activities and national authorities of OECS Member States concerned with the granting of permission to conduct marine research activities.

50.3.3 Domestic Regulatory and Management Measures

Domestic regulations and management measures constitute a third source of emerging norms and standards aimed at the responsible conduct of marine scientific research. The geographical scope of such measures is frequently limited to specific areas within national jurisdiction – in particular, those taken in accordance with area-based management measures adopted pursuant to international commitments.

A prime example of legal developments in this area is the Endeavour Hydrothermal Vents (EHVs) marine protected area (MPA). The MPA was created to protect a seismically active seafloor spreading zone with deep ocean hydrothermal vent fields within Canada's EEZ, which has been a site of significant scientific interest since its discovery over 20 years ago. After consultations with members of the scientific community, other stakeholders and government agencies, in 2003 the Canadian government adopted the Endeavour Hydrothermal Vents Marine Protected Area Regulations under the Oceans Act (EVH MPA Regulations, SOR/2003–87), together with a management plan to provide guidance to government agencies, marine users and the public for achieving conservation objectives. The regulations prohibit carrying out any activity that disturbs, damages, destroys or removes any living marine organism or any part of its habitat or is likely to do so (EVH MPA Regulations, s. 2). However, they carve out an exception for 'scientific research for the conservation, protection and understanding of the Area', provided that the project proponents submit a research plan to the Department of Fisheries and Oceans at least 90 days before the start of the research cruise (EVH MPA Regulations, s. 3).

The five-year EHV MPA Management Plan defines specific management objectives and formulates measures for achieving these objectives. The primary conservation objective is to '[e]nsure that human activities contribute to the conservation, protection and understanding of the natural diversity, productivity and dynamism of the ecosystem and are managed appropriately such that the impacts remain less significant than natural perturbations (e.g. magmatic, volcanic or seismic)' (EHV MPA Management Plan 2009: 9). This objective implicitly recognizes the importance of research to achieving conservation aims. On the other hand, management measures aim at coordinating research activities to ensure responsible practices are followed and harm kept to a minimum (EHV MPA Management Plan 2009: 9–10). The EHV MPA is managed in line with modern conservation principles such as the ecosystem and precautionary approaches and adaptive management (EHV MPA Management Plan 2009: 10). Management measures govern access to the site by foreign and domestic vessels. They also aim at monitoring research with the goal of promoting understanding of the area and ensuring that it is carried out in line with MPA objectives and follows best practices (EHV MPA Management Plan 2009: 10–21).

The EHV MPA management plan identifies several stressors to hydrothermal vent ecosystems from scientific activities. These include the introduction of light, noise or materials (debris, moorings, permanent structures, ballast weights etc.) as well as other disturbances to habitats and organisms. Impacts from research may be cumulative over time (EHV MPA Management Plan 2009: 37). On the other hand, the management plan acknowledges the large uncertainties surrounding the impacts of research on these sites, and calls for more work to be done to establish baselines for measuring impacts. Mitigation measures are to be implemented provisionally to ensure that ecosystem disturbances are minimized also taking a precautionary approach. Measures are to be informed by the InterRidge Statement of Commitment to Responsible Research Practices at Deep-Sea Hydrothermal Vents, which is explicitly endorsed in the EHV MPA management plan (EHV MPA Management Plan 2009: 18).

Though not as comprehensive as the Canadian scheme, in 2006 the Irish Department of the Environment, Heritage and Local Government set up permitting and management measures for marine scientific research conducted at four sites containing coldwater coral reefs set under the European Union Habitats Directive (Council Directive 92/43/EEC 1992). Irish authorities deemed marine scientific research to be an operation or activity that would be likely to alter, damage, destroy or interfere with the integrity of the cold water coral located within these sites pursuant to the Habits Directive. In response, the government imposed a permitting requirement for all marine research activities conducted at these sites for domestic vessels as well as foreign vessels in accordance with Parts XII and XIII of UNCLOS.

It also developed a Code of Practice for Marine Scientific Research at Irish Coral Reef Special Areas of Conversation in consultation with members of the scientific community. The Irish Code provides guidance on the use of equipment and sampling procedures, including the use of remotely operated vehicles (ROVs), benthic sampling, moorings deployment, fisheries gears, seismic survey and near-bottom towing. Such activities are not generally prohibited, but scientists are required to minimise harm to coral reefs. The Code also imposes specific requirements related to reporting. These generally accord with the duty of a foreign researching State to comply with certain conditions in Article 249 of UNCLOS, including that the coastal State is, at its request, granted full access to, and copies of, data collected as well as assessments of such data. In some cases, however, these may extend beyond what is required in that article, for example, by stipulating that research publications acknowledge the cooperation of the Irish Government in providing access to the sites (Irish Code of Practice 2006, para. 30). Irish authorities regard reporting and publication as important to increasing the value of research cruises at these sites and necessary to avoid any redundancy in research effort since this contributes to environmental damage.

50.3.4 International Regulatory and Management Measures

Legally-binding regulation at the international level is a fourth source of norms and standards relating to sustainable marine scientific research. Examples of top-down, command-and-control approaches for governing marine scientific research are uncommon, but do exist. An example is the recent amendment to the 1996 Protocol (London Protocol) to the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention) on marine geoengineering. The amendment incorporates several innovative design features in developing a new instrument for regulating marine scientific research. It balances the need for coercive, hard-law regulation to achieve greater legal certainty against the need for a flexible approach given the rudimentary understanding of geoengineering at this time.

The text of the amendment adopts a broad definition of 'marine geoengineering' which establishes the general subject matter to be regulated (London Protocol Resolution LP.4(8), Art. 5*bis*). This definition is coupled with a 'positive-listing approach' which narrows the scope of the regulation. Under this approach, provided that an activity falls within the definition of 'marine geoengineering', the only activities subject to binding regulation are those that the Contracting Parties have agreed to include in a new annex London Protocol Resolution LP.4(8), Art. 6*bis*. Since it is easier procedurally to amend an annex than it is to change the text of the treaty itself, this provides a mechanism for 'future proofing' the London Protocol, allowing the Contracting Parties to respond quickly to marine geoengineering activities that may have deleterious effects on the marine environment while clearly establishing the rights and obligations under the regulation. The marine geoengineering regulation also creates a new assessment framework for the assessment activities listed for regulation and to provide a basis for developing specific assessment frameworks (London Protocol Resolution LP.4(8), Annex 5).

Currently, the only marine geoengineering activity that has been listed for regulation is ocean fertilization. The amendment incorporates previous legally non-binding resolutions all ocean fertilization activities, which in substance prohibited all ocean fertilization activities except for those that constitute legitimate scientific research. In particular, it integrates a 2010 resolution which established an assessment framework for determining whether research is 'legitimate' or not. Under this framework, a proposed ocean fertilization project must have 'proper scientific attributes' and undergo a full environmental risk assessment (Resolution LC-LP.2 (2010)). Though not yet in force, 2013 amendment on marine geoengineering transforms non-binding decisions them into legally binding international law offering greater legal certainty and the possiblity of enforcement.

The amendment to the London Protocol arguably provides a science-based, global, transparent and effective regulatory and control mechanism for marine geoengineering in a flexible and adaptive form. It provides a balanced framework that allows research into marine geoengineering to continue, while also providing for governance in light of the risks and uncertainties associated with research and development of geoengineering techniques. As strongly precautionary and adaptive instrument, international regulation emphasizes environmental assessment, post-project monitoring and reporting.

50.4 Emerging Principles and Best Practices for The Environmentally Sustainable Management of Marine Scientific Research

There is significant overlap and convergence in the content of the different regulatory and management measures for the promotion of environmentally responsible marine scientific research. This can be attributed to the fact that subsequent instruments tend to borrow from previous sources in the norm-building process.

For example, the OSPAR Code of Conduct draws upon several previous sources including the InterRidge Statement and elements of the ISOM Code of Conduct for Marine Scientific Research Vessels. As a result, it is relatively straightforward to identify common best practices for sustainable marine scientific research.

50.4.1 Objectives and General Principles

Management measures aimed at promoting sustainable marine scientific research balance three main objectives: (1) the prevention or minimisation of environmental harm from the conduct of marine scientific research; (2) the promotion marine scientific research to contribute to environmental protection and understanding; and (3) application of the precautionary approach in light of the scientific uncertainties associated with this emerging concern.

Though not always explicitly mentioned, it is clear that the precautionary approach drives the development of regulatory and management measures for the responsible conduct of marine scientific research. In its conservative Rio formulation, the precautionary approach requires that where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing measures (Rio Declaration, Principle 15). Its relevance as a guiding principle for ocean science is clear, since in many cases environmental risks from research activities may be identified, but not necessarily quantified and proven scientifically (Freestone 2014: 311–12). In some cases, codes of conduct and national management plans explicitly note the provisional nature of precautionary measures recognizing that they should be reviewed in light of new scientific information, but maintained as long as scientific knowledge is insufficient and risk of harm too great (EHV MPA Management Plan 2009: 10). This proceduralisation of precaution builds in an adaptive, learning component, in which precautionary measures directed at sustainable marine scientific research should be reviewed on a regular basis in accordance with the best available knowledge.

50.4.2 Planning Marine Scientific Research

Notification and pre-cruise planning are important aspects of sustainable research practices. Those wishing to conduct marine scientific research are encouraged to follow the following requirements and best practices:

- Obtain all necessary research permissions in areas of national jurisdiction (OCES Code of Conduct, para. 2.5; Irish Code of Practice 2006, paras. 1–5).
- Communicate research plans to avoid duplication of research effort as far as possible and disturbing the experiments and observations of other researchers

(OCES Code of Conduct, para. 2.2; OSPAR Code of Conduct 2008, para. 17; Irish Code of Practice 2006: 7).[2]

- Develop a marine research plan (OCES Code of Conduct, para. 2.3; OSPAR Code of Conduct 2008, para. 17).
- Carry out an appropriate level of risk assessment (OCES Code of Conduct, para. 2.4; London Protocol Resolution LP.4(8), Annex 5).

50.4.3 Conduct of Marine Scientific Research

Instruments typically adopt a due diligence requirement to avoid or minimise harm to marine species and habitats in the conduct of marine scientific research (OCES Code of Conduct, para. 3; OSPAR Code of Conduct 2008, para. 12–13; Resolution LC-LP.2(2010), para. 4.1). The OSPAR Code adopts a higher standard of care in areas of particular ecological vulnerability, where 'utmost care' should be taken not to disturb or damage the features 'as far as possible' OSPAR Code of Conduct 2008, para. 14). This approach is in line with the duty to protect and preserve rare or fragile ecosystems in Article 194(5) of UNCLOS.

Flowing from this general due diligence obligation to prevent or minimize environmental damage is the commitment to use best practices in conduct of marine scientific research. The OSPAR Code advises that scientists 'use the most environmentally-friendly and appropriate study methods which are reasonably available' (OSPAR Code of Conduct 2008, para. 14; see also OCES Code of Conduct, para. 3; InterRidge 2006) Some codes of conduct formulate specific technical measures designed to minimize the harm associated with certain marine research activities. For instance, the Irish Code of Practice sets out specific guidance on the use of ROVs, as well as procedures for benthic sampling, moorings deployment, the use of fishing gears, seismic survey, and near-bottom trawling. The OSPAR Code also mentions the use of tracers and other expendable devices. Overall, these measures amplify obligations in UNCLOS to use 'best practicable means', 'appropriate scientific methods and means' etc. in the context of marine scientific research.

50.4.4 Marine Research Data and Knowledge

Management measures not only seek to minimize environmental harm, but also to maximise the value of the science and avoid redundancies in research effort. There is strong emphasis on enhancing cooperation through information, data and sample sharing, and publication and dissemination of information. The

[2] For example, InterRidge has established a voluntary research cruise database which provides a resource for coordinating ocean-ridge research, see https://www.interridge.org/IRcruise

EHV MPA management plan emphasizes the by timely follow-up on cruise reporting, data- and sample-sharing, and enhanced coordination between projects through a geo-referenced database and web mapping system to avoid duplicated research effort (DFO at 11). Similar requirements are imposed in the Irish MPA. These national measures are examples of how coastal states are reinterpreting the conditions imposed on a researching State under Article 249 of UNCLOS to serve environmental ends. These include obtaining results arising from research activities, enforcing post-cruise reporting requirements, and sample and data-sharing.

50.4.5 Capacity Building and Transfer of Technology

An important new element in the draft OECS Code of Conduct is the emphasis on best practices related to capacity-building and the transfer of marine technology. It includes the general principle that 'marine research projects should be designed with a view to building independent marine research capacity in OECS Member States and to facilitating the transfer of marine technology. To the extent possible, marine research projects shall take account of the IOC Criteria and Guidelines on the Transfer of Marine Technology (CGTMT)' (OECS Code of Conduct, para 5.1). This provision is an extension of the general requirements in UNCLOS relating to capacity-building with respect to research activities and technology transfer.

50.5 Management Results and Next Steps

Effectiveness is measured across several dimensions, including the stringency of commitments, levels of participation and implementation, and compliance (Bodansky 2012: 2). Relatively little work has been done to empirically assess the results of regulatory and management measures aimed at the environmentally responsible conduct of marine scientific research. Most of these schemes are relatively new so information may still be forthcoming. The Canadian EHV MPA Management Plan, for example, is up for review this year.

InterRidge in collaboration with social scientists from Duke University conducted a voluntary survey of awareness and perceptions of the InterRidge Statement of Commitment to Responsible Research Practices at Deep-Sea Hydrothermal Vents. The vast majority of survey respondents thought the code was useful, and believed that they followed its principles. However, they were unsure about whether other vent researchers abided by it. A key conclusion from this study is that '[i]t is difficult to measure the extent to which scientists comply with the [InterRidge Code], and, in the end, sustainable use of hydrothermal vents by scientists relies on voluntary behaviour and respect for the ideals behind [the Code]. The [InterRidge

Code] is a useful reminder for scientists, but is probably not sufficient to ensure sustainable scientific activity' (Godet et al. 2011). The authors of this study pointed out that a better option was to manage scientific activities at vulnerable sites as conservation areas (Godet et al. 2011: 211).

The Canadian and Irish examples demonstrate that it is possible to implement this recommendation in national waters, where the coastal State has jurisdiction to enforce domestic regulations and measures relating to marine scientific research and the protection of the marine environment. However, in marine areas beyond national jurisdiction (ABNJ) the challenge is much greater, and would require extensive flag state cooperation. Discussions are currently underway under the auspices of the United Nations General Assembly to develop a new legally-binding instrument for the conservation and sustainable use of marine biodiversity in ABNJ (UNGA A/RES/69/292 2015). The 'package deal' of elements to be included in a new agreement provides for area-based management tools, including marine protected areas. This would help to address gaps in the current legal framework in support of measures aimed at the sustainable research practices at intensively researched sites. Negotiations will also address environmental impact assessments (EIAs). EIA requirements could include that marine scientific research activities which transgress a particular risk threshold are subject to a compulsory assessment. However, based on current discussions at the UN, it is unlikely that States will create a general framework to specifically regulate marine scientific research in ABNJ. This is arguably not necessary nor advisable given that overly broad or stringent regulation could adversely impact knowledge-gathering efforts at a time when the global oceans are undergoing remarkable changes caused by human activities.

To ensure compliance with its code of conduct, the OSPAR Code recommends that when assessing research plans, States Parties are encouraged to ensure that the granting of research permission, research funds, and ship time should be contingent on the application of the code of conduct (OSPAR Code of Conduct 2008, para. 10). The EU-funded Eurofleets project, for example, which aims to coordinate Europe's marine research infrastructure, has implemented this recommendation by requiring that principal investigators make a declaration when applying for ship-time. Researchers must agree to observe and carry out any scientific investigation in accordance with the general principles of the OSPAR Code 'regardless of the area of operation' (Eurofleets 2010).

Scientists are key stakeholders in this process. They inevitably need to play a large role in the ongoing development of regulatory and management measures directed at the sustainable conduct of marine scientific research. It is paramount that any future work in this area should be taken in close consultation with the scientific community in order to achieve an appropriate balance between minimising the environmental impact of research activities and promoting the acquisition of new knowledge about the oceans. There are several reasons that support this policy recommendation. On the risk prevention side, scientists regularly provide advice on the conservation of marine ecosystems, and have the expertise to define best practices and technical guidance on research methods. Scientists themselves are the main users of scientifically important marine sites, and thus in their best interest to promote sustainable research practices in these locations. The research community will also be most affected by the regulation and governance of marine scientific research, and thus should be consulted on design choices so that measures do not have an unreasonable impact on scientific work.

Overall, significant progress is being made with regard to the development of best practices for the sustainable conduct of marine scientific research. Instruments and measures build on the existing legal framework laid down in UNCLOS, and attempt to find an appropriate balance between the potential benefits, risks and uncertainties surrounding the conduct of marine scientific research. In some cases, some level of environmental damage from the conduct of research may be justified in order to obtain new information. This determination depends upon the specific circumstances, and should subject to principles of reasonability and proportionality.

References

Benn, A.R., Weaver, P. P., Billet, D. S. M., van den Hove, S., Murdock, A. P., Doneghan, G. B., Le Bas, T. (2010). Human Activities on the Deep Seafloor in the North East Atlantic: An Assessment of Spatial Extent. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0012730#s1 .

Bodansky, D. (2012). The durban platform: issues and options for a 2015 Agreement. Center for climate and energy solutions. http://www.c2es.org/publications/durban-platform-issues-options-2015-agreement

Boyle A (2005) Further development of the law of the sea convention: mechanisms for change. Int Comp Law Q 54:563–584

Breslin, J., Nixon, D., and West, G. (2007). International Ship Operators Meeting (ISOM) Code of Conduct for Marine Scientific Research Vessels. http://www.irso.info/wp-content/uploads/International_RV_Code_final.pdf. Accessed 8 July 2016

Buesseler KO, Boyd PW (2003) Will ocean fertilization work? Science 300:67

Buesseler KO, Doney SC, Karl DM, Boyd PW, Caldeira K, Chai F, Coale KH, de Baar HJW, Falkowski PG, Johnson KS, Lampitt RS, Michaels AF, Naqvi SWA, Smetacek V, Takeda S, Watson AJ (2008) Ocean iron fertilization–moving forward in a sea of uncertainty. Science 319:162

Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 11 ILM 1358. n.d.

Department of Fisheries and Oceans Canada, Endeavour Hydrothermal Vents: Marine Protected Area Management Plan 2010–2015 (2009). Retrieved July 8, 2016. http://www.pac.dfo-mpo.gc.ca/oceans/protection/mpa-zpm/endeavour/docs/EHV-CHE-mgmtplan-gestion-eng.pdf

Division for Ocean Affairs and the Law of the Sea Office of Legal Affairs (2010). Law of the Sea: MSR: a revised guide to the implementation of the relevant provisions of the United Nations Convention on the Law of the Sea. New York, United Nations, 2010

Dotinga HM, Oude Elferink AG (2000) Acoustic pollution in the oceans: the search for legal standards. Ocean Dev Int Law 31:151–182

Endeavour Hydrothermal Vents Marine Protected Area Regulations, SOR/2003–87, March 4, 2003

European Union (1992). Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31992L0043. Accessed 8 July 2016

Freestone D (2014) Satya Nandan's contribution to the development of the precautionary approach in international law. In: Lodge MW, Nordquist MH (eds) Peaceful order in the World's Oceans: essays in honour of Satya N Nandan. Brill, Leiden

Friedrich, J. (2010). Codes of Conduct [Electronic Version]. Max Planck Encyclopedia of Public International Law
Gjerde, K.M. (2008). Options for addressing regulatory and governance gaps in the international regime for the conservation and sustainable use of marine biodiversity in areas beyond national jurisdiction. Gland: IUCN. https://cmsdata.iucn.org/downloads/iucn_marine_paper_2.pdf. Accessed 15 July 2016
Godet L, Zelnio KA, van Dover CL (2011) Scientists as Stakeholders in Conservation of Hydrothermal Vents. Conserv Biol 25:214–222
International Law Commission (ILC) (2001). Report of the Commission to the General Assembly on the work of its fifty-third session, Draft Articles on Prevention of Transboundary Harm from Hazardous Activities, with commentaries, UN Doc A/56/10
InterRidge (2006). InterRidge Statement of Commitment to Responsible Research Practices at Deep-Sea Hydrothermal Vents. https://www.interridge.org/IRStatement. Accessed 15 July 2016
Irish Department of the Environment, Heritage and Local Government (2006). Code of Practice of Marine Scientific Research at Irish Coral Reef Special Areas of Conservation. https://www.marine.ie/Home/sites/default/files/MIFiles/Docs/ResearchVessels/Code%20of%20Practice%20for%20Marine%20Scientific%20Research%20at%20SACs.pdf. Accessed 15 July 2016
ITLOS Reports (2011). Responsibilities and obligations of States with respect to activities in the Area (Request for Advisory Opinion submitted to the Seabed Disputes Chamber) (No. 17) (Advisory Opinion, 1 February 2011)
Leary DK (2006) International Law and the Genetic Resources of the Deep Sea. Martinus Nijhoff, Leiden
Nordquist MH, Nandan SN (1991) United Nations Convention on the Law of the Sea 1982, Volume VII: A Commentary. Martinus Nijhoff, Leiden
Organisation of the Eastern Caribbean States (OECS) (n.d.) 'OCES Code of Conduct for Responsible Marine Research'. http://intfish.info/wp-content/uploads/2015/04/Code-of-Conduct-for-Marine-Research.pdf. Accessed 8 July 2016
OSPAR Commission (2008). OSPAR Code of Conduct for Responsible Marine Research in the Deep Seas and High Seas of the OSPAR Maritime Area. OSPAR 08.24/1, Annex 6
Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 36 ILM 1 (1996)
Request for an advisory opinion submitted by the Sub-Regional Fisheries Commission (SRFC) (No. 21) (Advisory Opinion, 2 April 2015)
Resolution LC-LP.2 (2010). 'Assessment Framework for Scientific Research Involving Ocean Fertilization' (11–15 October 2010)
Resolution LP 4(8) on the amendment to the London Protocol to Regulate the Placement of Matter for Ocean Fertilisation and Other Marine Geoengineering Activities (18 October 2013) in 'Report of the Thirty-Fifth Consultative Meeting and the Eighth Meeting of the Contracting Parties' UN Doc LC 35/15 (21 2013)
Ribeiro MC (2010) The 'Rainbow': the first national marine protected area proposed under the high seas. International Journal of Marine and Coastal Law 25:183–207
Rio Declaration on the Environment and Development (Rio Declaration). UN Doc. A/CONF.151/26 (vol. I)/31 ILM 87 (1992)
Smetacek V, Naqvi SWA (2008) The Next Generation of Iron Fertilization Experiments in the Southern Ocean. Phil Trans R Soc A 366:3947
United Nations Convention on the Law of the Sea, 1833 UNTS 3 (1982)
United Nations General Assembly (2005). Report of the Secretary General, Oceans and the Law of the Sea, Addendum. UN Doc. A/60/63/Add.1
United Nations General Assembly (2015). Development of an international legally-binding instrument under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction. A/RES/69/292

Verlaan PA (2007) Experimental activities that intentionally perturb the marine environment: implications for the marine environmental protection and marine scientific research provisions of the 1982 united nations convention on the law of the sea. Mar Policy 31:210

Eurofleets. Ship-time Application Call 2010. http://www.eurofleets.eu/np4/%7B$clientServletPath%7D/?newsId=90&fileName=EUROFLEETS_Call_Ship_time_Application.pdf Accessed 8 July 2016

Chapter 51
An Emerging Environmental Issue: Marine Discharge of Mine Tailings

Craig Vogt and Jens Skei

Abstract Marine disposal of mine tailings is being viewed by a significant number of new and existing mines as a potential disposal technique, given the serious local technical, economic, social, and environmental concerns related to land disposal options. Mine tailings storage dams used by existing mines are filling up, and for some of these mines, other land-based sites are not available. Mining operations that currently use marine disposal of mine tailings discharge via a pipeline at final deposition depths of 30–1000 m. Disposal of mine tailings presents a unique issue in that both on-land disposal and marine disposal result in significant environmental risks and damage to habitats as well as fish and wildlife. This chapter provides information on the rationale for marine disposal of mine tailings, disposal techniques, potential environmental impacts, best management practices, and the issues associated with land versus sea disposal.

Keywords Mine tailings • Submarine tailings disposal • Submarine tailings placement • Marine discharge • Deep sea tailing placement • DSTP • STD • STP

51.1 Introduction

Marine disposal of mine tailings is used by 16 mines world-wide, and a significant number of new and existing mines are considering marine disposal as a potential alternative. Of the approximately operating 2500 industrial-sized mines worldwide, 99% dispose of their mine tailings on land, but these are not without environmental and public safety issues, such as the size of the footprint (i.e., area of disposed

C. Vogt (✉)
Craig Vogt Inc Ocean and Coastal Environmental Consulting, Hacksneck, VA, USA
e-mail: craig@craigvogt.com

J. Skei
Skei Mining Consultant, Løvenstad, Norway
e-mail: jens.skei@gmail.com

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_51

mine tailings on the seafloor), potential contamination to surface waters and groundwater, and safety and long term integrity of the engineered facilities. There have been 140 significant recorded failures of mine tailing storage dams, with a recent example being the *Germano Mine* in Brazil in 2015.

Marine disposal of mine tailings is disposal into marine waters via a pipeline at final deposition depths of 30–300 m in Norway and over 1000 m in Turkey, Indonesia, and Papua New Guinea. The intent is for the tailing plume to move intact to a deep-water basin below the productive euphotic zone. The potential effects of marine disposal are the complete loss of healthy habitat in the disposal site for in-situ benthic organisms and those in the ecosystem that depend on them as a food source. If the deposition site and the disposal infrastructure were not properly designated, currents may move the mine tailings out of their intended deposition zone.

Best management practices are used to minimize environmental impacts, and include engineering factors to ensure that mine tailings are discharged in a controlled manner and that tailings settle within a predicted area. Best management practices also include comprehensive assessments of the potential physical and biological impacts at the disposal site before and after disposal.

New and existing mines are considering marine disposal, because nearby land for mine tailing storage facilities is either not available, technically infeasible for use as disposal facilities, or its use is very contentious among stakeholders. Disposal of mine tailings presents a unique issue in that both on-land disposal and marine disposal result in significant environmental risks and damage to habitats as well as fish or wildlife, and in some cases, marine disposal may be the best choice between unpopular alternatives.

Initially, this chapter provides a discussion of mining, mine tailings disposal techniques, the rationale for marine disposal, and the potential environmental effects of marine discharge. This is followed by identification of best management practices, case studies, and the international regulatory regime. The final discussion addresses the challenges in assessing the impacts of land versus sea disposal and whether those impacts are acceptable.

51.2 Mining, Mine Tailings, and Environmental Effects

Mining is essential to living, as we know it. It is the process of extracting minerals from the earth's crust. For mining considered in this chapter, mining is land-based and is accomplished by either open-pit surface mines or underground mines. Whether surface mines or underground mines are used depends on a number of on-site factors; surface mines can extend to about 200 m depth at which point underground mines become the more efficient mechanism for removal of the ore. Fig. 51.1.

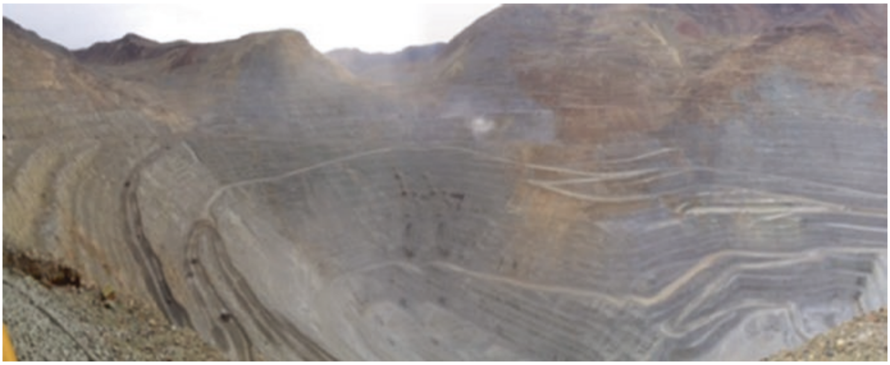


Fig. 51.1 Open pit copper mine in Chile. Credit: Craig Vogt

Why Mine Minerals?
Simply put, minerals are needed for living. For example:

- Mobile phones and computers have many metal components, including silver, gold, palladium, platinum, cadmium, lead, nickel, mercury, manganese, lithium, zinc, arsenic, antimony, beryllium, and copper.
- Gold is used in dentistry/medicine, in jewelry and arts, in medallions (e.g., Olympic medals) and coins, in ingots as a store of value, and for scientific/electronic instruments.
- Copper is used in building construction, electric cables and wires, switches, plumbing, heating, roofing; chemical and pharmaceutical machinery, and in paint coatings for bottoms of boats to resist barnacles and other marine growth (International Council on Mining and Metals website (n.d.)).

51.2.1 Environmental Effects of Mining

Mining is not an environmentally friendly activity. Extensive efforts have been made worldwide to minimize environmental damage from mining activities, but the job is not finished. The biggest environmental challenge in mining is the management of mine tailings. Mine tailings are what is left over from the mined ore after the target metal (e.g., copper or gold) or minerals have been separated from the ore. Separation is achieved by industrial processes, using physical grinding and crushing to break the ore into small particles, followed by chemical extraction and flotation methods. Some mine tailings are known to contain heavy metals, chemical reagents used in the separation process (e.g., cyanide from gold processing), and sulfide-bearing materials.

In general, two types of wastes are generated from mining, overburden/waste rock and mine tailings.

- The overburden is the top layer of soil and rock that must be removed to access the ore. The waste rock often contains the target minerals but at too low of concentrations to be economically separated from the rock. Overburden and waste rock are disposed on-land at the mine site, with three known exceptions, one of which places overburden and waste rock on barges to dump at sea and the other two use riverine disposal, although not directly in that the waste is stored on land in areas subject to serious erosion.
- Mine tailings contain the fine-grained materials from the ore and the residues of chemical reagents used in the separation process, all part of a slurry. Mine tailings contain some of the metal bearing minerals, such as copper, because the separation process does not recover all of the minerals. The share of ore that becomes waste is about 60% for iron, 99% for copper, and 99.99% for gold.

Mine tailings and waste rock may naturally include sulfide minerals (such as pyrite, pyrrhotite, marcasite), which when exposed to oxygen and water can lead to generation of sulfuric acid (acid rock/mine drainage). Acid mine drainage is one of mining's most pressing issues. Sulfuric acid, in addition to being potentially toxic in itself, accelerates the leaching of heavy metals from the mine tailings or waste rock. The potential for acid rock drainage from mine tailings and waste rock can be greatly reduced if they are kept under water, isolating the tailings and waste rock from air and the oxidation process.

51.2.2 Disposal Techniques for Mine Tailings

Of the approximately 2500 industrial-sized mines worldwide, 99% dispose of their mine tailings on land, placing the mine tailings under water in impoundments behind dams, or backfilling into closed sections of open-pit or underground mines (dry stacking of dewatered mine tailings is also practiced in a few places). Mine tailings storage facilities are engineered impoundments created from embankments or dams across valleys in areas of hilly or mountainous terrain (Vogt 2013) Fig. 51.2.

The fundamental objective of mine tailings storage facilities is to provide safe, stable, and economical storage of tailings presenting negligible public health and safety risks and acceptably low social and environmental impacts during operation and post closure.

At least 3500 active mine tailing dams/impoundments exist worldwide (Martin and Davies 2000) of the total of over 18,000 (Davies et al. n.d.). These exist but are not without environmental and public safety issues. Issues include (1) the size of the footprint and loss of habitat and land used for such activities as agriculture, (2)

Fig. 51.2 Mine tailings storage facility in Chile. Credit: Craig Vogt

potential contamination to surface waters and groundwater, (3) aesthetics, and (4) short and long term safety and integrity of the engineered facilities.

There have been 140 significant recorded failures of mine tailing storage dams since the first storage dam was created and continuing at a rate of about two per year in current times (Davies et al. n.d.) (Vogt 2013). Recent examples include:

- In 1985, 268 people died from the failure of a mine tailings storage dam in Stava, Italy.
- In 2015, two tailings dams failed at the Brazil's Germano Mine, releasing 32 million cubic meters, destroying 158 homes killing 17 persons, and polluting 663 km of the North Gualaxo River, Carmel River, and Rio Doce (Fig. 51.3).

In 2016, marine or riverine disposal of mine tailings was used by 20 mines, four of which used riverine disposal and 16 used marine disposal. The locations include Chile, France, Greece, Indonesia, Norway, Papua New Guinea, Togo, and Turkey.

Riverine disposal is a very simple concept: pipe the mine tailings to the river and discharge. This technique has been practiced throughout mining history. Because of the catastrophic environmental consequences experienced by the discharge of mine tailings to rivers, riverine disposal is no longer practiced, except at four mines in Indonesia and Papua New Guinea.

Marine disposal of mine tailings (also termed submarine tailings disposal (STD), submarine tailings placement (STP), or deep sea tailings placement (DSTP)) is disposal of mine tailings into marine waters via a pipeline. Disposal of mine tailings to the sea has been practised in some coastal states for as long as 50 years. Disposal near the coast at relatively shallow depths (20–100 m) in fjord basins has been practiced in Norway and Canada. During the last 30 years, more emphases have been placed on deep disposal (>100 m depth), to make sure that the tailings are not influencing the biologically productive euphotic zone. The discharge takes normally

Fig. 51.3 Damage from the tailings pond failure in Brazil in 2015. Credit: Vitor Machado Lira

place some distance off the coastline, on a slope at depths between 150 and 300 m. The intent is for the tailing plume to move intact to a deep water basin with depths beyond 1000 m in deep stratified waters below the pynocline (and the euphotic zone) such that the mine tailings flow as a dense coherent slurry to a deposition site on the bottom, essentially trapped below the biologically productive, oxygenated zone (i.e., not mixing with the surface layer). After release into marine waters from the pipeline, plumes of finer material including tailings process water and suspended sediment can form at various depths. The intention is for these plumes to remain in the deep waters because of the stratification of the marine waters (Ramirez-Llodra et al. 2015). This has particularly been the practise in countries like Indonesia, Philippines, and Papua New Guinea (Jones and Ellis 1995; Shimmield et al. 2010). While some have been designed and are in locations to minimize the environmental impacts, a number of locations such as a nickel mine in Papua New Guinea and a closed mine on Vancouver Island, British Columbia, discharge(d) in locations and at depths with existing currents and up-welling that spread the mine tailings beyond their targeted footprint (Vogt 2013). An excellent review of current practices and environmental issues related to submarine and deep-sea tailing placement was published in 2015 (Ramirez-Llodra et al. 2015).

The main differences between disposal in the open ocean and in fjords are:

- Longer pipelines from the processing plant to the point of tailing discharge in the case of deep sea disposal compared to fjords.
- The distance which the tailing plume has to travel from the point of discharge (normally at 100–200 m depth) to the tailing deposition site (normally 1000–2000 m depth) is much longer in the case of the deep sea compared to fjords.
- The subsea basins planned for tailing disposal are often well defined in the case of fjords which allow tailings to build up to great thicknesses rather than thin layers in large areas in ocean disposal. Fig. 51.4.

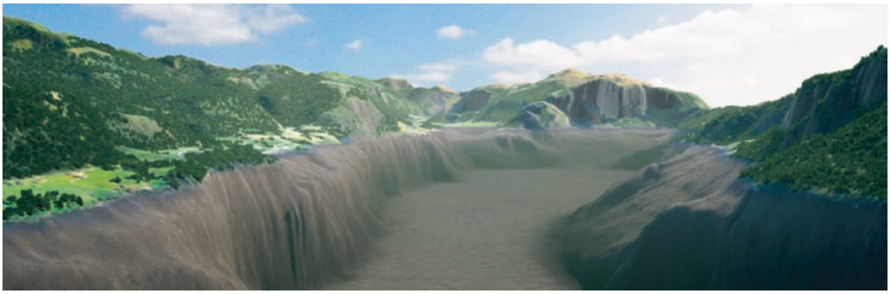


Fig. 51.4 This is Førdefjorden where Nordic Mining received a license to discharge mine tailings. The depth of the basin is about 380 m. Credit: Asplan Viak.

The success of marine disposal depends on the design of the disposal facilities, type of tailing, and the environmental suitability of the selected disposal site.

51.2.3 Why Marine Mine Tailings Disposal

The selection of marine disposal of mine tailings is primarily based upon economics and technical feasibility factors, distance and availability of potential disposal/storage areas, properties of the mine tailings, and comparisons to the availability of land and to social/environmental impacts of land-based disposal. The technical advantages of marine disposal over land disposal include:

- There is no risk related to on land storage dams failure (e.g., 2015 in Brazil). Impoundments of mine tailings have to be managed forever to avoid failure. Climate change and torrential rain may be a challenge for ensuring their long-term safety.
- In land disposal, tailings solids might oxidise and generate low pH, acidity, and release of soluble heavy metals, whereas in ocean disposal acidic mine tailings are quickly neutralized in seawater due to its buffering capacity.
- Weak advective flows near the sea floor compared to rainwater drainage and groundwater flows reduce release of metals from the deposit area.
- Natural processes (i.e., natural sedimentation) over time will act to restore benthic ecosystems after the disposal period in the sea.

In Indonesia and Papua New Guinea, it is argued that:

- Creation of a mine tailings storage facility in the mountainous terrain is not technically feasible because they are located in very active earthquake prone areas;
- The rainfall is up to several meters per year making water management in tailings storage facilities extremely difficult; and
- The terrain is unstable for construction of safe mine tailing storage dams.

In Norway, the argument is that suitable land for disposal of mine tailings near the mines is not available, and that sea disposal may in some cases be a better alternative from an environmental perspective.

One of the key future issues in some countries is the competition between use of land for disposal of mine tailings verses other uses and concerns including agriculture, population growth and development, “not in my backyard,” and tourism.

51.2.4 Environmental Impacts of Marine Disposal of Mine Tailings

The basic understanding is that the mine tailings will smother everything in the intended footprint (i.e., area of disposed mine tailings on the seafloor) on the sea bottom. The intention is that these impacts are only in the disposal site and do not spread to surrounding areas. The potential impacts of marine disposal are widely discussed in the literature (Ramirez-Llodra et al. 2015). Briefly, they include:

- Known effects are the complete loss of healthy habitat in the disposal site for in-situ benthic organisms and those in the ecosystem that depend on them as a food source. There is a potential for impacts from heavy metals in local marine life, including changes in species composition and abundance, depending upon the metals’ bioavailability.
- Smothering of the seabed by mineral materials with no nutritional value to the bottom fauna certainly has a negative effect on the benthic ecology in the area where the rate of sedimentation of tailings by far exceeds the tolerable sedimentation rate with respect to bottom fauna.
- What is not well known is the extent of these effects, including the reduction in species composition/abundance and biodiversity of marine communities, outside of the intended deposition site.
- Two issues related to the extent of the potential impacts are the possible shearing off of plumes of turbid materials from the discharged slurry of mine tailings as they settle to the sea bottom, caused by up-welling and spreading of mine tailings to adjacent areas caused by strong currents.
  - Up-welling is a phenomenon of movement of deep ocean water to the surface of the sea, usually occurring along the coastline, but also in the open ocean. Upwelling is caused by winds pushing surface water, which causes water to rise from the depths to the surface. Upwelling brings nutrients from deeper ocean waters to surface waters, enhancing biological productivity of the surface waters. Up-welling currents can also disturb the discharge plume or parts of the plume which tail off from the main plume (the very fine particles with low sinking rates) and bring these particles to shallower waters (McKinnon 2002).
  - The second issue is the risk of currents influencing a portion of the mine tailings plume as they settle to the bottom, such that they are deposited in adjacent areas, not at the designated disposal site.
  - Both of these issues can be avoided with proper disposal site designation, such that up-welling and currents do not interfere with the mine tailings reaching the intended deposition site.

- Mine tailings often contain sulfide compounds, which can generate sulfuric acid when exposed to air and water. Therefore, in case of land disposal mine tailings should be placed under water to avoid exposure to air. In case of marine disposal, generation of sulfuric acid due to oxidation of sulfur minerals is not a problem due to the buffering capacity of seawater Fig. 51.5.

The question of recovery of the living marine resources at the disposal site is really one of how long (i.e., years, decades, centuries) and what is equivalent in marine life prior to mine waste disposal. Studies indicate that recolonization will occur but not necessarily with the same species that were originally present at the sites (IIED 2002, Jensen 2009). In general, benthic species that re-colonize mine tailings are different than the original species, both in number and types, which can shift marine species community structures. Species that colonize mine tailings on the sea bottom will vary depending upon the physical, chemical, and toxicological characteristics of the mine tailings.

Sites with higher natural sedimentation are likely to naturally bury the mine tailings more rapidly. Scientific studies in Norway showed that re-colonization began immediately when disposal of mine tailings ceased. In Jøssingfjord, recolonization took place in 5–10 years whereas in Frenfjorden, a biological community was established in 1 year (Vogt 2013). In estuarine areas, it has been observed that a new benthic fauna was established within a period of 10 years (Ellis 2003). Average sedimentation rates are very low in the deep ocean; depending upon the location of

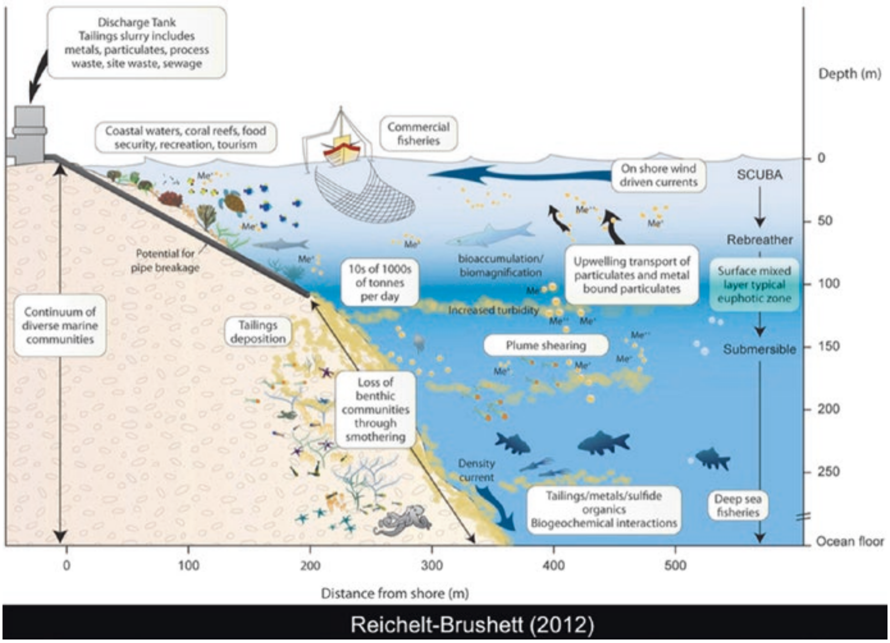


Fig. 51.5 Conceptual model of marine disposal of mine tailings. Credit: (Reichelt-Brushett 2012)

the disposal site, it may take tens to hundreds of years before an appreciable layer of natural sediment caps the footprint of the disposal site.

51.3 Best Management Practices for Marine Disposal of Mine Tailings

Acknowledging that marine disposal of mine tailings results in environmental impacts at the disposal site, mining companies are obligated to minimize the potential environmental impacts by application of best management practices.

Mining companies cannot discharge to marine waters without a permit issued by each country's national authority. International guidelines for disposal of mine tailings in marine waters are in development by the London Convention and Protocol, under the United Nations, which will assist national authorities in the issuance of permits. Permits are issued based on experience, research, and monitoring of existing sea disposal facilities. These permits include special conditions such that impacts to the marine environment are managed and minimized.

The objective is to dispose mine tailings in a controlled manner, where the tailings settle within a predicted area. To promote controlled disposal of mine tailings in the sea, the technical design of the disposal infrastructure should include a mixing tank where the slurry containing tailing particles and freshwater is mixed with high saline seawater before the tailings are disposed in the sea. This increases the density of the tailing plume and maintains the homogeneous feature of the plume. Additionally, initial natural flocculation of fine tailing particles reduces the uncontrolled dispersal of fine tailing particles in the sea (Skei and Syvitski 2013). Installation of a de-aeration unit on the tailing pipe is necessary to avoid air bubbles in the tailing slurry that carry small tailing particles to shallow water.

In addition, best management practices include the following (GESAMP 2016):

- Baseline surveys of physical, chemical, and biological characteristics of the disposal site and surrounding areas before disposal.
- Comprehensive information on suitable discharge locations, e.g., depth and current regimes, ecological resources, and minimum surface area.
- Full knowledge of the physical, chemical, and toxicological characteristics of the mine tailings proposed for discharge.
- Identification of in-plant process changes and controls, or mine tailings treatment prior to discharge, e.g., pre- treatment of process reagents, manipulation of tailings size, and consider more efficient reuse or recycling.
- Engineering elements of the discharge pipe and location.
- Identification of key elements of environmental impact assessments, including impact hypotheses and ecosystem risk evaluations.
- Identification of the detailed elements of monitoring programs to assess the extent of impacts of on-going discharges.

Example of Best Management Practices

An example of the application of best management practices is an iron ore pellet plant in Chile, Fig. 51.6. Once discharged along the shoreline, the discharge location was moved to a depth of 35 m in the Bay in 2002. Comprehensive studies of the physical oceanography and the biological resources were carried out in preparation of an EIA in 2015–2016, which found that the best location for the discharge would be in deep water 6.4 km offshore at final deposition depths of 200–800 m.

Fig. 51.6 Deep sea disposal site in Chapaco Bay, Husaco, Chile. Photo: Craig Vogt

Environmental impact assessments are an important element of best management practices. Even if the technical engineering requirements are satisfied for a marine discharge, there are still questions to be asked about the environmental feasibility of sea tailings disposal. A comprehensive environmental impact assessment (EIA) is required where the impacts and risks of sea disposal are assessed and compared to land disposal. In Norway, for example, marine disposal is only allowed when land-based tailings disposal and management options are not environmentally, socially, technically and economically feasible, or when sea tailings placement exhibits the least environmental and social risk.

To understand impacts in the deep sea, it is important to understand the natural variability and functioning of the deep-sea ecosystem (see Mengerink et al. 2014). There are a number of gaps in understanding of the deep sea. Consequently, identification of critical gaps of knowledge and design of research programs to fill these gaps is a fundamental platform for an EIA. Additionally, a baseline study of the area, which will be potentially influenced by the disposal, is critical to the long-term understanding of the impacts. In the next generation of mining projects, both the research programs and the baseline studies should be carried out in full transparency and published in the open literature.

51.4 Case Studies in Indonesia and Norway

The Batu Hijau copper and gold mine (Indonesia) has operated since year 2000 and is located on the Island of Sumbawa. Deep sea disposal was selected as the preferred tailings management alternative a as result of the environmental impact analysis (PT Newmont Nusa Tenggara 2011). The major factors leading to this decision included:

- On-land disposal would have impacted more than 2000 ha of productive jungle and agricultural lands;
- Annual precipitation exceeding 2.5 m would have made management of water within land-based tailings impoundments extremely difficult;
- A tailings impoundment constructed in an area prone to earthquakes was at risk of failure which could have threatened the surrounding environment, including the safety of nearby communities; and
- Tailings placed in the sea below the biological productive photic zone would minimize impacts on the environment.

The infrastructure used for marine disposal at the Batu Hijau operation was as follows:

- Tailings flow by gravity as a slurry (mixture of water and crushed rock) through a pipeline from the ore processing facility to the edge of a submarine canyon.
- The end of the pipeline lies approximately 125 m below the sea surface and approximately 3.2 km from the shoreline.
- The density of the mine tailings slurry is higher than seawater, such that the tailings sink and flow down the steep walls of the canyon like a submarine river. Most of the tailings deposit at a depth of around 3000 m and some continue to the bottom of Lombok basin at a depth of >4000 m.

An Indonesian Research Center conducted deep-sea surveys to map the tailings footprint and the impacts to the marine ecosystem including water quality and benthic communities. The survey results indicated that the tailings flow down the Senunu Canyon towards the Lombok Basin as predicted. The impact to the water quality was limited to the bottom waters of Senunu Canyon. Water quality outside the tailings mixing zone was at background concentrations level. There was no evidence of bioaccumulation of metals in fish tissues. Shallow-water field experiments using tailings from Batu Hijau showed that meiofaunal abundance returned to levels statistically indistinguishable from natural unaffected controls after 200 days (Gwyther et al. 2009).

In Norway, sea tailing placement has been practiced for more than 50 years at coastal mines where land disposal has been considered unsuitable from environmental, logistical, and social points of view. Fjords, as a geomorphological element, only exist in the part of the world where glaciations took place and basins and sills were formed by glacial erosion and deposition (Syvitski et al. 1987). Consequently, fjords were formed circumpolar around the north and the south pole. In the northern hemisphere, fjords are found in Norway, Greenland, and Canada and in all of these regions sea disposal of mine tailings has been practiced in the past.

Fjords are unique in terms of geomorphological setting, with sills and basins, and may be considered suitable for secure tailing placement if the local conditions are acceptable and where this alternative is preferable to land disposal. Fjords are very different form tidal estuaries in the European Union countries, which are typically shallow and very dynamic, and where control of the placement of tailing would be almost impossible. Fig. 51.7 shows the two submarine disposal sites; Jøssingfjorden where disposal took place between 1960 and 1984 and Dyngadjupet between 1984 and 1994, when a land disposal site was established.

In 2015, two major mining operations, a rutile mine situated near a deep fjord on the west coast of Norway and a copper mine situated near a fjord in northern Norway, received licences from the Norwegian Environment Agency to discharge mine tailings into the fjords. Comprehensive background investigations in the fjords were conducted of environmental resources, the current regimes, and background concentrations of suspended matter, which take account for seasonal and natural variations. Both mining companies are required to operate under strict conditions with respect to impact on water quality, such that the flow of the tailing plume is directed down-

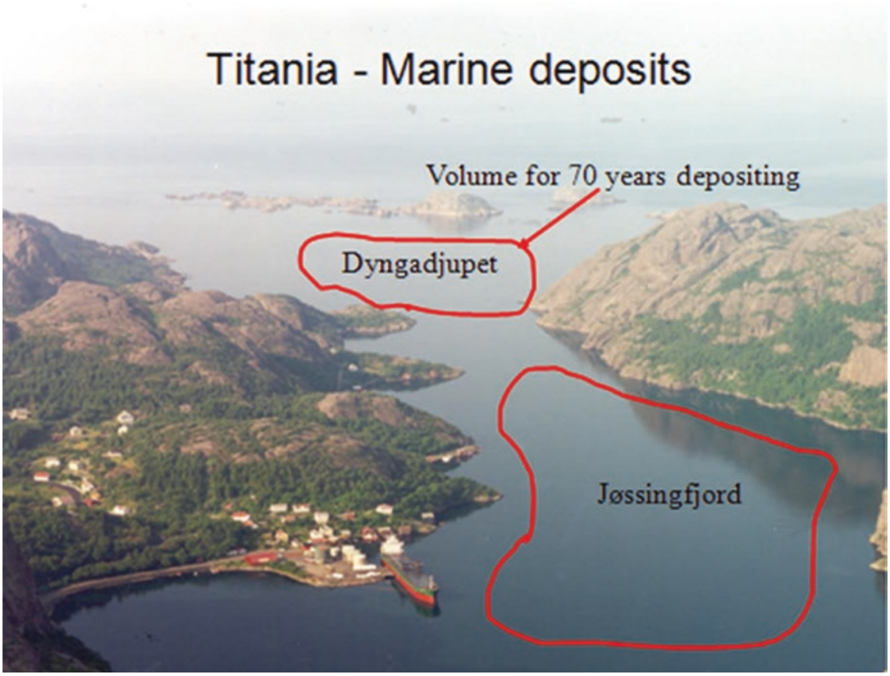


Fig. 51.7 Two submarine disposal sites in Norway. Credit: Ann Heidi Nilsen, Titania

wards and not into surface waters. Prior to issuance of the licenses, land-based alternatives were assessed, and sea disposal was found to be the best option in these cases.

51.5 International Authority for Regulating Marine Discharge of Mine Tailings

The Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter, *1972 (London Convention)* and its update and more modern version, the *1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter*, *1972* (London Protocol) are the primary international instruments under the United Nations that protect the world's oceans from pollution from dumping activities. While focused upon regulation of dumping of waste materials into the sea, the mandate of the treaties is to control all sources of marine pollution and prevent pollution of the sea, which includes such marine discharges as mine tailings.

The 134 countries that are signatories to the London Convention and London Protocol have developed international guidelines to assist national authorities responsible for regulating ocean dumping in meeting their obligations under the two instruments. The guidelines contain step-by-step procedures to evaluate wastes and other matter being considered for ocean dumping, including characterization of the wastes, assessment of alternatives to ocean dumping, waste characterization, assessment of potential adverse environmental effects of dumping, disposal site selection, and monitoring and permitting procedures. In the timeframe of 2016–2017, the London Convention and Protocol is preparing international guidelines specifically for disposal of mine tailings in marine waters (London Protocol 2016), which will be similar to the existing guidelines for other wastes; the new guidelines also will include identification of best management practices.

One key element of the London Convention and Protocol is that every disposal action should receive a licence or permit prior to disposal. In every case of current marine dischargers of mine tailings, national governments have issued permits to the mining operations after considering the alternatives through an environmental impact assessment (or an equivalent). These permit decisions, and the permit renewals have not been without controversy, as certain interest groups, such as local landowners, downstream communities, fishery organisations, and environmental interest groups, have argued against marine disposal.

51.6 Decision-making: Comparing Impacts on Land vs. the Sea

When impacts on land or in the sea are to be assessed, it is important to consider the risks in the both the short and long term, which should include assessment of the potential of rehabilitation of disposal sites after termination of the mining operation.

Both options will cause loss of habitat, and fish and wildlife associated with that habitat. Loss of land for agriculture or economic development, as well as the critical need to ensure that dam impoundments are managed to ensure their safety forever, are considerations in the decision-making of land versus sea disposal. Whether those are acceptable losses is a local decision considering a multitude of economic, social, and environmental factors.

A tailing dam on land normally has a water cover. What happens when the mine closes and discharge of tailings to the dam ends depends on the local climate and whether the dam is located in an arid or high precipitation area. If the water cover is not maintained a dust problem can occur and fine tailings particles can be transported by wind long distances. If the dam is in a high precipitation area, the overflow of water may contaminate surface water and ground water used for other purposes. This is particularly a problem where the tailing contains high levels of sulphide minerals which are easily oxidized, causing low pH, acid mine runoff, and elevated levels of dissolved metals. Finally, dam failure occurs periodically, with severe consequences.

Tailing disposed in the sea should stay on the seabed if the disposal site was correctly determined to be a deposition site and not influenced by up-welling or strong currents. Mine tailings vary in composition and environmental concern. The environmental risk assessment should consider a series of tests of the tailing composition and behaviour in seawater (e.g., sedimentation properties, currents, release of metals from the mineral particles, toxic properties, the extent of potential impacts to marine life, and the time to recovery by natural sedimentation and recolonization of the tailings with benthic fauna). Biogeochemical processes may alter the stability of the minerals due to redox changes and the fluxes of metals at the sediment-water interphase may either increase or decrease over time. It is therefore important to do experimental work with tailings and how changes in redox influence the release of metals. When the mining operation has terminated, natural sedimentation of mineral particles and organic matter will take over and gradually a new natural sediment substrate will develop (i.e., the natural rate of sedimentation at the disposal site can be measured by isotopes to predict how long it will take to cover up the tailings).

Understanding and comparing the implications on local and national economic values, societal needs and social issues, and impacts upon environmental resources for land disposal and sea disposal is key to decision-making on what is an acceptable impact, and the choice of disposal alternative.

51.7 Going Forward: Challenges and Issues

Mining and disposal of mine tailings is not an environmentally friendly activity. However, mining is absolutely essential to work, live, and play. Disposal of mine tailings presents a unique issue in that both on-land disposal and marine disposal result in significant environmental risks and damage to habitats and fish/wildlife.

The vast majority of mines dispose of mine tailings in well-designed and managed on-land tailings storage facilities.

Because land availability for mine tailings disposal facilities is scarce, technically infeasible, or because mining operations are in competition for the land with agricultural interests, urban activities, or environmental resources, marine disposal is being considered by 20–30 mining operations, either new or existing mines. Another factor is that land-based storage facilities must be managed after mine closure forever, to avoid failure and risks to downstream residents. Marine disposal will damage living marine resources at the disposal site, but over the very long term, natural sedimentation will allow the ecological resources to return. These are not simple assessments to carry out, and are not simple decisions at the local and national level.

The international guidelines for marine disposal of mine tailings, being developed by the London Convention and Protocol, should provide assistance to decision-makers. While marine disposal of mine tailings may have substantial impact on marine ecosystems, it may prove to be the best of a damaging set of options for a specific location.

References

Davies M, Martin T, Lighthall P (n.d.) Mine tailings dams: when things go wrong. AGRA Earth & Environmental Limited, Burnaby BC. http://www.infomine.com/library/publications/docs/Davies2002d.pdf

Ellis DV (2003) The concept of "sustainable ecological succession"; and its value in assessing the recovery of sediment seabed biodiversity from environmental impact. Mar Pollut Bull 46:39–41

Joint Group of Experts on Scientific Aspects of Marine Environmental Protection (GESAMP) (2016) Proceedings of the GESAMP international workshop on the impacts of mine tailings in the marine environment, GESAMP Reports & Studies No. 93; GESAMP, London 2016

Gwyther D, Batterham GJ, Waworuntu J, Gultom TH, Prayogo W, Susetiono W, Karnan D (2009) Recolonisation of mine tailing by meiofauna in mesocosm and microcosm experiments. Mar Pollut Bull 58:841–850

IIED (2002) Mining for the future; Appendix A: large volume waste working paper

IMO (2013) International assessment of marine and riverine disposal of mine tailings. Accessed from International Maritime Organization Web site: http://www.imo.org/en/OurWork/Environment/LCLP/newandemergingissues/Documents/Mine. Tailings Marine and Riverine Disposal Final for Web.pdf

International Council on Mining and Metals website. https://www.icmm.com/en-gb/metals-and-minerals

Jensen T (2009) Re-building fauna in marine mining disposal with examples from Titania and Hustadmarmor (Paper presented at the Egersund Conference, Egersund)

Jones SG, Ellis DV (1995) Deep water STD at Misima gold and silver mine. Papua New Guinea Mar Geores Geotechnol 13:183–200

Martin TE, Davies MP (2000) Trends in the stewardship of tailings dams. In: Balkema AA (ed) Proceedings of tailings and mine waste '00. Balkema Publishers, Fort Collins, pp 393–407

McKinnon E (2002) The environmental effects of mining waste disposal at Lihir Gold Mine, Papua New Guinea. J Rural Remote Environ Health 2:40–50

Mengerink KJ, Van Dover CL, Ardron J, Baker MC, Escobar-Briones E, Gjerde K, Koslow A, Ramirez-Llodra E, Lara-Lopez A, Squires D, Sutto T, Sweetman AK, Levin LA (2014) A call for deep-water stewardship. Science 344:696–698

PT Newmont Nusa Tenggara (2011) Management of deep sea tailings placement system at Batu Jijau Mine. http://www.amnt.co.id/

Ramirez-Llodra E, Trannum HC, Evenset A, Levin LA, Andersson A, Finne TE, Hilaio A, Flem B, Christensen G, Schaanning M, Vanreusel A (2015) Submarine and deep-sea mine tailing placements: a review of current practices, environmental issues, natural analogs and knowledge gaps in Norway and internationally. Mar Pollut Bull 97(1-2):13–35

Reichelt-Brushett AJ (2012) Risk assessment and ecotoxicology—limitations and recommendations in the case of ocean disposal of mine waste. Oceanography 25:40–51

Shimmield TM, Black KD, Howe JA, Hughes DJ, Sherwin T (2010) Final report: Independent evaluation of deep-sea mine tailings placement (DSTP) in PNG. SAMS, Oban

Skei JM, Syvitski JPM (2013) Natural flocculation of mineral particles in seawater—influence on mine tailing sea disposal and particle dispersal. Mineralproduksjon, 3:A1–A10

Syvitski JPM, Burrell DC, Skei JM (1987) Fjords. Processes and products. Springer-Verlag, New York, Berlin, Heidelberg, p. 379

Vogt, Craig (2013) International Assessment of Marine and Riverine Disposal of Mine Tailings, International Maritime Organization, London Convention/Protocol.

Chapter 52
Managing and Regulating Underwater Noise Pollution

Till Markus and Pedro Pablo Silva Sánchez

Abstract Over the last decade the issue of underwater noise pollution has received increased attention from scientific bodies, the media, NGOs, and institutions at the national, supranational and international levels. This in turn, has led to the development of several regulatory initiatives that seek to mitigate the negative impact of this source of pollution. This article outlines and analyses existing legislation and management regimes that govern marine activities that generate noise. Best practices and specific mitigation measures are also addressed and assessed.

Keywords Underwater noise pollution • Anthropogenic noise input • Underwater sound • Sonar • Pile driving • Whale watching • Seismic surveys • Air guns • Shipping • Off-shore constructions • Offshore infrastructures • Precautionary approach • Marine environment • Marine mammals • Marine life

52.1 Why Does Underwater Noise Pollution Require Management?

In recent times, the issue of anthropogenic noise input to the marine environment, or "underwater noise", has received increased attention from scientific bodies (ICES 2005; MMC 2005; NRC 2005; IUCN 2004), the media,[1] NGOs (IFAW 2008; WDC

[1] E.g. see BBC, Earth News, Reporting Life on Earth, 1 June, 2010, available at: http://news.bbc.co.uk/earth/hi/earth_news/newsid_8708000/8708318.stm.

T. Markus (✉)
Research Centre for European Environmental Law, University of Bremen, Bremen, Germany
e-mail: tmarkus@uni-bremen.de

P.P.S. Sánchez
GLOMAR – Bremen International Graduate School for Marine Sciences, University of Bremen, Bremen, Germany
e-mail: ppss@uni-bremen.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_52

2004), as well as national, supranational and international institutions such as the European Parliament or the UN General Assembly (UNGA 2005, 2014).[2] This attention is largely a response to the increased incidence of whale stranding related to the use of military mid- and low-frequency sonar. Other potentially harmful noise sources include commercial and scientific sonar, ships, aircrafts, and seismic instruments, as well as explosions, dredging, piling and other construction activities associated with near and offshore infrastructures (wind farms, oil and gas platforms, harbor development, etc.). Fear is mounting that underwater noise pollution may burden the marine environment to the point that it harms or even kills marine mammals and fish.

Increasingly, studies have been carried out which examine the effects of noise on marine fauna caused by different activities (see Boebel et al., in this book). They indicate, *inter alia*, that underwater noise can have adverse effects on marine mammals and fishes (IFAW 2008: 16–25; ICES 2005: 12–29; NRC 2005: 83–108). Among such effects are damages to auditory organs (including physical damage as well as temporary or permanent auditory threshold shifts, i.e. hearing loss), injuries to other body tissues and inner organs, or even the death of single specimens. Underwater noise may also lead to aberrant behavioural responses, whether at the individual or group level. This could include changes in swimming, diving, and breathing patterns, as well as changes in communication (vocalization rate/amplitude) (Miller et al. 2000: 203). All these effects are plausibly connected to stress and health problems such as cardiac arrhythmia, disorientation, or nitrogen oversaturation. In addition, underwater noise can mask sounds made by marine species to communicate, orient themselves, or detect predators and prey. Less is known regarding the effects of underwater noise on fishes (ICES 2005: 44–48, 45; McCauley et al. 2003); existing studies suggest, however, that these effects are to some extent similar to those sound can have on mammals. It has also been pointed out that simultaneous and successive exposures to underwater noise as well as to other non-acoustic stressors (e.g. fishing activities, climate change, or chemical or physical pollution) must eventually be considered cumulatively when assessing the overall effects of noise on marine fauna (ICES 2005: 36–38; Erbe 2013).

52.2 What Are the Challenges for Managing Underwater Noise Pollution?

The effectiveness of current marine management approaches is limited in many ways. This is particularly so in the context of underwater noise; the release of non-material discharges in the marine environment is less comprehensively and

[2] In 2005, the UNGA encouraged further studies on the impacts of ocean noise on marine living resources (UNGA 2005, para.84). From then on, every year's UNGA Resolutions on "Oceans and the Law of the Sea" have identified "ocean noise" as an important topic, being the last one in 2014 (UNGA 2014: 237–238); EP 2005).

systematically regulated in international and national law than “classic” impacts such as fishery, shipping, or physicochemical pollution. The biggest obstacle to the protection of marine environment from underwater noise, however, is the current knowledge gap. Although concern about and understanding of the effects of underwater noise in marine environment continue to grow, a significant lack of information still exists regarding the nature of underwater noise, the auditory ability of marine mammals and fish, and, ultimately, the overall effects of noise on these sea dwellers (ICES 2005: 17; NRC 2005: 83; Gillespie 2006: 214–216). Currently, there are few studies on the auditory capacity of specific species, and thus great uncertainty remains about the indirect, long-term, and cumulative effects of noise emissions on these species, especially regarding potential behavioral changes of marine mammals. Moreover, only a handful of (regional) evaluations or mappings of underwater noise emissions currently exist.[3] Finally, even when studies have been conducted, the nature and effects of underwater noise are often strongly dependent on the specific circumstances of particular ecosystems, including the variables of time, space, species, and source.

Against this backdrop, it is difficult to assess at what exact point underwater noise emissions become biologically significant. *Gillespie* concludes that only two observations may be made with some certainty at the moment: First, that the problem has already received substantive international attention, and second, that the problem may represent a serious threat in some instances (Gillespie 2007: 82). One may add to this that it is widely assumed that underwater noise has sharply increased in the previous decades and will likely continue to increase (ICES 2005: 39; (NRC 2005): 74–82). Apart from this, however, much knowledge already does exist about human activities which generates underwater noise and this knowledge could be included relatively easily into a systematic management approach (e.g. seismic studies in the oil and gas industry, ship movements, mid- and low-frequency sonars) (NRC 2005: 52 ff.).

52.3 Institutional and Legal Frameworks Governing Underwater Noise Input

At the moment, underwater noise is neither systematically nor comprehensively regulated by international or national law. Existing legal systems currently approach underwater noise as either a form of pollution to the marine environment, or as a danger to species (Dotinga and Elferink 2000: 155–167; McCarthy 2001). In the following section, the most significant legal principle regarding underwater noise will first be discussed, followed by descriptions and analyses of relevant content from international treaties and then national laws.

[3] See for instance, Stellwagen Bank National Marine Sanctuary (USA East Coast) www.orcalab.org; Puget Soundscape (USA); Ocean Tracking Network, www.oceantrackingnetwork.org (Canada); LIDO—Listening to Deep Ocean Environment (Mediterranean), www.esonet-noe.org.

52.3.1 International Law

The following section will address the significance of the precautionary principle in relation to the subject at hand. Next, the relevance of the existing international treaties for the management of underwater noise will be assessed.

52.3.1.1 The Precautionary Principle

Despite its legal status being uncertain, the precautionary principle has gained enormous importance when it comes to governing environmental problems in situations of scientific uncertainty, including in the case of underwater noise. Quite generally, environmental law principles like the precautionary principle guide states in their political, legislative, administrative, and judicial approaches to marine management (see Winter, in this book). As already discussed, jurisprudential discourse and current legislative initiatives to limit the adverse effects of underwater noise are emerging against the backdrop of a considerable lack of scientific knowledge regarding the nature and effects of underwater noise as well as the physiological (auditory) traits of potentially affected marine life. Nevertheless, as also explained above, there are clear signs that noise input to the marine environment can result in significant damage, especially to marine mammals (Horowitz and Jasny 2007: 227). It is precisely this type of situation in which the precautionary principle becomes relevant in guiding state actions, i.e. when a potential concern rises regarding a causal relation between a human activity and an adverse environmental impact. The core of the principle is reflected in Principle 15 of the 1992 Rio Declaration; it states that where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation (Rio Declaration, Principle 15).

Despite its still somewhat unclear substance and legal status in international law, the precautionary approach gives legislators a framework for action (Birnie et al. 2009: 162; Sands 2012: 222).[4] As some have pointed out, viewed simply as a general principle of law, this approach may still be relied upon by decision-makers and courts (Birnie et al. 2009: 162–163; Mauermann 2008). So in accordance with this principle, environmental law and political decision-making should not be limited to the mere prevention of imminent environmental hazards or to the restoration of environmental damage, but rather should consist in the duty to prevent damages by taking preemptive action before the danger threshold is reached. (Birnie et al. 2009 152 ff.; Rehbinder 1991). Keeping this in mind, known and conceivable hazard potentials of underwater noise should be proactively confronted (Gillespie 2007:

[4] At the international level, the meaning and content of the principle is still disputed. E.g. it remains open what these "measures to prevent damage" should be, how strong they should be, or even which scientific evidence would be sufficient to override arguments for postponing such measures. (Birnie et al. 2009, p.162; Sands 2012, p. 222).

85–86; Horowitz and Jasny 2007: 227; Inkelas 2005: 221–222; Van Dyke et al. 2004: 349–352). At any rate, it is clear that the precautionary principle has support in the international community (Sands 2012: 222; Birnie et al. 2009: 159). Both the Conference of the Parties (COPs) to the Convention on Migratory Species (CMS) (CMS 2008, para. 4) and the Meetings of the Parties (MOPs) to the ASCOBANS (ASCOBANS 2009a), have emphasized the principle's importance with regard to the issue of anthropogenic underwater noise.

52.3.2 International Treaties

Currently no international legal instrument exists which specifically and exclusively addresses underwater noise. Relevant conventions usually contain general provisions regarding marine environmental protection, the protection of various species, biodiversity, or the protection from pollution by material input. Only a few treaties explicitly mention noise or sound input (e.g. ASCOBANS, Annex, paragraph 1(d)). However, an in-depth look at the international framework, especially the United Nations Convention on the Law of the Sea (UNCLOS), is warranted for two reasons. First, the international law of the sea and marine environmental law set the regulatory framework for further international and national law making as well as any kind of future management action. Second, the international legal perspective is necessary due to the cross-border nature of the matter and the affected species (Erbe 2013: 17).

52.3.2.1 UN Convention on the Law of the Sea (UNCLOS)

According to Art. 192 of UNCLOS, parties are obliged to "protect and preserve the marine environment". The general consensus with regard to this article is that it includes only a vague duty to carry out active measures to maintain the *status quo* of the marine environment (Dotinga and Elferink 2000: 160). This obligation is concretized by Art. 194 et seq., especially regarding marine pollution and the use of technology; parties are obliged under Art. 194 (1) to take measures to "prevent, reduce and control pollution of the marine environment from any source". It must be asked, however, whether noise input may be interpreted as pollution according to Art. 194 (1). According to Art. 1 (1) (4), pollution of the marine environment means "the introduction by man, directly or indirectly, of substances or energy into the marine environment, […] which results or is likely to result in such deleterious effects as harm to living resources and marine life". Though the authors of UNCLOS did not have the regulation of underwater noise in mind while constructing this article, it would make sense from a literal and systematic perspective to recognize it as a form of energy input according to Art. 1 (1) (4). In the first place, noise is a form of energy from a scientific point of view (Dotinga and Elferink 2000: 158). In addition, the wording of Art. 194 (1), "from any source", and Art. 194 (3) "the measures taken pursuant to this Part shall deal with *all sources* of pollution of the marine environment" call for a broad interpretation of the definition.[5] Finally, the definition in Art. 1 (1) (4) was drafted in a broad and expansion-friendly manner, especially because it *expressis verbis* covers not only material input. The obligation under Art. 194 (1) is moderated, however, by the fact the article also states that parties must only take "the best practicable means at their disposal and in accordance with their capabilities".

Art. 196 obliges the parties to take "all measures necessary to prevent, reduce and control pollution of the marine environment resulting from the use of *technologies*".[6] Though the authors of UNCLOS were primarily thinking of biotechnology when including the term "technologies" (Dotinga and Elferink 2000: 160), a broad interpretation of the provision is relevant here for the same reasons stated above. In that respect, the use of technologies such as sonar or seismic air guns should be subsumed under Art. 196. It must be noted, however, that the relevant damage threshold to be considered is high, because the changes must be "significant and harmful" (Art. 196 (1) UNCLOS).

Furthermore, according to Art. 204, the parties shall endeavor to, "as far as practicable, […] observe, measure, evaluate and analyze, by recognized scientific methods, the risks or effects of pollution of the marine environment". Additionally, they are obliged by Art. 197 to cooperate on "formulating and elaborating international rules, standards and recommended practices and procedures consistent with this Convention, for the protection and preservation of the marine environment".

With regard to pollution of the sea by ships, under Art. 211 (2) states shall "adopt laws and regulations for the prevention, reduction and control of pollution of the marine environment from vessels flying their flag or of their registry". These laws and regulations shall "at least have the same effect as that of generally accepted international rules and standards established through the competent international organization or general diplomatic conference". According to Art. 211 (1), states have a duty to create such international regulations. The responsible authority for this task is the International Maritime Organisation (IMO). To date, no binding regulations on ship noise have been made within the IMO framework—not even under the MARPOL Convention. Nevertheless, the IMO's Marine Environment Protection Committee has paid attention to the topic since 2008 (IMO 2008) and in 2014 approved the non-mandatory Guidelines for the Reduction of Underwater Noise from Commercial Shipping to Address Adverse Impacts on Marine Life (IMO 2014). These are aimed at commercial ship designers, shipbuilders, and ship operators, and focus on propellers, hull form, onboard machinery, and operational noise (IMO 2014, para. 3).

Coastal states are furthermore obliged under Art. 208 to "adopt laws and regulations to prevent, reduce and control pollution of the marine environment arising from or in connection with seabed activities". Again, the extent of this duty is not left at the sole discretion of the states; such laws and regulations "shall be no less effective than international rules, standards and recommended practices and procedures". Also in this case, international standards should be developed and coordinated. Like other UNCLOS

[5] *Italics have been inserted by the authors.*

[6] *Italics have been inserted by the authors.*

provisions, Art. 208 was not initially intended to address underwater noise. However, as stated above, the word “pollution” is to be interpreted broadly under UNCLOS and should include all kinds of input from all sources including nonmaterial entries and thus includes sound input from seabed activities. Accordingly, Art. 208 provides a mandate to regulate noise emitting activities on the seabed including all sorts of piling or drilling. To this day, however, no such rules targeting specifically the restriction of underwater noise yet exist at the international level.[7] UNCLOS also confers obligations with regard to pollution from the air and by the air (see Art. 212 (1–3)), but the same absence of rules is found with regard to the underwater noise produced by those activities.[8]

UNCLOS also sets a legal framework for research and the exploitation of living aquatic resources. According to Art. 240 (d) marine scientific research “shall be conducted in compliance with all relevant regulations adopted in conformity with this Convention including those for the protection and preservation of the marine environment” (see particularly, Hubert, in this book; Hubert 2011: 329 ff.). This rule thus provides a mandate, for example, to regulate the scientific use of air guns if international standards were established in this field.

52.3.2.2 Other International Treaties

Besides UNCLOS, other international treaties exist which aim to prevent pollution of the seas and protect marine species and their habitats. These include, *inter alia,* the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention), the International Convention for the Prevention of Pollution from Ships (MARPOL), the International Convention for the Regulation of Whaling,[9] the Convention on the Conservation of Migratory Species of Wild Animals (CMS), and the Convention on Biodiversity (CBD). Regional treaties include the Antarctic Convention and its Environment Protocol from 4 October 1991, the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention), the Convention on the Protection of the Marine Environment of the Baltic Sea (Helsinki Convention), the Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish, and North Seas (ASCOBANS), and the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS). These conventions have varying objectives, material, and geographical scopes. If, after relevant assessment, one were to consider underwater noise to be within the scope of these conventions, their regulatory content and level of protection would have to be considered as very general. A few treaties, however, provide more concrete

[7] There are measures addressing noise input at the national level (see below).

[8] It is yet unclear, however, to what extent such a regulation would be necessary. The cases where noise entering the sea from air adversely affects marine fauna seem relatively few. If regulation would be necessary, this could rather be developed under special or regional regimes. Regarding the effects see, for example, Patenaude et al. 2002.

[9] Since the IWC 1998, underwater noise has been a priority topic for the IWC 1998.

measures than the others: ASCOBANS and ACCOBAMS, the Antarctic Convention and its Environment Protocol, the CMS, and the CBD.[10]

ASCOBANS

According to subparagraph 2.1 of the agreement, the parties "undertake to cooperate closely in order to achieve and maintain a favourable conservation status for small cetaceans". Following subparagraph 2.2, the parties shall apply the conservation, research and management measures prescribed in the Annex. Paragraph 1(d) of the Annex states that parties shall "work towards the prevention of other significant disturbance, especially of an acoustic nature" to species covered by the Agreement.

Several resolutions within ASCOBANS call for the development of guidelines to protect small cetaceans from noise produced by seismic experiments. Furthermore, it has been demanded that research be done on so-called noise deterrence technology, as well as on the effects of ship noise (especially high-speed ferries) and offshore industries (including wind mills) on small cetaceans. Additionally, protective measures should be developed in cooperation with militaries to reduce damages caused by military exercises (ASCOBANS 2003, 2006, 2009a). Guidelines addressing all these noise issues were eventually proposed through the 2009 "Effective Mitigation Guidance for intense noise generating activities in the ASCOBANS region" (ASCOBANS 2009b: 11–23).

ACCOBAMS

The Agreement does not expressly refer to underwater noise, but its general provisions apply to the subject. As prescribed by article II, paragraph 1, the parties "shall take coordinate measures to achieve and maintain a favourable conservation status for cetaceans". According to paragraph 3, they shall apply the conservation, research and management measures prescribed in the Conservation Plan established in Annex 2 of the Agreement (Art. II (4) ACCOBAMS), which, *inter alia*, requires the parties to regulate the discharge at sea of pollutants believed to have adverse effects on cetaceans (ACCOBAMS Annex 2, para. 1 (d)).

Parties to ACCOBAMS have addressed the impact of underwater noise on the conservation status of protected cetacean species since 2004 (ACCOBAMS 2004, 2007, 2010b, 2013a). Resolution 3.10 in 2007 established a Working Group to tackle underwater noise deriving from different activities, develop appropriate tools to assess the impacts of underwater noise on cetaceans, and further elaborate measures to mitigate such impacts (ACCOBAMS 2007, para. 13). In addition, the 2010 Resolution 4.17 presented the "Guidelines to Address the Impact of Anthropogenic Noise on Cetaceans in the ACCOBAMS Area". These include guidelines targeting

[10] Further analyses are provided by, for example, Scott 2004; Scott 2007: 179; Schachten 2011; Van Dyke et al. 2004; Dotinga & Elferink 2000: 155–167.

many different specific operations including high power sonar (military and civil), seismic surveys and air gun uses, coastal and offshore construction work, offshore platforms, and shipping. The guidelines are not static and are expected to be further developed by the Working Group, in cooperation with the Secretariat, Scientific Committee, and the parties (ACCOBAMS 2010b, para. 13 and Annex).

A Joint Noise Working Group of CMS/ACCOBAMS/ASCOBANS (JNWG) has also been also established,[11] vested with advisory competences only. Its main aim is to ensure progress is being made towards mitigating the negative impact of underwater noise on cetaceans and other marine biota (ASCOBANS 2014b). Among other functions, it is mandated to improve the existing guidelines on the subject based on new scientific findings (ASCOBANS 2014a, para. ii).

Antarctic Treaty System

The Antarctic Treaty System is made up of several treaties whose regulations may be significant to the regulation of underwater noise input. The central treaty in the system is the Antarctic Treaty itself.[12] Art. I.1 declares that Antarctica shall be used only for peaceful purposes and expressly prohibits military maneuvers and the testing of weapons in the areas covered by the Treaty, which according to article VI includes the whole continental and marine areas south of 60° South Latitude (Art. I (1) and VI, Antarctic Treaty). Consequently, the use of mid- and low-frequency sonar by military submarines is generally prohibited.

Bearing article VI in mind, it is worth mentioning the Protocol on Environmental Protection to the Antarctic Treaty from 4 October 1991 (Madrid Protocol). According to Art. 2, the objective of the Protocol is "the comprehensive protection of the Antarctic environment and dependent and associated ecosystems". Art. 7 of the Protocol categorically prohibits any form of commercial exploitation of mineral resources. Thus the use of air guns is generally limited to scientific and other non-commercial purposes. Further, Art. 8 of the Protocol calls for an environmental impact assessment of all activities whether scientific research, tourism, governmental or non-governmental activities. The impact assessment categorizes each activity by one of three descriptions:

- less than a minor or transitory impact;
- a minor or transitory impact; or
- more than a minor or transitory impact.

If the assessment determines that the activity has "less than a minor or transitory impact," it may proceed forthwith (Art. 1 (2), Annex I, Madrid Protocol). If it is determined that the impact is "not less than minor or transitory" or "more than

---

[11] It was first established in 2012 as the joint ACCOBAMS/ASCOBANS Noise Working Group. The CMS was included in 2014. See ASCOBANS 2014c. Also see: http://www.ascobans.org/es/species/threats/underwater%20noise.

[12] See at www.ats.aq.

minor or transitory", a *preliminary* evaluation of the impact will be carried out (Art. 2 (1), Annex I, Madrid Protocol). If the initial or in the preliminary assessment indicate that the activity is "likely to have more than a minor or transitory impact", a qualified, *comprehensive* environmental evaluation will take place according to the procedures in Annex I of the Protocol (Art. 3 (1) Annex I, Madrid Protocol). As the terms "minor" and "transitory" are not further defined, state practice varies regarding the assessment of noise emissions (Scott 2007: 181).

Furthermore, with regard to underwater noise, Art. 3 (2) of the Protocol requires activities in Antarctica to be planned and executed in a particular manner that avoids, *inter alia*, detrimental changes in the distribution, abundance or productivity of species or populations of species of fauna and flora; further jeopardy to endangered or threatened species or populations of such species.

Moreover, Art. 3 of Annex II prohibits both the "taking" of mammals and birds and the "harmful interference" of nature. Both of these activities are further defined by Art. 1 of Annex II. Accordingly, "taking" means "[to] kill, injure, capture, handle or molest, a native mammal or bird […]". It has been argued that this provision should be considered relevant in the context of underwater noise (Scott 2007: 186). This is justifiable with regard to both the wording of the provision and its *telos*. The meaning of "taking" includes the removal of a mammal or bird from the Antarctic ecosystem. This displacement also occurs as a byproduct of noise emissions, as described in the first part of this article. It should be noted, however, that the term "harmful interference" as defined in Art. 1 (h) (i) includes "flying or landing helicopters or other aircraft in a manner that disturbs concentrations of birds and seals". As most activities included in Art. 1 (h) (i-vi) are ones that are carried out from land (Scott 2007: 186), the prohibition of "harmful interference" is not applicable to underwater noise. Solely Art. 1 (h) (ii) could be applied to the use of underwater sonars. According to that, harmful interference includes "using vehicles or vessels […] in a manner that disturbs concentrations of birds and seals".

CMS

Migratory species—including some marine species—cyclically cross one or more national jurisdictional boundaries (Art. I (1) (a) CMS). The parties to the CMS acknowledge the importance of conserving these species and the need to take action to prevent them from becoming endangered (Art. II (1) and II (2) CMS).

By virtue of article II.3.(b) of the Convention, all parties should provide immediate protection for the "endangered migratory species" included in Appendix I (Art. II (3) (b) CMS). According to article III.5, the so called *range states parties*[13] of such species shall, subject to certain specific exceptions, prohibit the taking of animals belonging to such species (Art. III (5) CMS). Under the CMS "taking" is a broad notion that covers taking, hunting, fishing, capturing, deliberate killing, and

[13] For a definition of "Range State", see CMS article I.1.h.

harassing or attempting to engage in any such conduct (Art. I (1) (i) CMS). Such effects can also result from anthropogenic noise input. As regards the conservation and management of species listed in Appendix II,[14] parties and range states parties (Art. II (3) (c) and IV (3) CMS) should conclude international agreements to ensure their favorable conservation status (Article V CMS).

In 2005, the COP's Resolution 8.22 on Adverse Human Induced Impacts on Cetaceans requested the CMS Secretariat and Scientific Council to review the extent to which the CMS and CMS cetacean-related agreements are addressing human induced marine noise (CMS 2005, para. 3 (b) (vi)). In 2008, Resolution 9.19 on Adverse Anthropogenic Marine/Ocean Noise Impacts on Cetaceans and other Biota called the parties to adopt mitigation measures on the use of high intensity active naval sonars (CMS 2008, para. 2). It also announced the development by the Scientific Council of voluntary guidelines on activities of concern (CMS 2008, para. 3). Moreover, it encouraged the parties to facilitate the assessment and monitoring of marine noise, further understanding with regard to the potential sources and acoustic risks for marine species, and studies on the extent and potential impact on the marine environment of high intensity active naval sonars, seismic surveys, and shipping, as well as studies reviewing the potential benefits of "noise protection areas" (CMS 2008, para. 5).

CBD

The CBD framework may also be a forum where underwater noise could be targeted at the international level, insofar as protection from underwater noise can be derived from its general obligations. The main objective of the CBD is the conservation of biological diversity (Art. 1 CBD), which includes marine organisms (Art. 2 CBD). To that end, the parties shall, *inter alia*, identify what "processes" and "activities" carried out under their jurisdiction or control (regardless of where their effects occur) (Art. 3 (b) CBD) have or are likely to have significant adverse impacts on the conservation of biological diversity. They are also to monitor the effects of their activities (Art. 7 (c) CBD), and regulate them (Art. 8 (l) CBD). According to Art. 22.2., contracting parties shall implement the CBD with respect to the marine environment, consistent with the rights and obligations of States under the law of the sea.

In 2012, adverse impacts of underwater noise on marine and coastal biodiversity were addressed by the COPs to the CBD in Decision UNEP/CBD/COP/DEC/XI/18 on "Marine and coastal biodiversity: sustainable fisheries and addressing adverse impacts of human activities, voluntary guidelines for environmental assessment, and marine spatial planning". This Decision requested that the Executive Secretary

[14] These are migratory species which have an unfavourable conservation status and which require international agreements for their conservation and management, as well as those which have a conservation status which would significantly benefit from the international co-operation that could be achieved by an international agreement, See article IV (1) CMS.

collaborate with other parties, governments and competent organizations to organize an expert workshop to improve and share knowledge on underwater noise and its impacts on marine and coastal biodiversity. The goal was to develop practical guidance to assist when applying management measures, which eventually would mitigate significant adverse impacts of underwater noise on marine and coastal biodiversity. The workshop was also to cover issues such as the development of acoustic mapping of areas of interest as part of its scope. The results of this initiative are available in the "Report of the Expert Workshop on Underwater Noise and its Impacts on Marine and Coastal Biodiversity", which was adopted in 2014. That same year, the COP to the CBD encouraged parties, non-parties, indigenous and local communities, and other relevant stakeholders to take appropriate measures to "avoid, minimize and mitigate the potential significant adverse impacts of anthropogenic underwater noise on marine and coastal biodiversity" (UNEP 2014, para.3).

52.3.3 The EU's Marine Strategy Framework Directive

The EU undertook a unique effort in managing underwater noise. Through its Marine Strategy Framework Directive (MSFD) it has initiated a process that develops a common approach between Member States to address underwater noise pollution. The structure of this development, particularly with a view to conceptual and methodological intercalibration, may serve as a reliable blueprint for how to target the issue of underwater noise pollution at the international level.

The EU's MSFD establishes a framework for joint action in the field of marine environmental policy. Its overall objective is to create a framework within which the Member States take the necessary measures to maintain or create a good environmental status in their waters by 2020 at the latest, their waters including, in principle, Member States' territorial waters, EEZs and adjacent continental shelfs (where relevant). Member States are required to take the necessary measures "to achieve or maintain good environmental status [GES] in the marine environment by the year 2020 at the latest" (Art. 1 (1) MSFD). To this end Member States must develop and implement marine strategies to protect and preserve the marine environment (Art. 1 (2) (a) MSFD). The process of developing the marine strategies is divided into six procedural steps (Art. 5 (2) MSFD):

- Initial assessment of the current environmental status (Art. 8 MSFD).
- Determination of good environmental status (Art. 9 MSFD).
- Establishment of a series of environmental targets and associated indicators (Art. 10 (1) MSFD).
- Establishment and implementation of a monitoring programme for ongoing assessment and regular updating of targets (Art. 11 (1) MSFD).
- Development of a programme of measures designed to achieve or maintain good environmental status (Arts. 13(1) to (3) MSFD).
- Entry into operation of the programme (Art. 13 (10) MSFD).

Currently, Member States are in the process of implementing programmes of measures. In guiding Member States in developing their marine strategies, Article 3(5) of the MSFD had put forward a highly ambitious and broad definition of GES: "[T]he environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions […]". This definition is complemented by several additional general criteria that require, for example, that ecosystems "function fully" and that anthropogenic inputs "do not cause pollution effects" (Art. 3(5). Ultimately, however, the content of the words "good environmental status" will be determined by the Member States themselves based on the descriptors set out in Annex I, entitled "qualitative descriptors for determining good environmental status". Regarding underwater noise, Descriptor 11 on Energy entrances requires that the introduction is at levels "that do not adversely affect the marine environment". The Commission's "Decision on Criteria and Methodological Standards on Good Environmental Status of Marine Waters" further specifies this criterion (EC 2010; Markus 2013). Given the extensive scientific gaps, the Commission Decision decided on two indicators: (a) "distribution in time and place of loud, low and mid frequency impulsive sounds"[15]; and (b) "continuous low frequency sound"[16] (for further information see Van der Graaf 2012). Both indicators require assessments and measurements of activities like pile driving, seismic surveys, and ambient noise levels (EC 2013).

At this point, however, Member States are finding it difficult to accomplish even the first steps of the MSFD with regard to underwater noise. The UK, for example, stated in early 2015 that at that point it was neither possible to provide a full assessment of underwater noise and its impacts, nor to define a relevant baseline (Defra 2015: 168–175). According to the UK, it was also not possible to set specific targets for either impulsive or ambient sounds to define GES. Nevertheless, as a next step a noise registry will be developed and established which will record noise generating activities in space and time. The data registered will then be used in future research to assess levels and patterns of noise in order to determine whether these could potentially compromise the achievement of GES. The data is also intended to inform the current licensing practices regarding offshore noise emitting activities under UK marine and coastal regulations.[17] At present, the Commission is also planning to review its decision on scientific criteria and methodological standards. Most likely,

[15] "Proportion of days and their distribution within a calendar year over areas of a determined surface, as well as their spatial distribution, in which anthropogenic sound sources exceed levels that are likely to entail significant impact on marine animals measured as Sound Exposure Level (in dB re 1µPa.s) or as peak sound pressure level (in dB re 1µPa peak) at one meter, measured over the frequency band 10 Hz to 10 kHz (11.1.1)".

[16] Trends in the ambient noise level within the 1/3 octave bands 63 and 125 Hz (centre frequency) (re 1µPa RMS; average noise level in these octave bands over a year) measured by observation stations and/or with the use of models if appropriate (11.2.1). For further information see Van der Graaf et al. 2012.

[17] The JNCC has produced statutory guidelines for minimising the risk of injury to marine mammals from seismic activities, piling and explosive use which are frequently set as license conditions (JNCC 2010a, b, B74).

this will help to further develop the shared understanding between the Member States of what GES can mean with regard to underwater noise.

52.3.4 National Legislation

To this day, no country has comprehensively regulated underwater noise. Existing national guidelines or regulations mostly concern whale-watching activities, the use of active military sonar, the application of air guns for commercial or scientific purposes, and pile-driving in offshore construction (Weir and Dolman 2007; Dolman et al. 2009; Compton et al. 2008; Firestone and Jarvis 2007: 144 ff.; ICES 2005: 33; Inkelas 2005: 215 ff).

52.3.4.1 Whale-watching

Many countries have adopted rules or guidelines governing whale-watching activities in their respective waters. Many of them have been influenced by the general guidelines adopted by the International Whaling Commission (IWC) and under ACCOBAMS (IWC 1996; ACCOBAMS 2010a). Accordingly, many of the existing national legal approaches resemble each other to some extent.[18] The purpose of the whale-watching management systems is not primarily to reduce noise input into the marine environment but to reduce the overall disturbance of the cetaceans being watched. Nevertheless, measures being included in these regimes contribute indirectly to reducing adverse noise impacts on marine cetaceans (Schachten 2011: 94 ff.).

Generally, most national rules and guidelines include a permit regime, i.e. they require an official authorization prior to whale-watching activities. Permit applicants often have to provide information about their vessels, the area of operation, and the frequency and length of the whale-watching activities. The permit is then subjected to more specific management requirements. These requirements often include, for example, that cetaceans should only be approached diagonally from the side, not be separated from their group, and not watched longer than a specified amount of time (e.g. 15 min). Many permits also establish some sort of "no approach zones" often surrounded by "caution zones". While the first type of zones usually range from 50 to 300 m and must not be entered, operators are required to reduce their speed in the caution zones and turn off their motors in close proximity to the no approach zones. Watching mother whales with their calves is often subject to stricter management requirements.

[18] Most national whale-watching rules and non-binding guidelines are collected and made available by the International Whaling Commission (IWC), (See ACCOBAMS-SC8/2012/Inf 12).

52.3.4.2 Seismic Surveys (Air Guns)

Seismic surveys carried out with air guns are also regulated under different national legal orders. At present, regulatory approaches vary largely in different states. While some countries, such as Spain and Brazil, have simply banned the use of air guns from specific areas (Real Decreto 1629/2011; CONAMA N° 350/2004), the UK, Australia (EPBC Act Policy Statement 2.1 2008), New Zealand (The Code 2013), Canada (Statement 2007) and the USA (BOEM 2014) have adopted policy statements or guidelines to reduce the adverse impacts of seismic surveys on marine mammals. As a much discussed example, the UK has adopted the "JNCC guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys" (JNCC 2010b). These guidelines are frequently used as license conditions where surveys are carried out for commercial purposes. They require users to implement a set of best practices, for example, to thoroughly plan seismic surveys, include on-board observers (Marine Mammal Observers = MMOs), undertake a "pre-shooting search", and to conduct a "soft-start" before the survey to scare away mammals potentially present in the area.[19]

52.3.4.3 Sonars

Existing national regulations regarding the use of sonar mainly address military sonar testing. Many countries' navies have individually, or—in the case of NATO or ACCOBAMS and ASCOBANS—jointly, developed mitigation guidance to protect marine life during naval exercises (Dolman et al. 2009, 2011). Most of these measures include requirements to take actions to proactively avoid mammals, to apply mitigation measures during operations, and to monitor for the purpose of maintaining an exclusion zone (Dolman et al. 2009). In some countries it has become highly contentious whether military sonar testing is subject to, national environmental law statutes. For example, despite the US Navy following mitigation measures when using sonar, NGOs have pursued several legal cases before US courts throughout the past decade (Zirbel et al. 2011). To our knowledge, only few States have by now adopted binding legislation. For example, the Spanish Government has adopted mandatory rules addressing the issue by simply banning military sonar tests from a specific marine protected area in 2008.[20]

---

[19] According to Sect. 52.3.3 of the JNCC-Guidelines the soft-start is defined as the time that air guns commence shooting until full operational power is obtained. Power should be built up slowly from a low energy start-up (e.g. starting with the smallest air gun in the array and gradually adding in others) over at least 20 min to give adequate time for marine mammals to leave the area. This build up of power should occur in uniform stages to provide a constant increase in output. A Critical approach to the JNCC Guidelines can be found in Parsons et al. 2009.

[20] ORDEN PRE/969/ 2008 N° 4 says: "Prohibition of military exercises involving the conduction of underwater explosions or use of low frequency sonars" *(Authors' translation)*. In addition, in response to whale stranding incidents the Spanish Ministry of Defense has agreed with the Regional Government of the Canary Islands that based on scientific advice it would establish a list of areas where sonar tests could be carried out in general (Schachten 2011: 100).

52.3.4.4 Offshore Constructions (Particularly Pile Driving)

The fast development of offshore wind farms draws much attention to the topic of noise mitigation for pile-driving. Many states require some type of mitigation measures as license conditions where offshore wind farm projects are being authorized. At this point administrative practices seem to vary substantially. For example, a dual threshold value has been defined by the approving authority in Germany. The observance of this threshold value of 160 dB (single event sound pressure level)/190 dB (peak-to-peak) at 750 m from the source is mandatory for the installation of offshore wind turbines in the German EEZ (BfN 2013: 1). For those foundation-types regularly used, this requirement can only be met by applying noise mitigation measures, so the industry has undertaken substantial efforts to improve available noise mitigation techniques. In contrast, no threshold value has to be met in the UK. Rather, piling operators should go through a three-step procedure. Mitigation measures have to be applied before, during, and after the piling. This includes, for example, the use of best available techniques and MMOs, the conducting of soft-starts, and reporting requirements (JNCC 2010a).

52.4 Central Management Instruments and Strategies

Quite generally, measures to reduce, limit or mitigate noise input into the sea can be grouped in measures that are to be taken before, during, or after the noise creating activity. Current protective measures can roughly be divided into three groups (Other categories are imaginable, Erbe 2013: 14–15):

- Systematic observance and record-keeping of potentially affected species as well as emission planning geared toward them, e.g.
  - Marine mammal observers on board of ships.
  - Sightings logbooks.
  - Evaluation and reporting requirements to improve knowledge in the authorising administrations.
- Measures reducing the danger of damaging fauna during the input of noise, etc., e.g.
  - Soft starts procedures, acoustic deterrence devices and shut downs.
  - Safety distances (protective zones with different levels of protections).
  - Time restrictions (e.g. time of day, seasons).
- Technical noise minimisation measures when noise input exceeds specific threshold limits, e.g.
  - Bubble curtains.
  - Speed limits.

– Material requirements.
– Construction and design standards.

It will be one of the main tasks in the future to establish foreseeable requirements in the different international and national noise regimes that reflect the best available management solutions for the species affected by underwater noise.

52.5 Best Practices

In principle, best practices can guide political, administrative and judicial decision making. In the specific context of marine noise pollution, their impact seems to be substantial. Particularly, according to UNCLOS, states are duty-bound to adopt national laws to deal with pollution arising from shipping and seabed activities subject to national jurisdiction, which must not be less effective than international standards. It cannot, however, free decision makers from considering each case individually. Regulations that make reference to noise impacts on marine environment have been adopted at the global, regional and domestic level, and their mandatory force varies greatly. Although convergences between these regulatory frameworks are numerous, some of them stand out.

In the field of whale watching, the Australian National Guidelines for Whale and Dolphin Watching 2005 are noteworthy. These standards are interesting not only because they expressly recommend the reduction of noise input, but also because they are directed to "all people", i.e. whale watchers and other non-commercial operators. The regionally developed *"Guidelines for Commercial Cetacean Watching Activities in the ACCOBAMS area"* (ACCOBAMS 2010a) should also be highlighted. They establish a strict permit scheme for commercial operators, a measure that has since been adopted in almost all whale watching regulatory frameworks (ACCOBAMS 2011). As a standard of global reach, the approach taken by the IWC regarding underwater noise is to be mentioned, i.e. "*General Principles for Whale Watching*". All these regulations are included in the ACCOBAMS' Scientific Committee document "A review of Whale Watch Guidelines and Regulations around the World—version 2011", which is a complete worldwide catalogue on whale watching standards (ACCOBAMS 2011).

Another domestic initiative that deserves attention is the Spanish "Real Decreto 1629/2011", which declares a certain marine zone as a Marine Protected Area (MPA). Instead of establishing underwater noise mitigation measures, this domestic statute simply prohibits the use of air guns within the said MPA. Noise emission likely to disturb marine animals and the use of non-military active sonar are also banned (Real Decreto 1629/2011).

Although important, none of these regulations are exclusively directed to regulate the problem of underwater noise. An important exception in this regard is the already mentioned "JNCC guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys (2010b)". These guidelines have mandatory force within the UK's domestic legal order. More importantly, they have had an impact beyond

UK borders, having become a standard adopted by other countries including Australia, Brazil, Canada, New Zealand, and some U.S. states (Parsons et al. 2009: 644).

Two of the most comprehensive initiatives exclusively directed to regulate underwater noise are the *ACCOBAMS* Resolution 4.17 "*Guidelines to address the impact of anthropogenic noise on cetaceans in the ACCOBAMS area*" (ACCOBAMS 2010b) and the ASCOBANS *"Effective Mitigation Guidance for intense noise generating activities in the ASCOBANS region"* (ASCOBANS 2009b: 11–23). Grounded in a common source of inspiration, these instruments resemble one another.[21] Both documents first provide some general guidelines applicable to any source of anthropogenic noise, and then regulate specific activities including military sonars and civil high power sonars, seismic surveys and air gun uses, coastal and offshore construction works (e.g. noise from pile drivers), offshore platforms used in all sorts of activities, such as wind-farms or oil/gas extraction, and playback and other sound exposure experiments carried out to assess the behavioral or physiological responses of animals. Finally, both guidelines refer to "other activities that require mitigation guidance". These include marine traffic (commercial, recreational or touristic), whale watching, use or disposal of explosives, and underwater acoustically active devices. Despite their similarities, only the *ASCOBANS* Guidance establishes a framework in which mitigation measures, whether general or specific, are structured in three stages: (1) Planning (e.g. EIA); (2) Real-time mitigation (e.g. monitoring and assess cumulative impacts); (3) Post activity monitoring and reporting (see in ACCOBAMS 2013c: 25–26).

Later in 2013, the JNWG prepared the ACCOBAMS *Methodological Guide: "Guidance on underwater noise mitigation measures"* (ACCOBAMS 2013b), which outlines practices and existing technologies that should be used during or instead of the activities listed in Resolution 4.17 (ACCOBAMS 2010b) above, such as seismic surveys (air gun) and military sonar (ACCOBAMS 2013b: 3). Coherent with the JNWG mandate, this "living guide" should be regularly updated (ASCOBANS 2014a, para. iii).

Finally, another important example of specific underwater noise pollution regulation is the IMO *"Guidelines for the Reduction of Underwater Noise from Commercial Shipping to Address Adverse Impacts on Marine Life"* approved in 2014 (IMO 2014). These are non-mandatory guidelines intended to provide general advice on reduction of underwater noise to designers, shipbuilders and ship operators in the context of commercial shipping only (IMO 2014, paras. 2, 3, and 4.3). They are focused on underwater noise resulting from propellers, hulls, onboard machinery, and specific vessel operations. In particular, these guidelines recognize the usefulness of underwater noise computational models to predict and understand what reductions might be achievable in new and existing ships (IMO 2014, para. 5). Also, they stress that underwater noise should be measured in accordance with an objective standard, for instance the one developed by the International Organization for Standardization (ISO) (IMO 2014, para. 6). These guidelines highlight i.a. that the largest opportunities for reduction of underwater noise are during the initial design of the ship (IMO 2014, para. 7). Accordingly, they address issues concerning propellers and hull design which are primarily aimed for new ships

[21] Both initiatives were inspired in a Report of the ACCOBAMS Scientific Committee (ACCOBAMS-MOP5/2013/Doc.22, p 21).

(IMO 2014, para. 7). Yet they also refer to some "additional technologies" that are known to contribute to noise reduction by existing ships, namely the design and installation of new state-of-the-art propellers, the installation of wake conditioning devices, and the installation of air injection to propellers (IMO 2014, para. 9). Additionally, these guidelines address the issue of the proper selection and location of the onboard machinery (IMO 2014, para. 8). Finally, they also provide for some operational and maintenance considerations to reduce adverse impacts on marine life (applicable for both new and existing ships), such as the proper cleaning of propellers, maintenance of the underwater hull, and the selection of the ship speed and route decisions (IMO 2014, para. 10).

52.6 Status and Results of Management Efforts, and Perspectives

Underwater noise has increased in the previous decades and will continue to do so. The analysis above shows that the problem has been on the international and national agenda for more than a decade so far.

Despite the persistent lack of scientific knowledge regarding the effects of underwater noise on marine fauna, it is widely accepted that noise input to the marine environment can result in significant damage to marine life. Some important regulatory developments have been achieved in recent years, though not by binding international treaties or national legal statutes. As seen, international treaties often refer to marine pollution in broader terms, and explicit references to underwater noise in treaty provisions are rare. Meanwhile, few States have enacted national legislation, and even then only with respect to some specific sources of underwater noise.

Regulatory frameworks have instead been mostly developed in the form of soft-law standards. Guidelines and best practices governing the use of different sources of underwater noise have been generated within different fora, such as the ACCOBAMS or the IMO, and at different levels, whether national, supranational, or international (e.g. ACCOBAMS 2010a; ACCOBAMS 2010b; IMO 2014; JNCC 2010b; MSFD 2008). These standards can address either one specific (IMO 2014) or several (e.g. ACCOBAMS 2010b) source(s) of anthropogenic noise input to the marine environment, whereas others set mitigation measures aimed to reduce the overall disturbances on marine life, including underwater noise (IWC 1996). Soft-law, however, may present several weaknesses, the most evident being that it is not legally binding and therefore difficult to enforce. Against this background, it is interesting to ask if hard-law regulations on underwater noise would be better able to handle the problem. Put differently, is the current legal framework for the protection of the marine environment sufficient?

Guidelines and best practices have the advantage of being easily modifiable and therefore adaptable to new developments. Indeed, regular updates are often required by the guidelines. Unlike hard-law regulations, this task is often left to relevant expert bodies like the JNWG rather than to international conferences or the domestic legislatures. Accordingly, the whole standard-setting and updating process is faster and less complicated, and likely more appropriate to address the problem at hand. Given that scientific research regarding the impacts of underwater noise on marine life is still developing, this characteristic seems critical for the regulation of the subject. More to the point, this seems appropriate given that underwater noise sources (e.g. sonars, shipping, offshore wind farms are often linked to new technologies, which change and develop relatively fast.

All the aforesaid advantages, however, do not imply that the regulation of underwater noise is or should be exclusively relegated by means of soft-law. Binding international treaties do indeed play an essential role in the development of these standards. International law provides for general principles applicable to marine environmental protection. As previously discussed, these broad provisions are found in documents like UNCLOS. They can be applied to noise as well as any other type of marine pollution and in so doing provide some legally binding grounds for soft-law developments on underwater noise. The best outcome will probably be an interesting interplay between these two forms of regulation. While guidelines and best practices generally come to further develop existing broad international law provisions (i.e. general norms on marine environmental protection), they can be helpful as a means to interpreting already existing provisions too. In short, soft-law can be an important device for the attribution of meaning to already binding international legal rules (Boyle and Chinkin 2007: 12).[22]

Another interesting aspect of the many different underwater noise regulations is that measures adopted under different regimes and at different levels surprisingly resemble one another and are even frequently coordinated. This is because different regimes tend to work jointly on the topic at the international level. In turn, national regulations are influenced by international initiatives and vice-versa. This back-and-forth interplay can also be linked to the most evident shortcoming of the current crop of international underwater noise standards: the regulations are largely limited to one particular region. Most of the international approaches (including the ACCOBAMS, ASCOBANS, and MSFD guidelines) are limited to Europe, despite the fact that many marine mammals and fish migrate long distances across continents. So truly effective regulations would require that the development of underwater noise regulatory frameworks also occurs in other regions where these animals transit. In this regard, it would be interesting to map similar initiatives which might emerge in other regions of the world, and to study what impact European or other existing national standards have on them. Based on current developments, it can be expected that they may evolve in the same direction. It would also be interesting to analyze if and to what extent regimes evolve in a coordinated way.

Another important issue to be addressed in the future might be to determine what the relationship is between underwater noise and other stressors or sources of pollution (such as submarine cables, ocean acidification, or light).

It is also worth remembering that sound is energy,[23] and as such, it may yet be turned into an economic good with a variety of applications. At best, energy is trans-

[22] This holds particularly true where standards are developed within the framework of provisions such as article 208(2), 2010(6), 211(2) or of the UNCLOS. These provisions requires that states establish international standards and recommended practices and that states have to follow these standards when adopting national laws and regulations to deal with pollution. See, for example, in the context of indigenous peoples rights, the Inter-American Court of Human Rights hvas held that Environmental and Social Impact Assessments shall be conducted in conformity with relevant international standards and best practices like the Akwé: Kon Guidelines (*Saramaka* case, para. 41).

[23] See Section 3.2.1 above.

ferred, converted or simply stored for later use. In this vein, it is interesting to consider a statement made by the U.S. National Oceanic and Atmospheric Administration (NOAA) almost one decade ago (Southall and Scholik-Schlomer 2008: 7): underwater noise emanating from different activities, like propulsion systems, can be thought to represent inefficiency or wasted energy that could otherwise be used for more productive ends. Future management approaches under existing and developing regimes will have to keep this point in mind as they will try to make use of scientific and technological developments in order to reduce the adverse impacts of underwater noise.

Finally, the regulation of underwater noise is beneficial to the marine environment. However, as Boebel et al. point out, restricting noise inputs in the marine environment may also reduce potential benefits of those regulated activities or simply transfer or transform their negative effects (Boebel et al., in this book). For example, activities maybe prolonged which could lead to less offshore wind farms built per year, longer seismic surveys due to shut downs, longer shipping routes, or higher risks for personnel and gear due to longer times at sea. Thus, to be environmentally sound, effective, economically viable, and operationally realistic, regulations must consider all the relevant stakeholders' knowledge and interests and be flexible enough to facilitate implementation of new scientific insights into existing regulations (Boebel et al., in this book). An example of good governance in this regard seems to be the aforementioned JNWG-working group. Probably based in such concerns, its Terms of Reference establishes that its members may be relevant experts from the fields of science, policy and industry and relevant civil society organizations (ASCOBANS 2014a, para. ii). One of the main tasks of this working group is to further update and improve the existing guidelines (ASCOBANS 2014a; ACCOBAMS 2013b: 3).

References

1946 International Convention for the Regulation of Whaling (1946) 62 Stat. 1716; 161 UNTS 72

1959 Antarctic Treaty (1980) 12 UST 794; 402 UNTS 71; 19 ILM 860

1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter (London) 26 UST 2403, TIAS 8165; UKTS 43 (1976) Cmnd. 6486; 11 ILM (1972), 1294; B&B Docs, 174. In force on 30 August 1975. To be replaced by 1996 Protocol q.v. London Convention

1973 International Convention for the Prevention of Pollution from Ships (MARPOL) of 1973 12 ILM 1319 (1973) TIAS No. 10,561; 34 UST 3407;1340 UNTS 184; amended by the Protocol of 1978 Relating to the International Convention for the Prevention of Pollution from Ships, 1340 UNTS 61; 17 ILM 546 (1978), before entry into force

1979 Convention on the Conservation of Migratory Species of Wild Animals (CMS) 1651 UNTS 333; 19 ILM 15 (1980); ATS 1991/32; BTS 87 (1990), Cm. 1332

1991 Protocol on Environmental Protection to the Antarctic Treaty (Madrid Protocol) 30 ILM 1455 (1991)

1992 Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS) 1772 UNTS 217

1992 Convention on Biological Diversity (CBD) 1760 UNTS 79; 31 ILM 818 (1992)

1992 Rio Declaration on the Environment and Development (Rio Declaration) UN Doc. A/CONF.151/26 (vol. I) /31 ILM 87 (1992)

1992 United Nations Framework Convention on Climate Change (UNFCCC), 1771 UNTS 107; S. Treaty Doc No. 102–38; U.N. Doc. A/AC.237/18 (Part II)/Add.1; 31 ILM 849 (1992)

1992 Agenda 21 Programme of Action for Sustainable Development, U.N. GAOR, 46th Sess., Agenda Item 21, UN Doc A/Conf.151/26 (1992)
1992 Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) 2354 UNTS 67; 32 ILM 1069 (1993)
1992 Convention on the Protection of the Marine Environment Of the Baltic Sea (Helsinki Convention), 2099 UNTS (1992)
1996 Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS), November 24, (1996), 36 I.L.M. 777
1997 Agreement on the Conservation of Cetaceans in the Black Sea Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS), 36 I.L.M. 777 (1997)
ACCOBAMS (2004) Resolution 2.16 Assessment and impact assessment of man-made noise
ACCOBAMS (2007) Resolution 3.10 Guidelines to address the impact of anthropogenic noise
ACCOBAMS (2010a) Guidelines for Commercial Cetacean Watching Activities in the ACCOBAMS area
ACCOBAMS (2010b) Resolution 4.17 Guidelines to address the impact of anthropogenic noise on cetaceans in the ACCOBAMS area
ACCOBAMS. (2011) A review of whale watch guidelines and regulations around the world—version 2011, ACCOBAMS-SC8/2012/Inf 12
ACCOBAMS (2013a) Resolution 5.15 Addressing the Impact of Anthropogenic Noise
ACCOBAMS (2013b) Methodological Guide: "Guidance on underwater noise mitigation measures", ACCOBAMS-MOP5/2013/Doc.24
ACCOBAMS (2013c) Anthropogenic noise and marine mammals: review of the effort in addressing the impact of anthropogenic underwater noise in the ACCOBAMS and ASCOBANS areas ACCOBAMS-MOP5/2013/Doc.22
ASCOBAN (2003) Resolution No. 5 Esbjerg, Denmark
ASCOBANS (2006) Resolution No. 4. The Netherlands
ASCOBANS (2009a) Resolution No. 2. Bonn. Germany
ASCOBANS (2009b) Final Report of the ASCOBANS Intersessional Working Group on the Assessment of Acoustic Disturbance, Bonn, Germany
ASCOBANS Terms of Reference for a Joint Noise Working Group (JNWG) of CMS, ACCOBAMS and ASCOBANS (2014a)
ASCOBANS Operational Procedures for the Joint Noise Working Group (JNWG) of CMS, ACCOBAMS and ASCOBANS (2014b)
ASCOBANS (2014c). Report of the Joint ACCOBAMS/ASCOBANS Noise Working Group, AC21/Doc.3.2.1 (WG)
Australian National (2005) Guidelines for Whale and Dolphin Watching
Australian Government (2006) Department of the Environment and Heritage
Australian Government (2008) Department of the Environment, Water, Heritage and the Arts, EPBC Act Policy Statement 2.1—Interaction between offshore seismic surveys and whales
Baggs v United Kingdom (1985) 44 DR 13; (1987) 52 DR 29)
Barcelona Traction 1970 Light and Power Company Limited Judgement, I.C.J. Reports, p 3
Birnie P, Boyle A, Redgwell C (2009) International law & the environment. Oxford University Press, Oxford
Boyle A, Chinkin C (2007) The Making of International Law. Oxford University Press, Oxford
Case of the Saramaka People v. Suriname Interpretation of the Judgment on Preliminary Objections, Merits, Reparations, and Costs, IACtHR, 2008
Convention on Biological Diversity (2004) Akwé: Kon Guidelines for the Conduct of Cultural, Environmental and Social Impact Assessments Regarding Developments Proposed to Take Place on, or which are Likely to Impact on, Sacred Sites and on Lands and Waters Traditionally Occupied or Used by Indigenous and Local Communities. Secretariat of the Convention on Biological Diversity

Convention on the Conservation of Migratory Species of Wild Animals (CMS) (2005) Resolution 8.22 Adverse human induced impacts on cetaceans
Convention on the Conservation of Migratory Species of Wild Animals (CMS) (2011) Resolution 10.24. Further steps to abate underwater noise pollution for the protection of cetaceans and other migratory species. Bergen
Convention on the Conservation of Migratory Species of Wild Animals (CMS) (2008) Resolution 9.19 Adverse anthropogenic marine/ocean noise impacts on cetaceans and other biota
Code of Conduct for Minimising Acoustic Disturbance to Marine Mammals from Seismic Survey Operations (the Code), New Zealand, 2013
Compton R, Goodwin L, Handy R, Abbott V (2008) A critical examination of worldwide guidelines for minimising the disturbance to marine mammals during seismic surveys. Mar Policy 32:255–262
Johnson LS (2004) Coastal state regulation of international shipping. Oceana, New York
Department for Environment, Food & Rural Affairs (Defra) UK Government (2015) Marine Strategy Framework Directive consultations—Programmes of Measures
Dolman SJ, Weir CR, Jasny M (2009) Comparative review of marine mammal guidance implemented during naval exercises. Mar Pollut Bull 58:465–477
Dolman SJ, Evans PGH, Notarbartolo-di-Sciara G, Frisch H (2011) Active sonar, beaked whales and European regional policy. Mar Pollut Bull 63:27–34
Dotinga HM, Elferink AGO (2000) Acoustic pollution in the oceans: the search for legal standards. Ocean Dev Int Law 31:151–182
Erbe C (2013) International regulation of underwater noise. Acoustics Australia 41:12–19
European Commission. (2010) Decision 477/2010/EU on Criteria and Methodological Standards on Good Environmental Status of Marine Waters OJ L232/14
European Communities—EC Measures Concerning Meat and Meat Products (Hormones)—AB-1997-4—Report of the Appellate Body (1998) World Trade Organization, WT/DS26/AB/R; WT/DS48/AB/R
European Parliament Resolution on the environmental effects of high-intensity active naval sonars, 14.07.2005 ABl. 2005 Nr. C174 E/186
EU Communication from the Commission on the precautionary principle (COM (2000) 1 final of 2 February 2000)
EU Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive), Directive 2008/56/EC, OJ 2008 No. L164/19. (MSFD)
European Commission, Report, European Marine Strategy Framework Directive Working Group on Good Environmental Status (WG-GES) Guidance for setting up underwater noise monitoring in European Seas. 2013
Federal Agency for Nature Conservation (Bundesamt für Naturschutz, BfN), Development of Noise Mitigation Measures in Offshore Wind Farm Constructions. 2013
Federal Government of Canada and Provincial Governments of Nova Scotia (2007) Newfoundland and Labrador, British Columbia and Quebec, Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment
Firestone J, Jarvis C (2007) Response and responsibility: regulating noise pollution in the marine environment. J Int Wildlife Law Policy 10:109–152
Gabčíkovo-Nagymaros Project (Hungary v. Slovakia), Judgment, I.C.J. Reports 1997
Gillespie A (2006) Establishing reliable foundations for the international scientific investigation of noise pollution in the oceans. RECIEL 15(2):211–226
Gillespie A (2007) The precautionary principle in the twenty-first century: a case study of noise pollution in the ocean. Int J Mar Coastal Law 22:61–87
Hatton v United Kingdom (2002) 34 EHRR 1; (2003) 37 EHRR 28
Horowitz C, Jasny M (2007) Precautionary management of noise: lessons from the U.S. marine mammal protection act. J Int Wildlife Law Policy 10:225–232

Hubert AM (2011) The new paradox in marine scientific research: regulating the potential environmental impacts of conducting ocean science. Ocean Dev Int Law 42:229–355
International Maritime Organization (IMO) (2008) Document MEPC 57/INF.22. "Comment on document MEPC 57/INF.4"
International Maritime Organization (IMO) (2014) Document MEPC.1/Circ.833, "Guidelines for the Reduction of Underwater Noise from Commercial Shipping to Address Adverse Impacts on Marine Life"
Inkelas D (2005) Security, sound, and ceataceans: legal challenges to low frequency active sonar under U.S. and international environmental law. Wash Int'l L Rev 37:207–249
International Council for the Exploration of the Seas (ICES) (2005) Report of the Ad-hoc Group on the Impacts of Sonar on Cetacean and Fish (AGISC). Kopenhagen. CM 2006/ACE:06
International Fund for Animal Welfare (IFAW) (2008) Ocean noise: turn it down. Port, Yarmouth
International Whaling Commission (IWC) (2001) Draft Articles on Responsibility of States for Internationally Wrongful Acts, with commentaries. Yearbook of the international law commission. 2001. vol. II
International Whaling Commission (IWC) (1996) General Principles to minimise the risks of adverse impacts of whalewatching on cetaceans
International Whaling Commission (IWC) (1998) Resolution 1998–6 for the Funding of Work on Environmental Concerns
Joint Nature Conservation Committee (JNCC) (2010a) Statutory nature conservation agency protocol for minimising the risk of injury to marine mammals from piling noise
Joint Nature Conservation Committee (JNCC) (2010b) JNCC guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys
Joint Nature Conservation Committee (JNCC) (2010c) JNCC guidelines for minimising the risk of injury to marine mammals from using explosives
Markus T, Schlacke S, Maier N (2011) Legal implementation of integrated ocean policies: the EU's marine strategy framework directive. Int J Mar Coastal Law 26:1–32
Markus T (2013) Changing the base: legal implications of scientific criteria and methodological standards on what constitutes good marine environmental status. Transnation Environ Law 1:1–21
Markus T, Huhn K, Kai B (2015) The quest for sea-floor Integrity. Nat Geosci:163–164
Mauermann D (2008) Rechtsgrundsätze im Völkerrecht am Beispiel des Vorsorgeprinzips
Molenaar EJ (1998) Coastal state jurisdiction over vessel-source pollution. Kluwer Law International, The Hague
Miller PJO, Biassoni N, Samuels A, Tyack PL (2000) Whale songs lengthen in response to sonar. Nature 405:903–903
Ministério do Meio Ambiente (2004) Resolução CONAMA N° 350/2004—"Dispõe sobre o licenciamento ambiental específico das atividades de aquisição de dados sísmicos marítimos e em zonas de transição"—Data da legislação: 06/07/2004—Publicação DOU no. 161, de 20/08/2004, págs. 80–81
McCauley RD, Fewtrell J, Popper AN (2003) High intensity anthropogenic sound damages fish ears. J Acoust Soc Am 113:638–642
McCarthy EM (2001) International regulation of transboundary pollutants: the emerging challenge of ocean noise. Ocean Coastal Law J 6:257–292
National Research Council (NRC) (2005) Marine mammal populations and ocean noise: determining when noise causes biologically significant effects. NRC, Washington, DC
ORDEN PRE/969/2008, de 3 de abril, por la que se publica el Acuerdo de Consejo de Ministros, por el que se adoptan medidas para la protección de la zona marina "El Cachucho", Boletín Oficial del Estado (BOE), núm. 86 Nr. 6287, p 19331
Parsons ECM, Dolman SJ, Jasny M, Rose NA, Simmonds MP, Wright AJ (2009) A critique of the UK's JNCC seismic survey guidelines for minimizing acoustic disturbance to marine mammals: best practice? Mar Pollut Bull 58:643–651
Patenaude NJ, Richardson WJ, Smultea MA, Koski WR, Miller GW, Würsig B, Greene JR, C.R. (2002) Aircraft sound and disturbance to bowhead and beluga whales during spring migration in the alaskan beaufort sea. Mar Mamm Sci 18:309–335
Pulp Mills on the River Uruguay (Argentina v. Uruguay), Judgment, I.C.J. Reports 2010)

Real Decreto 1629/2011 por el que se declara como Área Marina Protegida y como Zona Especial de Conservación el espacio marino de El Cachucho, y se aprueban las correspondientes medidas de conservación, Boletín Oficial del Estado múm.295
Rehbinder E. (1991) Das Vorsorgeprinzip im internationalen Vergleich
Sands P (2012) Principles of international environmental law. Cambridge University Press, Cambridge
Scott KN (2004) International regulation of undersea noise. Int Compar Law Q 53:287–324
Scott KN (2007) Sound and cetaceans: a regional response to regulating acoustic marine pollution. J Int Wildlife Law Policy 10:175–199
Schachten, C. (2011) Akustische Meeresverschmutzung (2011)
Southall BL, Scholik-Schlomer A (2008) Final report of the NOAA International Conference: "Potential Application of Vessel-Quieting Technology on Large Commercial Vessels," 1–2 May, 2007, Silver Spring, MD, USA
Southern Bluefin Tuna Cases (provisional measures) ITLOS Nos 3&4 (1999)
The International Union for Conservation of Nature and Natural Resources (IUCN) (2004) Undersea Noise Pollution, Gland
United Nations Environment Programme (UNEP) (1989) 15th Governing Council Session, Decision 15/27—Precautionary approach to marine pollution, including waste-dumping at sea (decision 15/27)
United Nations Environment Programme (UNEP) (2008) UNEP/CMS/Resolution 9.19/2008 on Adverse Anthropogenic Marine/Ocean Noise Impacts on Cetaceans and Other Biota, Adopted by the Conference of the Parties to the CMS, at its Ninth Meeting (Rome 1–5 December 2008)
United Nations Environment Programme (UNEP) (2012) UNEP/CBD/COP/DEC/XI/18 on "Marine and coastal biodiversity: sustainable fisheries and addressing adverse impacts of human activities, voluntary guidelines for environmental assessment, and marine spatial planning". 2012
United Nations Environment Programme (UNEP) (2014) UNEP/CBD/COP/DEC/XII/23 on "Marine and coastal biodiversity: Impacts on marine and coastal biodiversity of anthropogenic underwater noise and ocean acidification, priority actions to achieve Aichi Biodiversity Target 10 for coral reefs and closely associated ecosystems, and marine spatial planning and training initiatives". 2014
United States Department of the Interior Bureau of Ocean Energy Management (BOEM) Bureau of Safety and Environmental Enforcement (BSEE) Gulf of Mexico Outer Continental Shelf (OCS) Region, Joint NTL N° 2012-G02, Implementation of Seismic Survey Mitigation Measures and Protected Species Observer Program 2014
US Marine Mammal Commission (MMC) 2005 Advisory committee on acoustic impacts on marine mammals, report to the marine mammal commission, Washington, DC
United Nations General Assembly (UNGA) (2005) Resolution "Oceans and the Law of the Sea", A/RES/60/30
United Nations General Assembly (UNGA) (2014) Resolution Oceans and the Law of the Sea, A/RES/69/245
Van der Graaf, A.J., Ainslie, M.A., André M., Brensing, K., Dalen J. Dekeling RPA, Robinson S, Tasker, ML, Thomsen, F. Werner, S (2012) European Marine Strategy Framework Directive—Good Environmental Status (MSFD GES): Report of the Technical Subgroup on Underwater noise and other forms of energy
Van Dyke JM, Gardner EA, Morgan JR (2004) Wales, Submarines, and active Sonar. Ocean Yearbook 18:330–363
Weir CR, Dolman SJ (2007) Comparative review of the regional marine mammal mitigation guidelines implemented during industrial seismic surveys, and guidance towards a worldwide standard. J Int Wildlife Law Policy 10:1–27
Whale & Dolphin Conservation Society (WDC) (2004) Ocean of Noise—a WDCS Science Report, Chippenham (WDC 2004)
World Health Organisation (WHO) 2016 Health topics, noise. http://www.euro.who.int/en/health-topics/environment-and-health/noise/noise. Accessed 30 Mar 2016
World Medical Association (WMA) (1992) Statement on Noise Pollution. World Medical Journal 54:7
Zirbel K, Balint P, Parsons ECM (2011) Navy sonar, cetaceans and the US Supreme Court: a review of cetacean mitiation and litigation in the US. Mar Pollut Bull 63:40–48

Chapter 53
Marine Geo-Engineering

Harald Ginzky

Abstract In this chapter an overview is given of the existing international regulation of marine geo-engineering techniques. Two techniques—ocean fertilization and the sequestration of carbon dioxide in sub-seabed geological formations—have been either experimentally studied or even deployed, whereas all other forms of marine geo-engineering have remained in their early infancy. Both techniques could pose a significant risk to the environment. In 2008 Contracting Parties to both the London Convention and the London Protocol and the Parties to the Convention on Biological Diversity (CBD) adopted a non-binding moratorium on ocean fertilization activities with the exemption of small-scale research projects. In 2010 this non-binding moratorium was extended to all climate-engineering activities by Parties to the CBD. In 2013 a—legally binding—amendment to the London Protocol with regard to the regulation of marine geo-engineering activities was approved. The amendment could serve as a model for the regulation of other climate-engineering activities (e.g. solar radiation management in the stratosphere) in many respects.

Keywords Marine climate engineering • Marine geo-engineering • Ocean fertilization • Sequestration of carbon dioxide in sub-seabed geological formations • Convention on biological diversity • London convention • London protocol

53.1 Introduction

Marine geo-engineering techniques like ocean fertilization and the sequestration of carbon dioxide in sub-seabed geological formations are regarded as options to mitigate climate change. At the same time both activities bear the potential to pose significant risks to the marine environment. The article will start with a short overview of marine geo-engineering technologies including their state of development and an

H. Ginzky
German Environment Agency, Dessau-Roßlau, Germany
e-mail: harald.ginzky@uba.de

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_53

explanation why management is required. The main part of the article will analyze the existing international legal framework which governs marine geo-engineering. Relevant provisions of international sea law (UN Convention on the Law of the Sea, London Convention and London Protocol) and of the CBD will be explained and key decisions taken by the Parties to these agreements will be presented. The amendment to the London Protocol in 2013 with regard to the regulation of marine geo-engineering activities will be analyzed in greater depth because it could serve as a model for future regulation of other climate engineering techniques. This will be followed by some instructive considerations for future regulation of climate change technologies. The article will end with conclusions and an outlook.

53.2 Marine Geo-engineering Technologies and Why Management Is Required

In recent years discussions have focused on the possibilities which deliberate, large-scale technological interventions in the climate system present for addressing man-made climate change. Two main categories of geo-engineering techniques can be distinguished: solar radiation management, which aims to reduce the incidence and absorption of incoming solar radiation so as to cool the atmosphere at ground level; and carbon dioxide removal, which aims to reduce the level of atmospheric carbon dioxide (The Royal Society United Kingdom 2009: 1; Ginzky et al. 2011: 2).

The development of geo-engineering techniques is highly controversial and divided. Those in favour argue that it is necessary to have a 'Plan B' in case mitigation and adaptation measures to combat climate change fall short. In contrast, those who oppose climate engineering techniques argue that these techniques could pose significant risks to the environment and human life. In addition, two arguments are usually highlighted: First, the so called moral-hazard argument which means that the option of large scale technological solutions to address climate change could reduce mitigation and adaptation efforts. Second, the slippery slope assumption which means that all research finally and inevitably slips into deployment (Schäfer et al. 2015: 58, 67; Bodle et al. 2014: 40).

Both categories of geo-engineering techniques have also been considered for use in the seas, and are then referred to as marine geo-engineering activities. As carbon dioxide removal techniques, physical methods for enhancing oceanic CO_2 uptake (artificial up- or downwelling, direct injection of CO_2 into the ocean, dumping of terrestrial biomass into the deep ocean) as well as chemical or biological methods for enhancing oceanic CO_2 uptake (for the latter: coastal management, ocean fertilization) are under consideration. For solar radiation management, theoretical concepts exist with regard to ocean albedo modification, marine cloud brightening, earth radiation management (Keller 2016, in this book).

So far most suggested climate engineering techniques are in their infancy, and while there is yet little or no evidence of their effectiveness, they could potentially pose significant risks for human beings and the environment (Ginzky et al. 2011: 41–43).

Among marine geo-engineering techniques there are two technologies which have gone beyond the stage of purely theoretical concepts. First, projects have been conducted to sequester carbon dioxide into sub-seabed geological formations (Keller 2016, in this book). Second, with regard to ocean fertilization[1] several field experiments have been conducted so far (Markus and Ginzky 2011: 477). Three projects attracted much publicity. In 2007 the intention of Planktos Incorporated, a California based company, to undertake a significant ocean fertilization activity near the Galapagos Islands was reported (IUCN 2007; Greenpeace 2007). In 2009 the German Alfred Wegener Institute for Polar and Marine Research, in cooperation with Indian partners, undertook the LOHAFEX experiment—almost immediately after the decisions taken by the Contracting Parties to London Convention and Protocol and the Parties to CBD. Additional impetus for regulating ocean fertilization was provided by the 'salmon enhancement' experiment undertaken by the Haida Salmon Restoration Corporation in international waters off the coast of British Columbia, Canada in July 2012.

The level of potential risk and the level of uncertainties are believed to differ for the two technologies. In the case of carbon dioxide sequestration risks are seen as being manageable (Resolution LP.1(1) of 2 November 2006). With respect to ocean fertilization the Scientific Group of the London Convention and Protocol stated in 2008 that "[b]ased on the *in situ* ocean fertilization and associated modelling studies conducted thus far, there is insufficient scientific evidence to determine whether ocean fertilization activities would or would not pose significant risks of harm to the marine environment." (IMO Doc. LC/SG 31/16).

During the regulation process the following aspects were deemed especially important:

- Overall effects for climate change policy.
- Efficiency as climate change mitigation measure.
- State of development of each technology.
- Potentially negative effects on humans or the marine environment of each technology.

53.3 Institutional and Legal Framework Governing Marine Geo-Engineering

The analysis of the institutional and legal framework will focus on carbon dioxide sequestration and ocean fertilization. Both activities are currently regulated under international law. No specific legal analysis is conducted here for all other forms of marine geo-engineering.

Of particular importance are the provisions of international sea law and of the CBD. Non-binding decisions were adopted in the context of the London Convention and London Protocol and CBD.

The following overview is intended to assist the reader to understand the analysis. First, international environmental law mostly comprises of treaty law which means that the provisions of an international treaty are obligatory only for the par-

[1] For a succinct description of the hypothesis which proposed stimulating the growth of phytoplankton in iron deficient areas of the ocean as a means of sequestering carbon dioxide see Roberts 2012, pp. 251–253.

ties to this treaty. Thus, as the USA is not party to the CBD it is not bound by its provisions. Second, international environmental law could be described as fragmented. Different treaties might tackle the same issue by adopting a similar approach but achieving different outcomes (which as stated are only mandatory for the respective parties). Third, much of international law is so called ‘soft law’ which means that it is not legally binding. For example, decisions taken by the Conference of Parties to an international treaty are often not legally binding.[2] From a political perspective, the difference might not be that important because most non binding agreements and decisions could potentially impose a strong de facto commitment (Ginzky 2010: 69). Fourth, amendments to a treaty usually require a specific quorum of ratifications by parties to this treaty to enter into force. In the case of the London Protocol, ratification by two thirds of the Contracting Parties is required (Article 22 (3) LP).

53.3.1 UNCLOS

The United Nations Convention on the Law of the Sea (UNCLOS) has been referred to as the “constitution of the oceans” (Freestone and Rayfuse 2008: 227). It is almost universally applicable, although the US has not yet ratified it.[3]

Part XII of UNCLOS which deals with the protection and preservation of the marine environment is of paramount importance to this chapter. Article 192 UNCLOS obliges the Parties to protect and preserve the marine environment. Article 193 UNCLOS states that “States have the sovereign right to exploit their natural resources” provided they abide by the other obligations stated in UNCLOS.

The crucial provision is Article 194 (1) UNCLOS. This provision requires the Parties to take—individually or jointly—all necessary measures to prevent, reduce or control pollution of the marine environment. According to Article 194 (1) together with (3) UNCLOS all sources of pollution have to be taken into account.

The term “pollution of the marine environment” is defined by Article 1(1)(4) of UNCLOS: it “means the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities constitution of the sea.”

This definition is very broad, including the direct or indirect introduction of substances or energy and also referring to effects which are only likely to occur

[2] Some treaties declare certain categories of decisions taken by its members as legally binding. See Article 13 (2) OSPAR. However, this is not the common approach, at least for global instruments.

[3] The US regards the UNCLOS provisions as a declaration of already existing international customary law.

(Schlacke et al. 2012: 10). Since most if not all marine geo-engineering activities pose risks to the marine environment the general obligation laid down in Article 194 UNCLOS has to be complied with.

Article 207 to Article 212 UNCLOS contain more detailed provisions with respect to pollution from different sources such as, inter alia, land based sources, dumping or vessels. However, UNCLOS does not contain any specific and distinct provision specifically with regard to marine geo-engineering activities.

Article 197 UNCLOS commits all Parties to working together at the regional or global level in order to formulate common and specific requirements for activities which are potentially detrimental to the marine environment.[4]

53.3.2 London Convention/London Protocol

The London Convention and the London Protocol have their basis in the framework provisions of Article 194, Article 197, and Article 210(4) of the UNCLOS. The core mandate of both the London Convention and the London Protocol is the regulation of dumping of "wastes or other matter" in the marine environment (Article I London Convention; Article 2 London Protocol). Both the sequestration of carbon dioxide and ocean fertilization are premised on the introduction of matter into the marine environment. This matter is, in the case of carbon dioxide sequestration, carbon dioxide streams, and, in the case of ocean fertilization, nutrients. These techniques are therefore covered by the mandate of London Convention and London Protocol.

It should be noted that the London Protocol which entered into force in 2006 is not an instrument implementing the London Convention. In fact, it is a stand-alone treaty, which supersedes the London Convention for its Contracting Parties.[5] However, the London Convention currently has 87 Contracting Parties whereas only 48 States have joined the London Convention.[6] It was agreed in 2006 to follow the concept of "two instruments, one family," which in practice means that both agreements work under the same organizational structures and that the Contracting Parties to the Convention and Protocol meet and negotiate jointly.[7]

In order to speed up ratifications to the London Protocol it was agreed amongst the Contracting Parties to both instruments that the London Convention should not be amended further (Circular letter No.2984 of 20 September 2009). In 2014 the

[4] For a more detailed analysis of the UNCLOS provision, especially with regard to OF, see Schlacke et al. (2012): 8 passim.

[5] See Article 23 LP. States being Parties to both the London Convention and the London Protocol have contractual obligations to the respective Parties of each treaty.

[6] See http://www.imo.org/en/OurWork/Environment/LCLP/Pages/default.aspx.

[7] The fundamental reason for this is to work efficiently by avoiding additional meetings of the Contracting Parties and the Scientific Group.

Contracting Parties to the London Protocol relaunched efforts to increase ratifications or accessions to the London Protocol.[8]

The London Protocol, compared to the Convention, pursues a modern and more stringent regulatory approach. In particular, it generally prohibits dumping and lists only *exempted* waste categories in its Annex 1 (reverse list approach). In contrast, the London Convention lists only *prohibited* waste materials in its Annex 1. The Protocol's reverse list approach could be considered an expression of the precautionary principle, which is one of the general principles underlying the London Protocol (Article 2).

The term "dumping" means, *inter alia,* "any deliberate disposal … of waste or other matter from vessels, aircrafts, platforms or man-made structures at sea." Both the London Convention and the London Protocol exclude an activity referred to as placement from the definition of "dumping", defining this activity as "placement of matter for a purpose other than the mere disposal thereof, provided that such placement is not contrary to the aims of this Protocol" (Article 1.4.2.2 London Protocol).[9]

In the case of both carbon dioxide sequestration and ocean fertilization, "wastes or other matter" are deliberately introduced into the marine environment. The legal categorization of both techniques as either dumping or placement was disputed amongst the Contracting Parties. Carbon dioxide sequestration was finally regarded as "dumping". As for ocean fertilization, it was argued that the technique has to be qualified as "placement" because nutrients are introduced into the ocean in order to increase primary production. It was argued that introducing nutrients for the purpose of fertilization has to be seen as a "purpose other than the mere disposal thereof" (Ginzky and Frost 2014: 83).

Marine geo-engineering activities which do not involve the "deliberate disposal" or "introduction" of matter (like most marine SRM techniques) do not fall within the ambit of either dumping or placement. In general, since both instruments obligate their Contracting Parties to "individually and collectively protect and preserve the marine environment from all sources of pollution," it would be legally possible for the Contracting Parties to take action, e.g. by amending the existing provisions.

53.3.2.1 Sequestration of Carbon Dioxide

In the first years of this century many Contracting Parties saw the sequestration of carbon dioxide as a feasible option to combat climate change. A lengthy discussion took place to analyze the existing legal framework of London Convention and London Protocol with regard to this technique. Finally, it was decided that an unequivocal provision is needed to clarify the extent of coverage for respective activities and to avoid detrimental effects for the marine environment.

---

[8] See LC 36/16—Report of the thirty-sixth Consultative Meeting and the ninth Meeting of Contracting Parties.

[9] An identical wording could be found in Article III 1 iii London Convention.

As stated above, under the London Protocol, dumping activities are prohibited, unless for such waste categories listed in Annex 1.Therefore, Contracting Parties to the London Protocol added the waste category "carbon dioxide streams from carbon dioxide capture processes for sequestration" to Annex 1 (new 1.8) in 2006 thereby allowing this waste category to be considered for dumping (Resolution LP.1(1) of 2 November 2006).

In order to protect the marine environment, conditions were inserted which have to be complied with for carbon dioxide sequestration. According to the new No. 4 in Annex 1 to the Protocol, "carbon dioxide streams" may only considered for dumping if all three of the conditions set out below are complied with:

- "Disposal is into a sub-seabed geological formation; and
- they consist overwhelmingly of carbon dioxide. They may contain incidental associated substances derived from the source material and the capture and sequestration processes used; and
- no waste or other matter are added for the purpose of disposing of those wastes or other matter."

The three conditions determine the legal scope of permissible sequestration activities. Condition No 1 excludes activities to sequester carbon dioxide streams into the water column, which was a major concern of several Contracting Parties because it was thought to involve unacceptable serious risks. The term "carbon dioxide streams" was chosen because carbon dioxide captured from industrial processes can never be pure. However, the view was that techniques should be applied to keep the streams as pure as possible and that in no case waste or other matter should intentionally be added in order to dispose of them (Conditions No. 2 and 3). The amendment entered into force 100 days after its adoption, as provided for in Article 22 (4) LP (LC-LP.1/Circ.5 of 27 November 2006).

Article 4.2 LP requires issued permits to comply with Annex 2, which lists general requirements for assessment of effects on the marine environment. Moreover, Contracting Parties have followed the approach of delivering "specific guidelines" for each waste category listed in Annex 1. Thus, guidelines were also adopted for carbon dioxide sequestration (LC 34/15, annex 8).[10]

In addition, Contracting Parties had to deal with the prohibition of the export of "waste or other matter to other countries for dumping or incineration" (Article 6 London Protocol) because cooperation in the case of the sequestration of carbon dioxide streams (export of carbon dioxide streams to other countries for the purpose of sequestration) was seen as reasonable, if not desirable. This was particularly crucial for European countries which had already started to develop respective projects. Within the European Union member states were in fact encouraged to

[10] In many respects, the Specific Guidelines were standard setting for latter regulation at national level. Moreover, Contracting Parties adopted a so called Assessment Framework for carbon dioxide sequestration. See http://www.imo.org/en/OurWork/Environment/LCLP/EmergingIssues/CCS/Pages/default.aspx.

cooperate with regard to sequestration of carbon dioxides.[11] Therefore the Contracting Parties of London Protocol adopted an amendment which was intended to lift the prohibition for such export activities (Resolution LP.3(4)). The amendment stipulates that exporting and receiving states should conclude an agreement or arrangement clarifying the "permitting responsibilities" (Article 6.2.1 (new)). If the export occurs to a non-Contracting Party "provisions at a minimum equivalent to those contained in this Protocol" should be included in the agreement or arrangement between exporting and receiving state (Article 6.2.2 (new)). The intention behind these provisions was to avoid regulatory loopholes with regard to the protection of the marine environment.

So far only a few Contracting Parties have ratified the amendment of 2009. It has therefore not yet entered into force.

53.3.2.2 Ocean Fertilization

The Contracting Parties to the London Convention and Protocol were first confronted with the issue of ocean fertilization in 2008 when the intention of Planktos Incorporated to embark on a significant ocean fertilization activity near the Galapagos Islands was reported.

It was at length debated amongst the Contracting Parties whether ocean fertilization is to be qualified as dumping or as placement activity. The interpretation is very important because the legal consequences are very distinct. Whereas for placement activities no permit is required the disposal of material can only be permitted as dumping activities if the type of material falls under one of the waste categories listed in Annex 1.

In October 2008—after intense discussion—Contracting Parties to the Convention and the Protocol adopted Resolution LC-LP.1 (2008) on the Regulation of Ocean Fertilization (LC 30/16, Annex 6). The policy position adopted in Resolution LC-LP.1 is to allow for legitimate scientific research to proceed, while placing a moratorium on other ocean fertilization activities. Operative paragraph 8 states that ocean fertilization activities, other than legitimate scientific research, should be considered contrary to the aims of the Convention and the Protocol and therefore prohibited. Operative paragraph 3 provides that, in order to allow for legitimate scientific research, such research should be regarded as 'placement'.

In 2010 the Contracting Parties adopted the so called Ocean Fertilization Assessment Framework (Resolution LC-LP.2 (2010). The Framework has two parts: the first provides for an initial assessment of whether a proposed activity falls within the definition of ocean fertilization and has proper scientific attributes, as distinct from being a commercial activity; the second provides for an environmental impact assessment. In the resolution of 2010 Contracting Parties committed them-

[11] See Article 24 Directive 2009/31/EC of 23 April 2009. See under: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0031&from=EN.

selves to "continue to work towards providing a global, transparent, and effective control and regulatory mechanism".

Both resolutions as well as the mentioned Assessment Framework were expressly understood by the Contracting Parties as being not legally binding. Therefore the aforementioned statement was very important as a mandate "to work towards "amendments to the London Protocol with regard to marine geo-engineering activities.

On 18 October 2013, the Protocol Parties adopted by consensus amendments to the London Protocol to regulate marine geo-engineering. The amendments are a landmark because, when they enter into force, they will be the first legally binding regulation of 'climate engineering' activities in international law.[12] In a nutshell, the amendments have two substantial parts. First, they regulate ocean fertilization activities by allowing only legitimate scientific research and prohibiting all other activities in this field. Second, they allow for the regulation of additional emerging marine geo-engineering activities which have the potential to impact adversely on the marine environment (LC 35/15, Annex 4).

A brief overview of the amendment is given below. The amendment has four key components: a legal definition of "marine geoengineering" in Article 1, the new Article 6bis and two new annexes.

The new paragraph 5bis of Article 1 defines "marine geoengineering":

> "Marine geoengineering" means a deliberate intervention in the marine environment to manipulate natural processes, including to counteract anthropogenic climate change and/or its impacts, and that has the potential to result in deleterious effects, especially where those effects may be widespread, long lasting or severe."[13]

The qualifier "deliberate" should exclude activities where the manipulation of natural processes is not directly intended, but is only a side-effect. Activities like "legitimate uses of the sea that have effects on the marine environment", e.g. submarine cable laying or the creation of artificial reefs, should therefore not fall under the definition.[14]

Since the operative provision, the new Article 6bis (1) LP refers to "the placement of matter into the sea from vessels, aircraft, platforms or other man-made structures at sea for marine geoengineering activities" only activities intended to introduce matter fall under the new regulation. Solar radiation management seems not to be covered by the amendment (Ginzky and Forst 2014: 86).

---

[12] The amendments will enter into force after they are accepted by two-thirds of Contracting Parties: Article 21, London Protocol.

[13] The development of the definition drew on the *Regulatory Framework for Climate-Related Geoengineering relevant to the Convention on Biological Diversity* (infra, fn8), the work of the Royal Society (infra, FN 1) and existing treaties such as the *UN Convention on the Prohibition of Military or any Other Hostile Use of Environmental Modification Techniques, 1976* (the ENMOD Convention), in force 5 October 1978, United Nations Treaty Series, Vol, 1108, p.151.

[14] LC 35/15, p 13. The adopting resolution also contains a reference to this explanatory text in the summary report, see footnote 1.

The main operative provision is Article 6bis (1) LP which provides:

> "Contracting Parties shall not allow the placement of matter into the sea from vessels, aircraft, platforms or other man-made structures at sea for marine geoengineering activities listed in Annex 4, unless the listing provides that the activity or the subcategory of an activity may be authorized under a permit.

Article 6bis (1) LP only prohibits the placement of matter for marine geoengineering activities which are listed in Annex 4. So far, Annex 4 lists only ocean fertilization. Consequently, for the time being, all other marine geoengineering activities are not regulated under the London Protocol.

In addition, activities or subcategories of an activity may only be authorized if the listing so provides. Currently, with regard to OF only legitimate scientific research may be considered for a permit according to the new Annex 4.

According to Article 6bis (2) LP a permit issued has to "comply with provisions of Annex 5 and take into account any Specific Assessment Framework". Furthermore pollution of the marine environment from the proposed activity has to be, "as far as practicable, prevented or reduced to a minimum". The wording of Article 6bis paragraph 2 clearly states that the requirements of Annex 5 have to be mandatorily complied with.

Annex 5 is titled "Assessment Framework for matter that may be considered for placement under annex 4". Annex 5 is modelled on Annex 2 of the Protocol, which contains the relevant assessment provisions for dumping activities, as well as on the Ocean Fertilization Assessment Framework. The new Annex 5 contains firstly criteria to distinguish between research and deployment and secondly requirements for an Environmental Impact Assessment.[15]

The criteria to distinguish between research and deployment in Annex 5 which are legally binding set a precedent in international law. Six criteria are mentioned:

- Addition to scientific knowledge, based on best available scientific knowledge and technology
- Appropriate scientific methodology.
- Subject to peer review.
- No economic interest involved.
- Commitment to publish scientific results.
- Available financial resources.

Annex 5 also provides for consultation procedures. Paragraph 10 requires that if an activity may have effects in an area within the jurisdiction of another State or in areas beyond national jurisdiction, the responsible Contracting Party should identify other potentially affected States or regional organizations and develop a plan for ongoing consultations. Paragraph 12 provides that Contracting Parties should consider "any advice on proposals from independent international experts or an independent international advisory body of experts" especially if there are effects on the jurisdiction of another State or on the high seas. The involvement of independent international expertise, either by individual experts or a body of experts, should help to achieve objectivity and transparency.

[15] For further details see Ginzky and Frost 2014, pp. 89.

Up to now, only one Contracting Party has ratified the new amendment. According to Article 21 (3) LP ratifications by two-thirds of the Contracting Parties are needed for the amendment to enter into force.

53.3.3 Convention on Biological Diversity (CBD)

The CBD of 1992 has currently 193 Contracting Parties. The US has not signed the convention.

The Parties to the CBD have dealt with ocean fertilization and marine geo-engineering techniques in general because they viewed that it touched upon the mandate of CBD. The three objectives of the CBD of 1992 are, according to Article 1 CBD, "the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources." The biannual Conference of the Parties (COP) to the CBD is the primary decision-making body. Decisions taken by the COP are prepared through technical, scientific and other meetings.

Article 2 CBD defines *"biological diversity"* to be "the variability among living organisms from all sources including, *inter alia,* terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part". The biological diversity in the oceans is therefore covered by the mandate of CBD.

Pursuant to Article 4 CBD, the provisions of CBD apply, in relation to each Contracting Party,

> "(a) In the case of components of biological diversity, in areas within the limits of its national jurisdiction; and
>
> (b) In the case of processes and activities, regardless of where their effects occur, carried out under its jurisdiction or control, within the area of its national jurisdiction or beyond the limits of national jurisdiction."

Since MGE activities are by definition carried out by humans being national to states and therefore under their control CBD provisions are applicable independently of whether the effects occur within or beyond the limits of national jurisdictions.

Article 14 CBD requests the Parties both to conduct an Environmental Impact Assessment of potentially detrimental projects and to duly consider the detrimental effects. The CBD does not however include specific provisions concerning MGE activities.

Nevertheless, two decisions have been taken in 2008 and in 2010 to address ocean fertilization and climate engineering techniques in general. The 9th Conference of the Parties approved decision XI/16 which requested Parties and urged other Governments:

> "in accordance with the precautionary approach, to ensure that ocean fertilization activities do not take place until there is an adequate scientific basis on which to justify such activities, including associated risks, and a global, transparent and effective control and regulatory mechanism is in place for these activities; with the exception of small scale scientific research studies within coastal waters."

Decision XI/16 provides for a moratorium on all ocean fertilization measures with the exemption of small scale research projects within coastal waters.[16]

In 2010, the Parties to CBD extended the moratorium to all climate engineering activities (Decision X/33). The decision foresees the same type of moratorium, but added three preconditions to be fulfilled for the conduction of research projects. First, research projects have "to be conducted in a controlled setting", second, "they are justified by the need to gather specific scientific data" and, third, "are subject to a thorough prior assessment of the potential impacts on the environment."

Decision X/33 of 2010 excluded Carbon Capture and Storage from its scope of application taking into account the existing regulation under London Protocol.[17]

Both decisions are legally not binding, but of an eminent political importance because they represent the political will of almost all states worldwide.

Article 22 CBD provides that the Parties to CBD shall apply CBD provisions regarding the marine environment consistently with the rights and obligations of states under the law of the sea. CDB therefore requests its Parties to observe the provisions of international maritime law, thus also the provisions of the London Protocol.

53.4 Central Management Instruments and Strategies and Paradigmatic Aspects

Summing up, it can be concluded that a relatively comprehensive (although mostly not legally binding) regulation has been put in place.

Particularly the adoption of the 2013 amendments under London Protocol is an amazing success. Within 6 years, the LP Contracting Parties developed and adopted a legally binding regulatory framework with regard to marine geo-engineering activities.

In the following some paradigmatic observations are made and conclusions are drawn which might be instructive for future regulation of marine geo-engineering techniques.

First, the approach of pragmatically starting with non-binding soft-law agreements and then moving on to legally binding instruments has proven successful. The main advantage of this approach is that Parties could initially focus on the core regulatory objectives while neglecting at this stage all the legalities and details which have to be considered, negotiated and resolved for a legally binding regulation. Examples of non-binding agreements are the CBD decision or the London Protocol resolution of 2008 by which the main regulatory aims were decided

[16] The term „coastal water"was very controversial especially with regard to the ocean fertilization research project „LOHAFEX"which was finally conducted in early 2009. For further information see Ginzky 2010, p 57.

[17] Both decisions were endorsed by the subsequent COPs.

(banning deployment/controlling research activities) (Markus and Ginzky 2011: 487). It took 5 years of consultations and negotiations under the London Protocol to establish a legally binding instrument. This approach should be considered if a new marine geo-engineering technique might evolve in future.

Second, the political will of states to work on and to finally agree on international regulation, especially a legally binding one, depends on the specific and actual dimension of the problem (Ginzky and Frost 2014: 94). It could be concluded that the most important supportive factor for the 2013 amendment to the London Protocol was that, compared with other climate engineering techniques, actual ocean fertilization activities were announced or conducted which posed real risks to the marine environment. In 2008 the intention of Planktos Incorporated to undertake a significant ocean fertilization activity near the Galapagos Islands was reported. In 2009 the German Alfred Wegener Institute for Polar and Marine Research, in cooperation with Indian partners, undertook the LOHAFEX experiment. Because of the timing—almost immediately after the LC-LP.1 (2008) resolution and CBD decision IX/16—the project attracted much publicity. Additional impetus for regulating ocean fertilization was provided by the 'salmon enhancement' experiment undertaken by the Haida Salmon Restoration Corporation in international waters off the coast of British Columbia, Canada in July 2012. Similarly, the 2006 amendment on carbon dioxide sequestration to the London Protocol was due to the announcement by Contracting Parties of specific projects.

Third, Contracting Parties to LP opted for different regulatory approaches with regard to carbon dioxide sequestration and ocean fertilization. Whereas for the first research and deployment were regulated as generally permissible (following assessment of their environmental impact), in the case of ocean fertilization deployment was prohibited and research was put under control. The decisive difference was the level of uncertainty and of potential detrimental effects. The regulatory approach to only allow for research (after assessment of the effects) and to prohibit deployment seems to be recommendable if major uncertainties exist. Projects can thus be conducted to increase knowledge without significant risks to the marine environment.

Fourth, if such an approach (prohibition of deployment/control of research activities) is appropriate, criteria to distinguish scientific projects from other activities are needed. The distinction criteria of Annex 5 of the 2013 LP amendment seem to be a good starting point.

Fifth, good regulation depends on scientific expertise, mainly because of the complexity of assessing specific marine geo-engineering techniques with regard to their effectiveness as climate change mitigation measure and their environmental impacts. The strong science based and interdisciplinary approach developed under the London Protocol is commendable. Besides the annual Meeting of Contracting Parties, there are annual meetings of the Scientific Group. Moreover, Contracting Parties to the London Convention and the London Protocol routinely establish *ad hoc* intersessional Correspondence or Working Groups which are usually mandated to further consider issues or prepare detailed proposals (Markus and Ginzky 2011: 481).

53.5 Conclusion and Outlook

To conclude: the provisions of UNCLOS and of the CBD are not sufficiently specific to regulate marine geo-engineering activities. Additionally, the 2013 amendment to the London Protocol is not yet in force as only one state has ratified it so far.

Nevertheless, the 2013 amendment could still serve as a model for future regulation of other climate engineering activities. First, the regulatory concept—prohibition of deployment and control of research activities—is appropriate in case of major uncertainties and potential significant risks. Second, the listing approach is reasonable because it allows specific regulation to be tailored as deemed necessary for each marine geo-engineering technique.

The pre-regulatory decisions of Contracting Parties to the London Convention and London Protocol as well of the Parties to CBD in 2008 and 2010 were crucial from a political perspective. They expressed the will of the states to cautiously deal with marine geo-engineering and paved the way for the 2013 amendment of London Protocol.

Since 2012, marine geo-engineering seems to have lost momentum. No major research project has been conducted. One might therefore question the need for all the regulatory effort. However, it could also be reasoned that the likelihood for irresponsible projects have been reduced through greater public awareness and international negotiations. From this perspective, the existing regulatory efforts are unquestionably justified.

References

Bodle R, Oberthür S, Donat L, Homann G, Sina S, Tedsen E (2014) Options and proposals for the international governance of geoengineering. Umweltbundesamt, Dessau-Roßlau

Freestone D, Rayfuse R (2008) Ocean fertilization and international law. Mar Ecol Prog Ser 9:227–233

Ginzky H (2010) Ocean fertilization as climate change mitigation measure–consideration under international law. J Euro Environ Planning Law 7:57–78

Ginzky H, Herrmann F, Kartschall K, Leujak W, Lipsius K, Mäder C, Schwermer S, Straube G (2011) Geoengineering: effective climate protection or megalomania? Umweltbundesamt, Dessau-Roßlau

Ginzky H, Frost R (2014) Marine geo-engineering: legally binding regulation under the london protocol. Carbon Clim Law Rev 8:82–96

Greenpeace International, “Challenging ‘geo-engineering solutions’ to climate change: The urgent need for detailed scientific scrutiny and international regulations to protect the oceans from large-scale iron fertilization programmes”, LC/SG 30/12/1, 8 2007

IUCN, “Regulation of CO2 sequestration”, LC/SG 30/12, 8 2007

Keller DP (2016) Marine climate engineering. In: Markus T, Salomon, M (eds), Handbook on marine environment protection

Markus T, Ginzky H (2011) Regulating climate change: paradigmatic aspects of the regulation of ocean fertilization. Carbon Clim Law Rev 4:477–490

Roberts C (2012) Ocean of life: how our seas are changing. Kindle edn, Allen Lane

Schäfer S, Lawrence M, Stelzer H, Born W, Low S, Aaheim A, Adriázola P, Betz G, Boucher O, Carius A, Devine-Right P, Gullberg AT, Haszeldine S, Haywood J, Houghton K, Ibarrola R, Irvine PJ, Kristjansson J-E, Lenton T, Link JSA, Maas A, Meyer L, Muri H, Oschlies A, Proelß A, Rayner T, Rickels W, Ruthner L, Scheffran J, Schmidt H, Schulz M, Scott V, Shackley S, Tänzler D, Watson M, Vaughan N (2015) The European ransdisciplinary assessment of climate engineering (EuTRACE): removing greenhouse gases from the atmosphere and reflecting sunlight away from Earth. Institute for Advances Sustainable Studies (IASS), Potsdam

Schlacke S, Markus T, Much S (2012) Rechtliche steuerungsmöglichkeiten für die experimentelle erforschung der meeresdüngung. Umweltbundesamt, Dessau-Roßlau

Specific Guidelines for the Assessment of Carbon Dioxide for Disposal into Sub-Seabed Geological Formations, Accessed 2 Nov 2012, LC 34/15, annex 8

The Royal Society United Kingdom (2009) Geoengineering the climate: science, governance and uncertainty. The Royal Society, London

Chapter 54
Marine Spatial Planning

Mathias Schubert

Abstract Marine spatial planning (MSP) is considered a key instrument for managing the conflicts resulting from the increasing utilization and industrialization of the world's seas and oceans. MSP is a public process by which the relevant authorities analyse and organise human activities in marine areas to achieve ecological, economic and social objectives. Even though environmental interests do not generally enjoy priority over economic and social interests, it must not be overlooked that MSP is a tool which substantially contributes to the protection of marine ecosystems. From the beginning of its evolution, MSP has been intrinsically tied to the concept of ecosystem-based management. Ecosystem-based MSP is promoted by the EU MSP Framework Directive (2014) which can be considered an important initial step towards an EU-wide harmonized and consistent comprehensive spatial planning approach for the European maritime waters.

Keywords Marine spatial planning • Ecosystem-based management • Ecosystem-based approach • UNCLOS • EU Directive establishing a framework for maritime spatial planning

54.1 Introduction

Marine spatial planning (MSP)[1] is considered a key instrument for managing the conflicts resulting from the increasing utilization and industrialization of the world's seas and oceans. In less than a decade, it has become "one of the most widely endorsed tools for integrated management of coastal and marine environments" (Carneiro 2013; Jay et al. 2013) or—according to Flannery and Ellis (2016)—"the dominant marine management paradigm".

[1] Also referred to as *maritime spatial planning*.

M. Schubert
University of Rostock, Rostock, Germany
e-mail: schubert.mathias@gmx.net

M. Salomon, T. Markus (eds.), *Handbook on Marine Environment Protection*,
https://doi.org/10.1007/978-3-319-60156-4_54

In the past, the application of spatial planning instruments at sea would have been unimaginable. Conflicts between traditional uses, such as fisheries, shipping, laying of cables and pipelines, extraction of mineral resources and the need to protect the marine environment were easily manageable without any form of planning. The capacity of the marine space exceeded the demands for use by far. In the last few decades, the situation has dramatically changed: traditional ocean uses have considerably expanded, and several new activities (particularly offshore renewable energy, aquaculture) have emerged (Douvere and Ehler 2009). These developments have led to a significant increase of competition for ocean space and potential for conflict. So-called *user-user conflicts* arise whenever there is competition between two or more parties to use the same sea space for the same purpose or for different but incompatible purposes. Additionally, spatial conflicts result from the negative (often cumulative) impact that many forms of use have on the marine environment *(user-environment conflicts)*. Inevitably, unregulated uses of the seas will lead to severe, possibly irreparable damage. Given the fact that ocean space and resources are not infinite, and in the light of the sensitivity of marine ecosystems, a future-oriented, integrated and sustainable development of marine space has become an urgent desideratum.

Certainly, the majority of coastal States already allocate ocean space, regularly based on international and regional agreements (e.g. concession zones for resource exploitation, areas for wind farms, delineation of cables, pipelines and shipping routes, marine protected areas etc.). But as long as areas for economic activities and nature conservation are designated by several authorities on a sectoral basis, the above mentioned conflicts cannot adequately be solved. Only a powerful strategic and cross-sectoral comprehensive spatial planning instrument will provide for the necessary long-term reconciliation of competing human activities and protection requirements in marine areas, and consequently, for legal and investment certainty for marine developers and users of ocean resources (Douvere 2008).

54.2 Definition and Main Functions of Marine Spatial Planning

The concept of marine spatial planning does not fundamentally differ from its terrestrial counterpart (Douvere 2008, see also Kidd and Ellis 2012). Therefore it is widely agreed that many of the principles, procedures, and processes of land use planning systems can be applied to developing MSP, as long as the significant differences between land and sea, such as the three-dimensional and dynamic nature of the sea, ownership and rights, and available data are taken into consideration (Gilliland and Laffoley 2008; Duck 2012, see also Chap. 28). According to a commonly accepted definition, MSP is

> "a public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic and social objectives that have been specified through a political process" (Ehler and Douvere 2009, Maes 2008, Rothwell and Stephens 2010).

As on land, it is crucial to distinguish between sectoral and comprehensive forms of spatial planning. *Sectoral planning* focuses on particular uses or concerns in a certain area, e.g. planning of cable laying, traffic routes, installations, conservation areas etc. The perspective is subject-specific, and the planning process is guided by specific sectoral objectives regularly pre-defined by law, such as the development of energy infrastructure or the protection and conservation of natural species and habitats. *Comprehensive spatial planning* on the other hand, is a means to coordinate all sectoral demands, activities and interests that are or will be relevant within a particular planning area, taking an unbiased, cross-sectoral, holistic perspective. Generally, comprehensive spatial planning aims for a sustainable overall development of the respective planning area, in which social and economic demands for space are consistent with its ecological functions. Even though the term "marine spatial planning" theoretically encompasses both sectoral and comprehensive forms of spatial planning, it is generally used only for comprehensive planning. To avoid misconception, marine spatial planning should therefore not be referred to as an "instrument of marine environmental protection" or an "instrument advancing economic or social interests" (Soininen and Hassan 2015: 8). As Soininen and Hassan (2015: 8) point out: "The somewhat idealistic aim of MSP is to achieve all of these objectives at the same time. The rationale of this thinking is to enable maximum utilization as well as maximum protection of biodiversity and ecosystems simultaneously."

Three *essential functions* of comprehensive spatial planning and MSP in particular can be differentiated: coordination, conflict resolution and precaution. First, MSP is an instrument to coordinate different, regularly conflicting demands for ocean space. Competing uses and functions of space, including those that are subject of sectoral planning, are being integrated in a single comprehensive spatial plan. Uses and/or functions that would impair one another need to be separated in space or time (e.g. wind farms and shipping). Uses and/or functions able to coexist next to each other without conflict can be bundled. In many cases of course, separation of incompatible uses and functions would be impossible. Particularly in densely used seas, MSP has to resolve actual and foreseeable conflicts, if necessary by preferencing single uses or functions and excluding others. Finally, MSP is an instrument for precautionary securing or reserving of marine space for potential future uses.

In the light of these vital functions, MSP particularly can—pursuant to Gilliland and Laffoley (2008)—contribute to:

- providing a strategic, integrated, and forward-looking framework for all uses of the sea space that takes account of economic, social, and environmental objectives and so helps sustainable development;
- organizing an efficient use of marine space to provide a balanced view between competing uses, clarifying where one activity might preclude another, helping avoid or minimize conflicts of interest, and, where possible, optimizing the co-location of compatible activities;
- better understanding the cumulative effects of different uses, both on marine ecosystems and each other;
- making rational decisions under the circumstances of uncertainty; these decisions should be guided by the precautionary principle.

54.3 Key Elements of MSP Promoting the Integration of Ecological Interests

Even though environmental interests do not generally enjoy priority over economic and social interests, it must not be overlooked that MSP substantially contributes to the protection of marine ecosystems. Several elements of MSP are meant to strengthen ecological interests in the planning process, most importantly

- the ecosystem-approach,
- the strategic environmental assessment,
- participation and consultation.

When applied effectively, these elements can significantly increase the ecological impact of MSP by providing the following environmental benefits (Ehler and Douvere 2009):

- Identification of ecological important areas;
- Incorporation of biodiversity objectives into the planning and decision-making process;
- Identification and reduction of conflicts between economic activities and environmental protection;
- Allocation of space for nature conservation, and
- Identification and reduction of cumulative effects of human activities on marine ecosystems.

From the beginning of its evolution, marine spatial planning has been intrinsically tied to the *ecosystem-based approach.* MSP has been considered a "tool to make ecosystem-based sea use management a reality" (Douvere 2008). Even though a broad consensus can be detected when it comes to the high value of global marine ecosystems, the immense pressures humans have inflicted on them, and the urgent need for a shift to a holistic approach of managing human activities that have an impact on marine ecosystems (Crowder and Norse 2008, Foley et al. 2010), there has been an ongoing debate on the principles that should guide marine ecosystem-based management (EBM) and, accordingly, marine spatial planning. As a result, an enormous variety of definitions and key principles for EBM can be found, basically depending on the respective emphasis placed on ecological, social, and governance factors (Long et al. 2015).

In 2005, more than 200 scientists and policy experts from the US released a "Scientific Consensus Statement on Marine Ecosystem-Based Management" (COMPASS 2005). The widely accepted and workable definition of EBM and its background laid down in this document, can be considered a basis for the conception of ecosystem-based marine spatial planning. According to the statement (COMPASS 2005: 1), ecosystem-based management is

> "an integrated approach to management that considers the entire ecosystem, including humans. The goal of ecosystem-based management is to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide the services humans want

> and need. Ecosystem-based management differs from current approaches that usually focus on a single species, sector, activity or concern; it considers the cumulative impacts of different sectors. Specifically, ecosystem-based management:
>
> - emphasizes the protection of ecosystem structure, functioning, and key processes;
> - is place-based in focusing on a specific ecosystem and the range of activities affecting it;
> - explicitly accounts for the interconnectedness within systems, recognizing the importance of interactions between many target species or key services and other non-target species;
> - acknowledges interconnectedness among systems, such as between air, land and sea; and
> - integrates ecological, social, economic, and institutional perspectives, recognizing their strong interdependences."

In view of this definition and the conceptual characteristics of MSP described above, it becomes evident that MSP and EBM are substantially and procedurally linked in many ways—that is the reason why MSP is considered an essential instrument to facilitate ecosystem-based ocean management.

As mentioned before, ecological interests do not generally enjoy absolute priority over economic and social interests when it comes to weighing of interests in the planning process. If one of the key elements of EBM is to "make protecting and restoring marine ecosystems and all their services the focus, even above short-term economic or social goals for single services" (COMPASS 2005), this does not necessarily hold true for MSP itself, even if it is ecosystem-based (Foley et al. 2010). However, the development of each MSP concept must be based on a clear decision over the relative roles of social, economic and ecological objectives. It is a widespread desideratum that "ecological principles should be at the foundation of any ecosystem-based process" (Foley et al. 2010). This issue goes back to the different paradigms of sustainability ("weak" vs. "strong" sustainability). The decision whether the three dimensions of sustainability (social, economic, ecological) are seen as equally important, or ecosystems are seen as boundaries for social and economic development, obviously has far-reaching implications in the decision-making process (Reuterswärd 2015; Soininen and Hassan 2015).

In European Union Law, for example, the application of an ecosystem-based approach in MSP is legally required in Article 5(1) of the MSP Directive 2014/89/EU (Kistenkas 2016). The Fourteenth Recital in the Preamble to the MSPD illustrates this requirement as follows:

> "In order to promote the sustainable growth of maritime economies, the sustainable development of marine areas and the sustainable use of marine resources, maritime spatial planning should apply an ecosystem-based approach as referred to in Article 1(3) of Directive 2008/56/EC with the aim of ensuring that the collective pressure of all activities is kept within levels compatible with the achievement of good environmental status and that the capacity of marine ecosystems to respond to human-induced changes is not compromised, while contributing to the sustainable use of marine goods and services by present and future generations."

It becomes clear that under the MSP Directive 2014/89/EU the ecosystem-approach is meant to restrain the economic and social development of marine space by setting boundaries marked by the Marine Strategy Framework Directive 2008/56/EC (MSFD). Being the environmental pillar of the EU Integrated Maritime Policy, the MSFD aims to achieve Good Environmental Status of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend (COM(2012) 662 final). Particularly, the cumulative impact of all human uses allowed on the basis of one or more marine spatial plans must not compromise the capacity of marine ecosystems to respond to anthropogenic changes. Obviously, Art. 5(1) MSPD is based on two important insights: (1) without functioning ecosystems, sustainable economic and social development of the seas and oceans are utterly impossible, (2) marine ecosystems must be maintained "within limits where they are resistant to change or are resilient, able to return to their former (desirable) state even after they experience a perturbation that puts them (temporarily) in a different state" (Crowder and Norse 2008).

One of the major challenges for both MSP-related science and practice is to operationalize the ecosystem-based approach and to cope with the issues of complexity and uncertainty on the one hand and practicability on the other. Most importantly, the ecosystem-based approach has to be gradually substantiated. Finding key guiding principles, rooted in "essential ecological insights" (Crowder and Norse 2008), is an important first step (see Foley et al. 2010; Long et al. 2015). Foley et al. (2010) have proposed *four basic ecosystem principles* to guide ecosystem-based MSP, describing structural components that are essential for healthy, functioning marine ecosystems:

– Maintain native species diversity;
– Maintain habitat diversity and heterogeneity;
– Maintain populations of key species;
– Maintain connectivity among habitats and populations.

Foley et al. recommend to incorporate these principles into a decision-making framework with clearly defined targets for these ecological attributes. Additionally, two overarching guidelines should be applied: the need to consider (1) *contextual factors*, such as geomorphology and biogeography, as well as the type, distribution, frequency, and intensity of existing and contemplated ocean uses, and (2) *uncertainty* (Foley et al. 2010). Definitely, one of the most important insights for ecosystem-based MSP is the *heterogeneity of marine areas* (differing values in biophysical and human dimensions, differing sensitivities etc.) that needs to be reflected by MSP at appropriate spatial and temporal scales (Douvere 2010). Further, MSP has to deal with the fact that marine ecology is not yet able to accurately predict how components of complex marine ecosystems respond to all kinds of plan-induced human influence and probably never will be. When it comes to dealing with this uncertainty, MSP should "provide a high level of assurance that we will not lose what we value" (Crowder and Norse 2008), by taking a *precautionary approach*, "such that the absence of information on the effect of an activity is not interpreted as the absence of impact or harm to the ecosystem" (Foley et al. 2010). Building *redundancy and buffer areas* into the MSP framework will also help to protect ecosystem functions and services in the face of uncertainty (Crowder and Norse 2008; Foley et al. 2010).

54.4 Legal Framework

54.4.1 International Law: UNCLOS

First and foremost, marine spatial planning must be applied in accordance with international law. In particular, national regulations on MSP have to be consistent with the rights and duties of States imposed by international law. Of course, there is no international convention originally stipulating the legitimacy or the general conditions of MSP. However, basic constraints for MSP activities are set in the United Nations Convention on the Law of the Sea (UNCLOS). Although the Convention does not contain any explicit provisions on MSP, it provides the legal basis for sea exploitation, the right to allocate activities and the obligation to conserve the marine environment. Most importantly, UNCLOS delivers legal mechanisms for resolving spatial conflicts.

The world's seas and oceans are divided by UNCLOS into six basic zones in which the types and degrees of State's rights and jurisdiction vary. These zones are: the territorial sea, the contiguous zone, the exclusive economic zone (EEZ), the continental shelf, the high seas, and the Area. Practically, the internal waters, the territorial sea and the exclusive economic zone are most relevant to spatial planning.

The waters on the landward side of the baseline of the territorial sea form part of the *internal waters* of the State (Art. 8(1) UNCLOS). As part of its territory the internal waters are under full sovereignty of the State which means complete MSP jurisdiction (Maes 2008), barring one exception concerning the right of innocent passage in specific internal waters enclosed by straight baselines (Art. 8(2) UNCLOS).

In the *territorial sea,* which extends up to a limit of 12 nm from the baseline (Art. 3 UNCLOS), the coastal State also has full jurisdiction based upon sovereignty (Maes 2008). The only limitation upon this is the right of innocent passage through the territorial sea, which ships of all States enjoy (Art. 17 UNCLOS). However, the coastal State may adopt laws and regulations relating to innocent passage in respect of the safety of navigation and the regulation of maritime traffic, the protection of facilities, installations, cables and pipelines, the conservation of living resources and other aspects enumerated in Art. 21(1) UNCLOS. Beyond these laws and regulations, the coastal State is not entitled to take spatial planning measures that could impede the innocent passage of foreign ships (Art. 24(1) UNCLOS). Yet, the coastal State may, where necessary having regard to the safety of navigation, require foreign ships to use such sea lanes and traffic separation schemes as it may designate or prescribe for the regulation of the passage of ships (Art. 22(1) UNCLOS). As a result, in the territorial sea the coastal State may adopt MSP regulations if they comply with the right of innocent passage (Schubert 2015).

The question whether the coastal State is entitled by international law to establish a spatial planning regime in the *exclusive economic zone* is rather difficult to answer. The EEZ must be proclaimed by the coastal State and shall not extend beyond 200 nm from the baseline (Art. 57 UNCLOS). It is neither part of the State's territory nor subject to its sovereignty. Art. 56 UNCLOS confers limited sovereign rights on coastal States for the purpose of exploring and exploiting, conserving and managing the natural resources, whether living or non-living, of the waters superjacent to the sea-bed and of the sea-bed and its subsoil. These sovereign rights apply to other activities for the economic exploitation and exploration, such as the production of energy from the water, currents and winds (Art. 56(1) lit. a UNCLOS). Furthermore, the coastal State has jurisdiction with regard to the establishment and use of artificial islands, installations and structures, marine scientific research and the protection and preservation of the marine environment (Art. 56(1) lit. b UNCLOS). In exercising these rights, the State shall have due regard to the rights and duties of other States, such as the freedoms of navigation and overflight and of the laying of cables and pipelines (Art. 56(2), 58(1) UNCLOS).

UNCLOS does not explicitly grant the sovereign right or jurisdiction for spatial planning. This does not necessarily implicate that the coastal States are not entitled to regulate MSP in the EEZ. A regulatory competence might be found by interpretation. There are no provisions in UNCLOS stipulating whether or how the coastal State has to exercise its sovereign rights. These matters are left to the State's decision, which indicates that the State is entitled to use planning instruments. Moreover, planning is commonly not regarded as a task itself but as a mode or method of exercising a task. The sovereign rights and jurisdiction conferred upon the coastal State imply the power to regulate the terms of use relating to those activities including spatial planning instruments. The State may adopt a binding sectoral planning decision as a basis for exercising each of its sovereign rights.

It needs to be clarified whether the coastal State also has the regulatory competence for comprehensive supra-sectoral spatial planning—which is qualitatively more than just the sum of the single sovereign rights and their exercise in the mode of sectoral planning. Of course, the State may not claim sovereign rights which are not expressly granted to him by international law. This leads to the question whether UNCLOS provides an unwritten competence to coordinate the functionally limited rights as well as the different sectoral plans. Such a competence can be derived from the doctrine of implied powers: in international law, implied powers are those powers authorized by a legal document which, while not stated, are deemed to be implied by powers expressly stated. In fact, there is an urgent necessity to balance the numerous conflicting forms of use and the duty to protect the environment which are all covered by the sovereign rights and duties set by UNCLOS. The overall objectives of UNCLOS are laid down in its preamble which states, that the problems of ocean space are closely interrelated and need to be considered as a whole. Thus, the convention shall establish a legal order for the seas and oceans which will promote the equitable and efficient utilization of their resources, the conservation of their living resources, and the study, protection and preservation of the marine environment. It is quite obvious, that these objectives could never be achieved if UNCLOS merely approved an uncoordinated, planless utilization. In the interest of a well-balanced and future-oriented exercise of sovereign rights and jurisdiction granted to the coastal States, the implied powers doctrine allows to derive a regulatory competence for comprehensive spatial planning from the convention (Erbguth and Müller 2003; Schubert 2015).

As a result, in the EEZ the coastal State has the regulatory competence for sectoral as well as supra-sectoral spatial planning, both within the scope of the limited sovereign rights and jurisdiction and in consideration of the rights and duties of other States (European Commission 2008), or as Soininen et al. (2015: 221) have put it: "UNCLOS provides coastal States with legitimate ways of exercising their competence over planning and utilizing marine areas [...] International law is on the one hand making MSP possible and on the other placing certain restrictions on it."

54.4.2 European Union Law: Directive 2014/89/EU

In 2014, the EU adopted the *Directive 2014/89/EU establishing a framework for maritime spatial planning* (MSPD), aiming to promote the sustainable growth of maritime economies, the sustainable development of marine areas and the sustainable use of marine resources (Art. 1(1) MSPD). With this legal act, which can be considered a milestone in the ongoing process of the Union's Integrated Maritime Policy, the legislator basically seeks to coordinate and harmonize national approaches to MSP (Soininen et al. 2015: 223).

The Directive defines MSP as a process by which the relevant Member State's authorities analyse and organise human activities in marine areas to achieve ecological, economic and social objectives (Art. 3(2) MSPD). The role of the EU is limited to providing a basic, mainly procedural framework while "Member States remain responsible and competent for designing and determining, within their marine waters, the format and content of such plans, including institutional arrangements and, where applicable, any apportionment of maritime space to different activities and uses respectively" (Recital 11; see also Art. 4(3) MSPD).

Art. 4(1) MSPD stipulates that each Member State shall establish and implement a marine spatial plan. According to Art. 4(3), the resulting plan or plans shall be developed and produced in accordance with the institutional and governance levels determined by Member States. The *objectives* of MSP are laid down in Art. 5 MSPD and encompass

- considering economic, social and environmental aspects to support sustainable development and growth in the maritime sector, applying an ecosystem-based approach, and to promote the coexistence of relevant activities and uses;
- contributing to the sustainable development of energy sectors at sea, of maritime transport, and of the fisheries and aquaculture sectors, and to the preservation, protection and improvement of the environment, including resilience to climate change impacts.

When it comes to the *content* of the maritime spatial plans, the Directive is rather restrained. Art. 8(1) MSPD obligates the Member States to set up maritime spatial plans which identify the spatial and temporal distribution of relevant existing and future activities and uses in their marine waters, in order to contribute to the objectives set out in Article 5. Art. 8(2) MSPD provides a catalogue of possible activities and uses and interests that *may* be covered by the maritime spatial plans.

One of the central issues that the MSP-Directive tries to tackle is *transboundary cooperation* in drafting and implementing marine spatial plans (Soininen 2015: 195). The European Commission has always emphasized *communication, consultation and cooperation* with neighbouring States as key elements of the MSP procedure that need to take place at an early stage in the planning process (COM(2010) 771 final: 5.). Consistently, Art. 11(1) MSPD obliges Member States bordering marine waters to cooperate with the aim of ensuring that maritime spatial plans are coherent and coordinated across the marine region concerned. The cooperation shall be pursued through existing regional institutional cooperation structures such as Regional Sea Conventions, networks or structures of Member States' competent authorities and/or other methods, for example in the context of sea-basin strategies (Art. 11(2) MSPD). In the case of Member States bordering third States, Member States "shall endeavour, where possible, to cooperate with third countries on their actions with regard to maritime spatial planning in the relevant marine regions and in accordance with international law and conventions, such as by using existing international forums or regional institutional cooperation" (Art. 12 MSPD).

In order to promote sustainable development in an effective manner (see Recital 21 of MSPD), the MSPD also provides for the *involvement of the public* in the planning process (Zervaki 2015). Member States shall establish means of public participation by informing all interested parties and by consulting the relevant stakeholders and authorities, and the public concerned, at an early stage in the development of maritime spatial plans, in accordance with relevant provisions established in Union legislation (Art. 9(1) MSPD). Further, Member States shall ensure that the relevant stakeholders and authorities, and the public concerned, have access to the plans once they are finalized (Art. 9(2) MSPD). As a good example of public consultation provisions, the MSP-Directive points out Art. 2(2) of Directive 2003/35/EC providing for public participation in respect of the drawing up of certain plans and programmes relating to the environment.

Even though the substantive requirements for national MSP legislation and national MSPs might be considered "normatively weak" (Soininen 2015: 193), the MSP-Directive marks an important initial step towards an EU-wide harmonized and consistent comprehensive spatial planning approach for the European maritime waters (Schubert 2015).

54.5 Perspective

According to Charles Ehler "the future of MSP and its ecological and economic outcomes looks bright" (Ehler 2013). This perspective is mainly based on the projection that until 2025, almost 60 countries in the world will have government-approved marine spatial plans, and by the same time, around 43% of the area of the world's exclusive economic zones will be covered by government-approved marine spatial plans (Ehler 2015). The EU MSP Framework Directive can be considered one of the main drivers of this development, since the 22 EU Coastal States shall bring into force the laws, regulations and administrative provisions necessary to comply with this Directive by September 2016, and the maritime spatial plans shall be established at the latest by March 2021 (Art. 15(1), (3) MSPD).

However, the mere quantitative expansion is not the single most important indicator to measure the worldwide success of the concept of MSP. It is even more important to keep filling the concept with substance which can only be achieved on the basis of further practical experience. Soininen et al. (2015: 221) rightly point out that "[d]espite the recent popularity, MSP still needs to prove its worth and added value compared to or in combination with existing instruments. […] MSP does not hold intrinsic value on its own but provides a framework for a more integrated multi-level approach to ocean governance."

References

Carneiro G (2013) Evaluation of marine spatial planning. Mar Policy 37:214–229

Communications Partnership for Science and the Sea (COMPASS) (2005) Scientific consensus statement on marine ecosystem-based management. http://www.marineplanning.org/pdf/Consensusstatement.pdf. Accessed 20 Aug 2017

Crowder L, Norse E (2008) Essential ecological insights for marine ecosystem-based management and marine spatial planning. Mar Policy 32:772–778

Douvere F (2008) The importance of marine spatial planning in advancing ecosystem-based sea use management. Mar Policy 32:762–771

Douvere F (2010) Marine spatial planning: concepts, current practice and linkages to other management approaches. Ghent University, Belgium

Douvere F, Ehler C (2009) Ecosystem-based marine spatial management: an evolving paradigm for the management of coastal and marine places. Ocean Yearbook 23:1–26

Duck RW (2012) Marine spatial planning: managing a dynamic environment. J Environ Policy Plan 14(1):67–79

Ehler C (2013) The present and future of marine spatial planning around the World. https://www.openchannels.org/blog/cehler/present-andfuture-marine-spatial-planning-around-world. Accessed 20 Aug 2017

Ehler C (2015) Maritime Spatial Planning and the Marine Environment: A personal perspective, Maritime Spatial Planning and the Marine

Environment Conference, Brussels, Belgium. https://ec.europa.eu/maritimeaffairs/content/conference-maritime-spatial-planning-and-marineenvironment_en. Accessed 20 Aug 2017

Ehler C, Douvere F (2009) Marine Spatial Planning: a step-by-step approach toward ecosystem-based management. In: Intergovernmental oceanographic commission and man and the biosphere programme. IOC Manual and Guides No. 53, ICAM Dossier No. 6. UNESCO, Paris

Erbguth W, Müller C (2003) Raumordnung in der Ausschließlichen Wirtschaftszone? Deutsches Verwaltungsblatt:625–631

European Commission (2008) Legal aspects of maritime spatial planning, Final Report to DG Maritime. Affairs & Fisheries, Brussels

Flannery W, Ellis G (2016) Exploring the winners and losers of marine environmental governance. Planning Theory Practice 17(1):121–151

Foley M et al (2010) Guiding ecological principles for marine spatial planning. Mar Policy 34:955–966

Gilliland PM, Laffoley D (2008) Key elements and steps in the process of developing ecosystem-based marine planning. Mar Policy 32:787–796
Jay S, Flannery W, Vince J, Liu W, Xue JG, Matczak M, Zaucha J, Janssen H, van Tatenhove J, Toonen H, Morf A, Olsen E, Suarez de Vivero JL, Mateos JCR, Calado H, Duff J, Dean H (2013) International progress in marine spatial planning. Ocean Yearbook 27:171–212
Kidd S, Ellis G (2012) From the land to sea and back again? Using terrestrial planning to understand the process of marine spatial planning. J Environ Policy Plan 14(1):49–66
Kistenkas FH (2016) sustainable development: new thoughts, new policy, new law? In: Mauerhofer V (ed) Legal aspects of sustainable development: horizontal and sectoral policy issues. Springer, Heidelberg, pp 535–548
Long RD, Charles A, Stephenson RL (2015) Key principles of marine ecosystem-based management. Mar Policy 57:53–60
Maes F (2008) The international legal framework for marine spatial planning. Mar Policy 32:779–810
Reuterswärd I (2015) Valuation of ecosystem services in ecosystem-based marine spatial planning in the baltic sea region. Lund: http://lup.lub.lu.se/student-papers/record/7358856/file/7358900.pdf. Accessed 20 Aug 2017
Rothwell DR, Stephens T (2010) The international law of the sea. Hart Publishing, Oxford
Schubert M (2015) Maritimes Infrastrukturrecht. Mohr Siebeck, Tübingen
Soininen N (2015) Marine spatial planning in the European Union. In: Hassan D, Kuokkanen T, Soininen N (eds) Transboundary marine spatial planning and international law. Routledge, London, pp 189–201
Soininen N, Hassan D (2015) Marine spatial planning as an instrument of sustainable ocean governance. In: Hassan D, Kuokkanen T, Soininen N (eds) Transboundary marine spatial planning and international law. Routledge, London, pp 3–20
Soininen N, Kuokkanen T, Hassan D (2015) Comparative and forward-looking conclusions on transboundary MSP. In: Hassan D, Kuokkanen T, Soininen N (eds) Transboundary marine spatial planning and international law. Routledge, London, pp 221–226
Zervaki A (2015) Introducing maritime spatial planning legislation in the EU: fishing in troubled waters? Maritime Safety Security Law J 1:95–114