Matthias Wolff
Sebastian C. A. Ferse
Hugh Govan *Editors*

Challenges in Tropical Coastal Zone Management

Experiences and Lessons Learned

Springer

Challenges in Tropical Coastal Zone Management

Matthias Wolff • Sebastian C. A. Ferse •
Hugh Govan
Editors

Challenges in Tropical Coastal Zone Management

Experiences and Lessons Learned

Springer

Editors
Matthias Wolff
Zentrum für Marine Tropenforschung
Bremen, Germany

Sebastian C. A. Ferse
Marine Ecology Department, Faculty of Chemistry and Biology
University of Bremen
Bremen, Germany

Leibniz Centre for Tropical Marine Research (ZMT)
Bremen GmbH
Bremen, Germany

Hugh Govan
University of the South Pacific
Suva, Fiji

ISBN 978-3-031-17878-8   ISBN 978-3-031-17879-5 (eBook)
https://doi.org/10.1007/978-3-031-17879-5

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

Foreword

This book has its roots in ISATEC, an international master course program created in 1999 by the Center for Tropical Marine Research (ZMT) and Bremen University. The authors of the book are mostly ISATEC graduates now working as scientists or administrators in their home countries. The editors asked them for case studies reporting about the planning and implementation of national and local projects of management of the resources and services of coastal zones.

The present book is a testimony to more than twenty years of joint efforts of a research center and a university, both of them being engaged in multi-disciplinary studies and interdisciplinary dialogues of natural sciences and humanities. They are wide open to students from all over the world, particularly the Global South. As founding director of ZMT and professor at Kiel University, I watched Matthias Wolff and his team during the founding and early development of ISATEC. To me, this book is a milestone on a long way which started more than half a century ago. In the late 1950s/early 1960s, farsighted oceanographers like Anton Bruun (Denmark), George Deacon (UK), and Roger Revelle (US) started a new era of ocean studies by initiating the International Indian Ocean Expedition as a multi-national, multi-ship exercise. The coordination of the sea-going efforts as well as organizing the storage of oceanographic data and the sorting of the biological material was entrusted to the Scientific Committee of Ocean Research (SCOR), founded in 1957 as the first non-governmental global organization in marine sciences. The Intergovernmental Oceanographic Commission (IOC), founded by UNESCO in 1960, became SCOR's governmental counterpart. When I entered the IOC secretariat in1964, it consisted of a US marine geologist, a marine chemist from Japan, and myself as German biologist. We were headed by a soviet physical oceanographer. Over more than two years, I had the opportunity to visit many coastal places all over the world, particularly in the tropics and subtropics. Many of those countries had become independent only recently. Their scientific capacity was very limited, as was the research infrastructure. In India, I met Kesava Panikkar. He was the leading oceanographer in his country and the first president of IOC. He was a strong advocate of

North/South partnerships under the acronym TEMA (Training, Education, Mutual Assistance), with four lines of activities:

1. Fellowships for *higher education* at universities of the North and delegation of lecturers to the young universities in the South.
2. *Specific technical training* by short-term courses or by hands-on training in joint research projects.
3. *Communication* by participation in regional conferences and workshops and by easy access to scientific literature.
4. Provision of scientific and technical *advisors* as well as of research tools.

When I was a professor at Kiel University, I tried to implement parts of TEMA. Many of my students in fisheries biology and marine ecology came from the Global South and wrote their thesis on problems related to their home waters. In addition, some of my European graduates like Daniel Pauly (Hempel and Pauly 2002) or Cornelia Nauen became engaged in bilateral research and teaching projects in Africa, Latin America, and Southeast Asia or joined UN organizations. Particularly in the 1960s and 1970s, governments of the North provided small research vessels, laboratory equipment, and libraries to institutes in the South. Modern fishing vessels fully equipped by bottom trawls and echo sounders were gifts during German state visits in countries of the Global South. In several cases, however, vessels, gear and instruments requiring sophisticated maintenance and repair turned out to be of little or no use to the recipient. In the Gulf of Thailand, the introduction of bottom trawling caused a collapse of local stocks and fisheries.

FAO financed and organized advanced regional training courses on stock assessment and fisheries management and provided expert advice to the establishment of national fishery research centers. Former colonial powers, particularly France and Britain, tried to assist their former colonies through the establishment of regional research centers and networks under the umbrellas of ORSTOM and the British Council, respectively. The regional concepts did not meet short-term national policy and personal interests of the local and national rulers, so much support was in vain. On both sides, it took a long time to realize that in most countries, the coastal zone is politically underrated or even neglected, in spite of its quickly growing human population, its rich natural resources and services, and its specific threats like storm surges and tsunamis.

The UN organizations, SCOR, and the well-established regional organizations like the International Council for the Exploration of the Seas (ICES) made great efforts to strengthen the North/South scientific contacts and to include “Southern” scientists in the marine dialogue. Of great value were the participation of those scientists in IIOE and subsequent multi-ship expeditions as well as the joint processing and analysis of their data and samples.

In the 1970s, the ocean-wide international multi-ship surveys became replaced by national single-ship studies of oceanic processes of ocean-atmosphere interaction and of marine food webs and productivity. Plate tectonics, sea-floor spreading, and paleo-oceanography became keywords, upwelling phenomena were studied in detail. The advances in molecular biology and computerized modelling became drivers for the new field of marine microbiology and for the study of nutrient cycles, energy budgets, and food webs.

The demand for fish meal and fish oil had increased, and hence had the exploitation of the swarms of small clupeoids in coastal upwelling areas. The fluctuations in those fisheries, the disastrous decline of many demersal fish stocks, and the increase of pollution and eutrophication led to the concept of Large Marine Ecosystems (LME), developed by Ken Sherman and widely adopted for regional research and management (Hempel and Sherman 2003). It provided the framework for international funding and North/South partnerships in regional projects of research, monitoring, and management.

The new Law of the Sea had excluded foreign distant-water fleets from most of the continental shelves. They looked for new resources like krill and for new fishing areas, including the Southern Ocean. Its living resources made it the target for the large international research effort BIOMASS (Biological Investigation of Marine Antarctic Systems and Stocks, 1977–1991) initiated by the US scientist Sayed Z. El-Sayed. "*Its main aim was to gain a greater understanding of the biological systems and stocks in the marine Antarctic environment*" (El-Sayed 1994). The wide scope of research of marine ecosystems like the Southern Ocean attracted many young scientists from not only the North, but also from countries like India and Brazil.

At the same time coastal states became obliged to monitor their extended economic zones (EEZ) and their living resources. Governments realized the need for strengthening the marine research capacity of their country and to foster regional cooperation. In response to the growing demand for marine scientists, we established the Centre for Tropical Marine Ecology (nowadays Leibniz Centre for Tropical Marine Research) (ZMT) in Bremen in 1991. The ZMT had three major objectives: (1) education and training of German and foreign students in tropical marine and coastal ecology, (2) long-term research projects in partnership with institutions in the tropics, and (3) coordination of German research activities in tropical coastal shores and waters. Teaching at ZMT started with special courses of one or two weeks mostly on ecological methods. They were held in Bremen or at partner universities in the tropics. A few years later, the University of Bremen and ZMT invited German and foreign students alike for the two-year M.Sc. curriculum ISATEC focussing on tropical marine ecology, including its human dimensions. It was the first curriculum in Bremen fully taught in English and focused on the management of tropical coastal areas and their resources. ISATEC started with one year of class work in Bremen followed by six months of field work at a partner university in a tropical or subtropical country and finished with a semester in Bremen for writing the M.Sc. thesis. Up to now over 360 students have graduated in the program. Many of them continued as Ph.D. students in Bremen or elsewhere. They then returned to their home country for positions in research, administration, or industry or became professors at local universities.

As witnessed in this book, students and alumni of ISATEC played and still play an important role in the research projects of ZMT. Over the past, long-term research programs have been developed in Brazil, the Middle East, SE-Asia, and in the South-

African Benguela LME. Those projects combine multi- and inter-disciplinary research with training on the job of local and German graduates and junior scientists. The projects are based on the concept of equal partnership as formulated in the Bremen Criteria, which request *inter alia*

- A significant contribution to a scientifically important theme
- Joint planning and execution on equal footing
- A major contribution to strengthening the scientific capacity in the host country
- Long duration of one or two decades with firm financial commitment by Germany and with substantial co-financing by the host country
- Unrestricted exchange of data
- Joint publications, preferably in international journals
- Joint participation in international conferences and workshops, not only for the "permanent ticket holders" but also for many young scientists.

The greatest need for further capacity building is in the tropical and subtropical countries.

A new generation of professionals is needed, addressing the sustainability issues in a much broader sense than before. Management goals have to be defined and defended under the pressure of conflicting ecological interests and political and societal constraints. Most of the authors of this book are part of this new generation.

Center for Tropical Marine Research (ZMT), Bremen, Germany
June 2022

Gotthilf Hempel

References

El-Sayed SZ (ed) (1994) Southern Ocean ecology: the BIOMASS perspective. Cambridge University Press, Cambridge, UK, p 399

Hempel G (2002) Capacity building in marine science. A review. In: Wesnigk J, Rolston S (eds) The European Challenge: Proceedings of *Pacem in Maribus* 28, Hamburg (Germany), 3–5 December 2002. International Ocean Institute, Halifax, Canada

Hempel G, Pauly D (2002) Fisheries and fisheries science in their search for sustainability. In Field JG, Hempel G, Summerhayes CP (eds) *Oceans 2002*. Island Press, Washington, DC, p 365

Hempel G, Sherman K (eds) (2003) Large marine ecosystems of the world: trends in exploitation, protection and research. Elsevier Science B.V., pp. 399–414

Nauen CE, Hempel G (2011) Science and capacity building for sustainable development in fisheries. In Christensen V, Maclean J (eds) Ecosystem approaches to fisheries. A global perspective. Cambridge University Press, Cambridge, UK, pp. 209–225

Acknowledgements

This book is the fruit of a complex collaboration of many people, drawing mainly on the knowledge and experience of young tropical scientists who have been trained within the M.Sc. Program ISATEC (International Studies in Aquatic Tropical Ecology) at the Center for Tropical Marine Research (ZMT) and Bremen University. Both these institutions have supported this program for more than two decades, and ISATEC was (and still is) sponsored through numerous full-time scholarships for students from developing countries through the German Academic Exchange Service (DAAD). We are very thankful for the support given by these institutions and also wish to acknowledge the role of Prof. Kai Bischof as interim director of ISATEC for the years 2007–2010.

The unwavering dedication of over 50 lecturers as well as the program coordinators Iris Freytag and Oliver Janssen-Weets was essential to the performance of ISATEC. Thank you so much for all those years of enthusiastic support.

When the idea of this book was born and our former students and colleagues asked about their interest to participate in this endeavor, we were overwhelmed by the many positive and encouraging responses. So, we started our journey, which ends today with the submission of the book.

We want to thank all the contributors to the book who embarked on this lengthier than expected process with multiple revisions. We wish also to thank numerous external reviewers for their great support of our book project. Much of the tedious and time-consuming work such as formatting, spell-checking, referencing, quality control of figures and photographs was done by our two great assistants, Teresa Nobre and Eugene Oboh, whom we also want to very much thank for their great labor without which this book would never have been finished.

The editors, Bremen and Brussels in June 2022

Contents

Part I Introduction and Context

1 Introduction 3
Matthias Wolff, Sebastian C. A. Ferse, and Hugh Govan

Part II Case Studies

2 Kenya Case Study One 13
Paul Tuda, Rashid Imam, Benedict Kiilu, and Johnstone Omukoto

3 Guatemala Case Study 25
Pilar Velásquez, Vanessa Dávila, and Manuel Ixquiac

4 Ghana Case Study One 41
Seth M. Abobi

5 Pacific Island Case Study 53
Natalie Prinz and Jonas Letschert

6 Saudi Arabia Case Study 73
Vanessa Robitzch, Alexander Kattan, Aislinn Dunne, and Darren J. Coker

7 Philippines Case Study One 95
Regina T. Bacalso, Ian J. Tajonera, Rina M. Rosales, James Kho, Marlito Guidote, Loretta Sollestre, and Nygiel B. Armada

8 Kenya Case Study Two 117
Benards Okeyo and Dishon Murage

9 Tanzania Case Study 133
Godfrey Fabiani, Mary Namukose, Robert Eliakim Katikiro, Yussuf S. Yussuf, Nuri M. Steinmann, and Flower E. Msuya

10 Indonesia Case Study 149
Wasistini B. Barnhart and Sebastian C. A. Ferse

11 Panama Case Study 165
Janina Seemann, Tania E. Romero, Arturo Dominici-Arosemena, Juan Maté, Anabell J. Cornejo, Jessica M. Savage, Felix Rodriguez, and Arcadio Castillo

12 Philippines Case Study Two 187
Kristina S. A. Cordero-Bailey, L. T. David, T. L. P. dela Cruz, A. T. Almo, S. Martinez, H. E. Amihan, W. Y. Licuanan, P. Z. Mordeno, V. S. Ticzon, C. L. Nanola, J. B. Cabansag, H. M. Nacorda, R. Rollon, C. L. Villanoy, E. Magdaong, M. J. R. Pante, G. Perez, A. Blanco, T. M. Lim, K. Rodriguez, M. Mendoza, DENR Regional Executive Director XIII, Protected Area Superintendent (PASu) SIPLAS, DENR Regional Executive Director VI, Protected Area Superintendent (PASu) SMR, Local Government of Sagay, Negros Occidental, DENR Regional Executive Director III, and Protected Area Superintendent (PASu) MOBMR

13 Bangladesh Case Study 207
Sucharit Basu Neogi, Shinji Yamasaki, Rubén José Lara, and Matthias Wolff

14 Ghana Case Study Two 227
Elizabeth Effah, Denis W. Aheto, Emmanuel Acheampong, and John Blay

15 Ecuador Case Study 247
Gabriela Navarrete-Forero, Alonso Del-Solar-Escardó, Eliana Alfaro-Cordova, Leonardo Rodríguez-Escalante, Solange Andrade-Vera, and Demian A. Willette

16 Thailand Case Study 277
Naomi R. Bauer, Isabell J. Kittel, Eike Schoenig, Sebastian C. A. Ferse, and Christian Wild

17 Peru Case Study 303
Alonso Del Solar, Eliana Alfaro-Cordova, Tania Mendo, Kelly Ortega-Cisneros, Milena Arias Schreiber, Jorge Grillo-Núñez, and Joanna Alfaro-Shigueto

Part III Evaluation and Synopsis

18 Evaluation and Synopsis 325
Matthias Wolff, Sebastian C. A. Ferse, and Hugh Govan

Part I
Introduction and Context

Chapter 1
Introduction

Matthias Wolff, Sebastian C. A. Ferse, and Hugh Govan

Abstract After 20 years of successfully running an M.Sc. programme, called ISATEC (International Studies in Aquatic Tropical Ecology) we considered it time to revisit the tropical areas and to reflect on the global challenges in Tropical Coastal Zone Management through the eyes of our former graduates involved in science and/or policy making in their home countries. We enquired if progress can be seen over the last three decades on the way toward reaching the Sustainable Development Goals in tropical coastal countries, and what the persisting crucial problems are that we need to focus our research, capacity development, and policy actions on. This book was then conceived to provide a platform for ISATEC alumni to (1) share their perspective on the current state of the art of coastal and resource management and conservation in their countries, (2) reflect on challenges and future needs in research and management for sustaining the ecosystems of the tropical coastlines for future generations on the way toward reaching the SDGs, and (3) allow us to evaluate our current training efforts to identify possible thematic gaps to be filled and training approaches to be improved. The book covers all regions of the tropical belt. It is structured into four parts: A first part (introduction and context)—that provides the background and context of this book. A second part (case studies)—that describes the state and current challenges in coastal and resource management in the countries of the ISATEC alumni and collaborators that contributed to this book. A third part (evaluation and synopsis)—that aims at a comparative analysis of the case studies presented and a synthesis of findings. We derive emergent key issues for management and conservation for the tropical coastal environments. A fourth, concluding part—that reviews the success and relevance of our and similar training programs

M. Wolff (✉) · S. C. A. Ferse
Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany

Faculty of Biology and Chemistry, University of Bremen, Bremen, Germany
e-mail: matthias.wolff@leibniz-zmt.de; sebastian.ferse@leibniz-zmt.de

H. Govan
University of the South Pacific (USP), School of Law and Social Sciences (SoLaSS), Suva, Fiji Islands

Locally Managed Marine Area (LMMA) Network International, Suva, Fiji Islands

M. Wolff et al. (eds.), *Challenges in Tropical Coastal Zone Management*,
https://doi.org/10.1007/978-3-031-17879-5_1

and looks at the progress made in ocean and coastal management over the past decades as well as at gaps for future research and capacity development.

1 Challenges in Tropical Coastal Zone Management and the ISATEC Program

As we write (May 2022), the global population is still being heavily impacted by the COVID 19 pandemic, with over 526 million of infected people globally already and over 6.3 million deaths. The extreme interconnectedness of our globalized world is illustrated by a minute virus affecting people of all continents, countries, and social strata. With a population close to 8 billion people, our species exceeds in abundance and density all other mammals on this planet and has increasingly needed to exploit a wider range of habitats and resources, so it is not surprising that *Homo sapiens* is becoming host to a variety of new bacterial and viral infections. Indeed, mounting evidence shows a clear link between human's impact on the environment and the risk of pandemics such as the present one (Tollefson 2020).

About half of our planet's population lives close to the tropical shores, which are also the areas of highest rates of population increase due to high birth rates and massive migration from inland areas (Neumann et al. 2015). Urbanization and tourism development are most pronounced here, contributing to complex webs of often conflicting economic activities such as fishery, aquaculture, port construction, oil drilling, or ship traffic, as well as the impacts of land-based activities such as agriculture, logging, and mining.

As a result of these activities, coastal habitats have been damaged; mangrove areas have decreased by about 6.6% in the past three decades FAO and UNEP 2020, and seagrass meadows are reported to have declined by a rate of 7% per year since the 1990s (Short and Wyllie-Echeverria 1996; Waycott et al. 2009). A loss of these vegetated areas reduces the capacity of the coastal zone to combat global warming and prevent coastal erosion (see http://thebluecarboninitiative.org/ and https://www.iucn.org/theme/forests/our-work/forest-landscaperestoration/).

Coral reefs, the habitat of about 1/3 of all marine species (Fisher et al. 2015), are severely threatened globally. Heat stress is causing mass bleaching and mortality of reef corals. The 2016 bleaching event resulted in the loss of 30% of the coral cover of the Great Barrier Reef within just 9 months (Hughes et al. 2018a, b). Since 2016, there have been four mass bleaching events, affecting reefs around the world with increasing intensity and frequency (Eakin et al. 2019; Hughes et al. 2018a, b).

In addition to ocean warming, other consequences of climate change in the ocean are the rising sea level, already endangering many small islands (Martyr-Koller et al. 2021), ocean acidification (Feely et al. 2004), oxygen depletion (Breitburg et al. 2018), and extreme weather events that increase in strength and frequency, with devastating effects on urban infrastructures and the functioning of coastal ecosystems (Holland and Bruyère 2014). Climate change and its impacts on species and ecosystems are expected to drive the loss of coastal resources and reduce the productivity of marine and coastal fisheries and aquaculture, especially at low latitudes (Bell et al. 2013; Cheung et al. 2010). The repercussions are likely to be huge and add to existing over-exploitation. Reductions in fisheries stock productivity will particularly affect coastal fisheries in the tropics, which are vital to the wellbeing of island and coastal communities. Meanwhile, further changes in stock distributions will have a particular impact on oceanic fisheries, which provide much revenue for tropical and islands nations (Barange et al. 2018).

Coastal waters are being polluted with plastic and other solid and liquid wastes deriving from near-by and far-away urban centers (Halpern et al. 2008). Effects of land-based activities such as logging and mining impact the coastal waters of the sea as do effluents from agriculture and animal husbandry, which contaminate rivers and coastal waters with high loads of nutrients and toxic chemicals including antibiotics, affecting coastal food webs and biota.

Due to this multitude of stressors, coastal habitats are greatly altered, species change their abundances and distributional ranges, biodiversity is lost at an alarming rate and many services provided by these ecosystems are lost, such as coastline stabilization and CO_2 storage and uptake by coral reefs, mangrove and sea grass areas, food production through fisheries and aquaculture resources, coastal water purification through extensive beach areas, climate stabilization by coastal wetlands, habitat provisioning for an extraordinary number of species, and genetic resources (Dasgupta 2021).

Global mapping of the different threats our planet is subjected to (IOC-UNESCO and UNEP 2016) reveals highest threat scores in the countries of the tropical belt, while low risk areas are all confined to the temperate zones. A very different picture emerges if we look at the ecological footprint of different societies, which is the highest in the wealthy countries of the global north (WWF 2016), since it is here that most of the global energy, food, and water are consumed and where most of the waste is produced and CO_2 emitted.

The unrelenting quest for economic growth has increased the pressure on the planet—the race among diverse and often competing interests for ocean food, material, and space has been termed "Blue Acceleration" and poses existential risks to humanity. At the same time, effectively applying norms of equity, conservation, and sustainable use pose a commensurate opportunity (Jouffray et al. 2020).

To counteract the planet's further degradation at multiple scales—from local and individual to national and global—we need a more holistic system thinking to better identify unsustainable consumption and production patterns, malfunctioning governance structures, and short-term focused economic planning, and may even consider radical reform of economic models to overcome fundamental structural problems. The concentration of power and state capture by economic interests is a widespread phenomenon, including food production systems in the ocean such as the industrial fleets of foreign, long-distance trawlers that operate along most of the tropical coastlines, often not only leading to overfishing, but also to devastating consequences for local small-scale food producers, who lose their livelihoods and fall into a poverty trap (Wolff 2015).

Most of the above issues were recognized by scientists and policy makers at least three decades ago, and during the United Nations Conference on Environment and Development (UNCED) ("Rio Conference", 3–14 June, 1992) were taken up in Agenda 21, the Rio Declaration on Environment and Development, a comprehensive plan of action to build a global partnership for sustainable development to improve human lives and protect the environment. Agenda 21 was adopted by 178 countries, and shortly afterward the Commission on Sustainable Development (CSD) was created to ensure effective follow-up of UNCED, to monitor and report on implementation of the agreements at the local, national, regional, and international levels. In 2000, the Millennium Development Goals (MDG) with the aim of reducing extreme poverty by the year 2015 were formulated by the UN member states. This was followed by the formulation of the Sustainable Development Goals (SDGs), a process that started during the Rio +20 conference in Rio de Janeiro in June 2012. This process culminated in the subsequent adoption of the 2030 Agenda for Sustainable Development, with the description of the 17 Sustainable Development Goals (SDGs) at its core, by 2015.

Shadowing the above-mentioned global processes of identification and reaction to major planetary threats, the Centre for Tropical Marine Research (ZMT) was created in Bremen (Germany) in 1991 to contribute with research and capacity development to the sustainable management and conservation of tropical areas to help fulfilling the global goals eventually formulated as the 17 SDGs.

A strong pillar of the ZMT was the development of an international and interdisciplinary Master of Science Program (ISATEC—International Studies in Aquatic Tropical Ecology). Launched in 1999, ISATEC offered capacity development to international students interested in research, management, and conservation of tropical aquatic ecosystems. The vision was to train young scientists in this multidisciplinary area of research and prepare them for work as scientists, managers, or teachers in institutions dedicated to the sustainable use and conservation of tropical habitats and their resources.

The ISATEC program was built on three pillars reflecting its main objectives (Table 1.1)

1. Provide knowledge and understanding about ecosystem structure and function,
2. Learn concepts and tools for modeling and management of systems and resources, and
3. Acquire skills for independent study, data analysis, and writing.

We envisioned a "coastal manager" (Olsen 1995) particularly skilled in conflict resolution, management of group processes, and the development of transdisciplinary research programs. At the same time, the graduate should have acquired "cultural literacy" through having been trained in an international and intercultural group of students and having spent his/her field research period in a tropical country, as well as profound knowledge of ecosystem functioning and relevant approaches to system studies.

This ongoing program has thus far graduated over 370 young scientists from more than 65 countries. Many of the graduates are currently working in their area of

Table 1.1 Thematic fields and study contents of the ISATEC program in 1999

Ecology	Evaluation and management	General skills
Basic understanding of ecosystem functioning and energy transfer	Theoretical concepts and methods for resource and ecosystem assessment	Independent self-studies and time management; scientific writing and presenting
Comparison of tropical aquatic systems in terms of representative biota and environmental envelope	Introduction to relevant models and computer software for fisheries and ecosystem studies	To learn how to study and work within an interdisciplinary and intercultural team; the transdisciplinary approach
Concepts and methods to study and model populations and communities	Cultivation systems for tropical resources; target species and environmental requirements	To know relevant databases and how to access them and make use of the data
Knowledge of the utilization and economic value of aquatic ecosystems and their resources	Understanding of the complexity of decision making in environmental management	Knowledge of approaches for ecosystem modeling, ability for analysis of complex problems and capacity for oral and written communication

expertise in their home countries, which mostly are located within the tropical belt. About 30% of the graduates have continued in academia, most progressing to PhD studies.

After 20 years of successfully running this program we considered it time to revisit those tropical areas and to reflect on the global challenges in Tropical Coastal Zone Management through the eyes of our former graduates involved in science and/or policy making in their home countries.

With former students, we enquired if progress can be seen over the last three decades on the way toward reaching the Sustainable Development Goals in tropical coastal countries, and what the persisting crucial problems are that we need to focus our research, capacity development, and policy actions on.

This book was conceived therefore to provide a platform for ISATEC alumni to (1) share their perspective on the current state of the art of coastal and resource management and conservation in their countries, (2) reflect on challenges and future needs in research and management for sustaining the ecosystems of the tropical coastlines for future generations on the way toward reaching the SDGs, and (3) allow us to evaluate our current training efforts to identify possible thematic gaps to be filled and training approaches to be improved.

The book covers all regions of the tropical belt. It is structured into four parts:

1. A first part (introduction and context)—that provides the background and context of this book.
2. A second part (case studies)—that describes the state and current challenges in coastal and resource management in the countries of the ISATEC alumni and collaborators that contributed to this book.
3. A third part (evaluation and synopsis)—that aims at a comparative analysis of the case studies presented and a synthesis of findings. We derive emergent key issues for management and conservation for the tropical coastal environments.

4. A fourth, concluding part—that reviews the success and relevance of our and similar training programs and looks at the progress made in ocean and coastal management over the past decades as well as at gaps for future research and capacity development.

References

Barange M, Bahri T, Beveridge MC, Cochrane KL, Funge-Smith S, Poulain F (2018) Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options. FAO

Bell JD, Ganachaud A, Gehrke PC, Griffiths SP, Hobday AJ, Hoegh-Guldberg O, Johnson JE, Le Borgne R, Lehodey P, Lough JM, Matear RJ, Pickering TD, Pratchett MS, Sen Gupta A, Senina I, Waycott M (2013) Mixed responses of tropical Pacific fisheries and aquaculture to climate change. Nat Clim Chang 3(6):591–599. https://doi.org/10.1038/Nclimate1838

Breitburg D, Levin LA, Oschlies A, Grégoire M, Chavez FP, Conley DJ, Garçon V, Gilbert D, Gutiérrez D, Isensee K, Jacinto GS, Limburg KE, Montes I, Naqvi SWA, Pitcher GC, Rabalais NN, Roman MR, Rose KA, Seibel BA et al (2018) Declining oxygen in the global ocean and coastal waters. Science 359(6371). https://doi.org/10.1126/science.aam7240

Cheung WWL, Lam VWY, Sarmiento JL, Kearney K, Watson R, 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. https://doi.org/10.1111/j.1365-2486.2009.01995.x

Dasgupta SP (2021) The economics of biodiversity the Dasgupta review abridged version. HM Treasury, London, p 103

Eakin CM, Sweatman HPA, Brainard RE (2019) The 2014-2017 global-scale coral bleaching event: insights and impacts. Coral Reefs 38(4):539–545. https://doi.org/10.1007/s00338-019-01844-2

FAO and UNEP (2020). The state of the worlds forests. Forests, biodiversity and people, Rom. https://doi.org/10.4060/ca8642en

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(5682):362–366

Fisher R, O'Leary RA, Low-Choy S, Mengersen K, Knowlton N, Brainard RE, Caley MJ (2015) Species richness on coral reefs and the pursuit of convergent global estimates. Curr Biol 25(4): 500–505. https://doi.org/10.1016/j.cub.2014.12.022

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(5865):948–952. https://doi.org/10.1126/science.1149345

Holland G, Bruyère CL (2014) Recent intense hurricane response to global climate change. Clim Dyn 42(3):617–627. https://doi.org/10.1007/s00382-013-1713-0

Hughes TP, Anderson KD, Connolly SR, Heron SF, Kerry JT, Lough JM, Baird AH, Baum JK, Berumen ML, Bridge TC, Claar DC, Eakin CM, Gilmour JP, Graham NAJ, Harrison H, Hobbs JPA, Hoey AS, Hoogenboom M, Lowe RJ et al (2018a) Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. Science 359(6371):80-+. https://doi.org/10.1126/science.aan8048

Hughes TP, Kerry JT, Baird AH, Connolly SR, Dietzel A, Eakin CM, Heron SF, Hoey AS, Hoogenboom MO, Liu G (2018b) Global warming transforms coral reef assemblages. Nature 556(7702):492–496

IOC-UNESCO and UNEP (2016) Large marine ecosystems: status and trends. United Nations Environment Programme (UNEP), Nairobi

Jouffray JB, Blasiak R, Norstrom AV, Osterblom H, Nystrom M (2020) The blue acceleration: the trajectory of human expansion into the ocean. One Earth 2(1):43–54. https://doi.org/10.1016/j.oneear.2019.12.016

Martyr-Koller R, Thomas A, Schleussner C-F, Nauels A, Lissner T (2021) Loss and damage implications of sea-level rise on Small Island developing states. Curr Opin Environ Sustain 50:245–259

Neumann B, Vafeidis AT, Zimmermann J, Nicholls RJ (2015) Future coastal population growth and exposure to sea-level rise and coastal flooding–a global assessment. PLoS One 10(3): e0118571. https://doi.org/10.1371/journal.pone.0118571

Olsen S (1995) The skills, knowledge, and attitudes of an ideal coastal manager. In educating coastal managers. In: Proceedings of the Rhode Island workshop, coastal resources Center/ USAID. W. Alton Jones Campus, University of Rhode Island, pp 3–7

Short F, Wyllie-Echeverria S (1996) Natural and human-induced disturbance of seagrasses. Environ Conserv 23:17–27. https://doi.org/10.1017/S0376892900038212

Tollefson J (2020) Why deforestation and extinctions make pandemics more likely. Nature 584(7820):175–176. https://doi.org/10.1038/d41586-020-02341-1

Waycott M, Duarte CM, Carruthers TJB, Orth RJ, Dennison WC, Olyarnik S, Calladine A, Fourqurean JW, Heck KL, Hughes AR, Kendrick GA, Kenworthy WJ, Short FT, Williams SL (2009) Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proc Natl Acad Sci U S A 106(30):12377–12381. https://doi.org/10.1073/pnas.0905620106

Wolff M (2015) From sea sharing to sea sparing–is there a paradigm shift in ocean management? Ocean Coast Manag 116:58–63. https://doi.org/10.1016/j.ocecoaman.2015.07.004

WWF (2016) World Wildlife Fund WWF. United States [Web Archive]. Retrieved from the Library of Congress. https://www.loc.gov/item/lcwaN0011596/

Part II
Case Studies

The 16 case studies presented in this book span tropical coastal areas of Africa, Latin America, Asia, and the Pacific Island States and thus allow drawing some general inferences for a global picture of current practices and challenges with regard to the management and conservation of the tropical coastal seas.

Contributions are from Africa (Ghana, Tanzania, Ethiopia, Kenya, and Saudi Arabia), Latin America (Peru, Ecuador, Guatemala, and Panama), Asia (Bangladesh, Philippines, Indonesia, and Thailand), and the Pacific Islands (Cook Islands). The individual authors selected the most relevant issues through coastal zone management case studies in their countries of work.

Chapter 2
Kenya Case Study One

Hit-and-Miss: Assessing the Current Fisheries Regulations in Light of the Changing Face of Marine Artisanal Fisheries in Kenya

Paul Tuda, Rashid Imam, Benedict Kiilu, and Johnstone Omukoto

Abstract Marine artisanal fisheries play an important role among Kenyan coastal communities, making a vital contribution to livelihoods and food security. Nevertheless, the contribution of this fishery sector to the national fishery and the gross domestic product (GDP) is low and minimal investments have been pumped back into the sector both in terms of budget and policies reflecting the status of the fisheries sector. Since Independence (1963), the Kenyan fisheries sector has operated without a comprehensive policy and legal framework. However, in 2008, the government, through the state department of fisheries, enacted the national oceans and fisheries policy to address the myriad of challenges facing the sector and to contribute to the overall sustainable use of fisheries resources and marine ecosystems. Nevertheless, the fishery has continued to face a myriad of challenges typical to most fisheries in the developing countries occasioned by declining catches, increasing effort and the use of unsustainable fishing practices, putting the livelihoods of future generations at risk. Besides, the government has committed to many international and regional instruments relevant to fisheries in an attempt to meet its international obligation in supporting global efforts towards sustainable fisheries.

Nevertheless, there are constraints towards implementing some of these resolutions and there is the risk that these commitments put further stress on the respective fisheries management agencies already under severe pressure. The government has prioritized participation in processes and forums towards the advance of international and regional treaties at the expense of the national needs. Therefore, while the national government might appear to be making significant progress in meeting the

P. Tuda (✉)
Leibniz Center for Tropical Marine Ecology (ZMT), Bremen, Germany
e-mail: paul.tuda@leibniz-zmt.de

R. Imam · B. Kiilu
Kenya Fisheries Service, Mombasa, Kenya

J. Omukoto
Kenya Marine and Fisheries and Research Institute (KMFRI), Mombasa, Kenya

M. Wolff et al. (eds.), *Challenges in Tropical Coastal Zone Management*,
https://doi.org/10.1007/978-3-031-17879-5_2

global targets, there is little evidence that there is compliance with national fisheries legislation. A continued decline in the status of the fisheries stocks can still be expected unless more resources and effort are put towards the fisheries sector nationally.

Keywords Fisheries Management and Development Act · Management plans · Co-governance · Kenya · Western Indian Ocean

1 Introduction

Marine artisanal fisheries play an important role among Kenyan coastal communities, making a vital contribution to livelihoods, food security as well as a socio-cultural identity (Munga and Ndegwa 2014). Among the many economic activities carried out along the Kenyan coastline, the artisanal fishery is practised along the entire coast, even in the remote areas making a significant contribution to the household income. However, the contribution of this fishery sector to the gross domestic product (GDP) is low (<1%), and as such, receives low priority at the national level (Mangi et al. 2007; Zeller et al. 2006). According to Malleret (2000), marine fisheries contribute approximately up to 80% of the total household income for most of the coastal communities in Kenya. However, these estimates are conservative, given the lack of adequate data and disaggregation of data to the socio-economic level (Le Manach et al. 2015; Tuda and Wolff 2015).

Recent efforts through an Economic and Financial Impact Assessment (EFIA) of Marine Fisheries in Kenya further revealed that comparison between official and reconstructed data indicates that the annual fish catch is almost six times (53,665 metric tonnes) the official published fisheries statistics (9000 m) with an estimated value to the fisherman being eight times the official published data (Owiti et al. 2018). The recommendation to review Kenya's official marine artisanal fisheries statistics in order to correct under-estimation in the economic estimates of Kenya marine fisheries was therefore made to enable adjust management cost recovery and revenue allocation framework by national and county governments with regard to the fisheries sector.

1.1 Description of the Fishery

The marine fisheries in Kenya broadly include the coastal nearshore waters mostly dominated by the artisanal fishers and the offshore fishery conducted mainly in the Exclusive Economic Zone (EEZ) (Aloo et al. 2014). The coastal nearshore fisheries are characterized by artisanal fishers using traditional fishing gears and small, mostly non-motorized vessels operating nearshore and not exceeding 20 m depth (Kaunda-Arara et al. 2003; Ochiewo 2004).

Typical catches from the artisanal fisheries are diverse, consisting of over 160 species targeted by an array of gears and mostly dominated by coral reef and seagrass associated species, which are estimated to constitute about 80% of fish catches (Bosire et al. 2012; Samoilys et al. 2017). Overall, the demersal fish species dominate the marine catch. According to the statistics from the State Department of Fisheries (2014), demersal fish species accounted for 45% of the total marine landings (10,135 metric tons) in 2014, followed by the pelagics accounting for 35% (7843 metric tons), molluscs 9% (2044 metric tons), and sharks, rays and mixed-species "nei" (not elsewhere included) and crustaceans, which contributed 8% (1762 metric tons) and 3% (620 metric tons), respectively.

Whereas the artisanal fisheries are characterized by high species diversity, only a few families and species dominate the catches, perhaps reflecting the most abundant and commercially important species (Hicks and McClanahan 2012; Tuda et al. 2016). Overall, fish catches are dominated by species from the families Siganidae, Scaridae and Lethrinidae, with at least 13 species from these families representing more than 75% of the overall catch.

Over the past decades, studies point to a declining fishery evidenced by a decline in the catch per unit effort (CPUE) and the mean trophic level of some commercially essential species (McClanahan et al. 2008). However, the status of most fish species remains unknown mainly due to the lack of comprehensive fish stock assessment, which is hindered by a paucity of data on exploited species (Fondo et al. 2014). Even though there are programs in place to collect routine fisheries data, these programs are pegged on budgetary allocation, limiting the data collection periods and type of data collected, resulting in nonspecific (mixed species) and highly aggregated data. Thus, the existing stock assessment studies are based on data-limited approaches focusing on specific species and/or regions but are not fully representative of the entire fishery (Wambiji et al. 2015).

1.2 Fishing Boat Fleets and Gear

The marine artisanal fishery in Kenya is multigear-multispecies. Results of the most recent frame survey of 2016 indicate that over 20 gear types are used with the five most common including gillnets, basket traps, handlines, spearguns and beach seines (Table 2.1) (Kimani et al. 2018). The use of these gears and techniques is primarily driven by a range of geographical, contextual, financial and socio-cultural factors such as resident village, choice of the landing site, financial capital, social networks and age (Evans 2010; Mangi et al. 2007; Omukoto et al. 2018).

The number of fishers and fishing crafts, an indication of the fishing effort, has dramatically increased in the past decade (see Tables 2.2 and 2.3). Whereas the non-mechanized vessels has traditionally been used as the descriptor of the fishery, an increasing number of fishers are now using mechanized vessels, which could also signify the entry of private actors with a reduced number of fishers owning the crafts (Karuga and Abila 2007; Wamukota 2009).

Table 2.1 Summary of the main fishing gears as reported by the bi-annual marine frame survey (Source: State Department of Fisheries 2014)

Fishing gears	Years					
	2004	2006	2008	2012	2014	2016
Gill nets	7431	5916	3956	4168	3325	3835
Monofilament gill nets	902	1050	1472	3239	2692	2739
Prawn seine	226	264	545	730	610	445
Beach seine	294	560	139	217	193	131
Reef seine	158	146	146	63	89	157
Trawl nets	21	20	28	3	–	–
Cast net	520	812	499	408	332	357
Ring nets	1	11	15	22	31	38
Trammel nets	28	23	35	48	9	–
Long lines	10,608	8224	9009	16,476	9349	14,511
Hand lines	5682	6540	4132	4686	5806	4358
Traps	6318	5224	3169	4438	4057	3483
Scoop nets	562	764	596	652	566	827
Trolling lines	608	500	625	741	803	554
Spear gun/harpoon	449	624	1007	2939	2423	1700
Hand gathering	–	–	–	–	391	376
Others	956	2116	290	443	8	45

Table 2.2 Summary of the bi-annual marine frame survey detailing the number of fishing crafts

Fishing crafts	Years					
	2004	2006	2008	2012	2014	2016
Inboard engines	66	61	98	71	72	41
Outboard engines	69	133	221	296	428	587
Paddles	1023	991	1021	1242	974	1243
Sails	1075	1179	1227	1340	1248	1042
Poles	–	3	120	167	191	61
Total crafts	2233	2368	2687	3118	2913	2974

Table 2.3 The number of fishers operating in the Kenyan coast as reported in the bi-annual marine frame survey

Year	Number of fishers	
	Male	Female
2004	9017	–
2006	10,254	–
2008	12,077	–
2012	13,706	–
2014	12,748	167
2016	13,162	255

2 Legal and Regulatory Framework

The legal and regulatory framework for managing the marine fisheries resources in Kenya encompasses the operational mandates of several national and international institutions and agencies responsible for the management of natural resources. Fisheries resources are governed by a number of legal, policy, and institutional frameworks.

2.1 Global Instruments and Conventions to Which Kenya Is a Signatory

2.1.1 Progress in Implementing the Instruments

This section presents important international instruments for fisheries management, which the country is part of as well as progress in their implementation in the country. The progress of implementation of these instruments was determined based on a review of available literature as well as the author's experience while working in the country's fisheries sector. Availability of provisions of the international agreements in the national legislation, policy documents and fisheries management plans of the country was assumed to be an indicator of progress as far as commitment to the implementation of the resolutions to which the country is committed.

Kenya is a signatory to various international legal instruments and other non-binding instruments with the objective of development and sustainable utilization of its aquatic resources for sustainable economic growth. The progress of the country in implementing some of the important goals ascribed to the global instruments and conventions the country is part of is described in Table 2.4. Overall, while the implementation of some of the resolutions requires more attention, it should be mentioned that there are positive indicators that the country is committed to its international obligations. Notably, the country has taken significant steps towards mainstreaming the Blue Economy sector and positioning it to substantially contribute to the country's economic growth as elaborated in the country's Blue Economy Sector Medium Term Plan (2018–2022). Further, in the Medium Term Plan, the country has prioritized participation in processes and forums towards the advance of international and regional treaties, conventions, and agreements relevant to fisheries, aquaculture and maritime.

Table 2.4 Progress in the implementation of important global instruments and conventions to which Kenya is a party

Global instrument/Convention	Aims/Objectives	Progress of implementation
The United Nations Convention on the Law of the Sea (UNCLOS) of 10 December 1982 (UN 1982)	To promote the peaceful uses of the seas and oceans, the equitable and efficient utilization of their resources, the conservation of their living resources, and the study, protection and preservation of the marine environment (UNCLOS preamble).	Kenya is a signatory to both the convention and the agreement. It is well reflected in the national fisheries legislation (the Fisheries Management and Development Act No. 35 of 2016–FMDA 2016) (National Council for Law Reporting 2016) and other national legislations as well as prioritized in the country's Blue Economy Sector Medium Term Plan (2018–2022) (SDFABC 2017).
Agreement for the establishment of the Indian Ocean Tuna Commission (IOTC) (FAO 1993)	Established to promote cooperation among the parties with a view of ensuring, through appropriate management, the conservation and optimum utilization of stocks covered by the agreement and encouraging sustainable development of fisheries based on such stocks.	The provisions are well reflected in the national fisheries legislation and other policy documents like the National Oceans and Fisheries Policy of 2008 and the Kenya Tuna Fisheries Development and Management Strategy of 2013 (Ministry of Agriculture Livestock and Fisheries 2013). While it is fairly implemented, there is limited capacity to implement some of the provisions.
Agreement for the implementation of the provisions of the UNCLOS relating to the conservation and management of straddling fish stocks and highly migratory fish stocks	Sets out principles for the conservation and management of those fish stocks and establishes that such management must be based on the precautionary approach and the best available scientific information.	The provisions are well reflected in the national fisheries legislation and other policy documents like the National Oceans and fisheries policy of 2008 and the Kenya tuna fisheries development and management strategy of 2013. There is fair implementation within the IOTC framework but limited capacity is a major constraint.
The Rome consensus on world fisheries	Maintaining world fish resources and aquatic ecosystems through improved fisheries conservation and management and better protection of fisheries from harmful sea- and land-based	Well reflected in the national fisheries legislation, the Environmental Management and Co-ordination Act of 1999 (EMCA –1999) (National Council for Law Reporting 1999) and the country's Blue Economy Sector Medium

(continued)

Table 2.4 (continued)

Global instrument/Convention	Aims/Objectives	Progress of implementation
	activities including sustainable development of aquaculture.	Term Plan (2018–2022). There are efforts to implement but limited capacity is still a major constraint.
FAO code of conduct for responsible fisheries	Sets out principles and international standards of behaviour for responsible practices with a view to ensuring the effective conservation, management, and development of living aquatic resources, with due respect for the ecosystem and biodiversity.	The provisions are well reflected in the national fisheries legislation and other policy documents like the National Oceans and Fisheries Policy of 2008 and the Kenya Tuna Fisheries Development and Management Strategy of 2013 (Ministry of Agriculture Livestock and Fisheries 2013).
Agreement to promote compliance with international conservation and management measures by fishing vessels on the high seas (compliance agreement)	Enhancing the role of flag states and ensure that a state strengthens its control over its fishing vessels to ensure compliance with international conservation and management measures.	While Kenya is not a signatory, the provisions are well reflected in the national fisheries legislation and well implemented. There is continuous inspection of fishing vessels to implement port state measures (PSM) and establishment of the National Fisheries Observer Program covering Kenyan flagged fishing vessels in the high seas.
International plan of action to prevent, deter and eliminate illegal, unreported and unregulated fishing (IPOA-IUU)	A voluntary instrument that applies to all states and entities as well as fishers and envisages broad participation and coordination and the use of a comprehensive and integrated approach to address impacts of IUU fishing, reduction in incidental catch of birds in longline fishing vessels, conservation and management of shark fisheries.	IPOA-IUU are well reflected in the national fisheries legislation. Key initiatives include continuous inspection of industrial fishing vessels to implement PSM; Establishment of National Fisheries Observer Program; Establishment of the Kenya Coast Guard Service (KCGS) (National Council for Law Reporting 2017) to enforce compliance within Kenya's EEZ; Construction and operationalization of the Fisheries Monitoring, Control and Surveillance (MCS) complex that is fully equipped with a Vessel Monitoring System (VMS).

(continued)

Table 2.4 (continued)

Global instrument/Convention	Aims/Objectives	Progress of implementation
Agreement on Port State Measures (PSM) to prevent, deter and eliminate IUU fishing (FAO 2009)	The objective of this agreement is to prevent, deter and eliminate IUU fishing through the implementation of effective port state measures, and thereby to ensure the long-term conservation and sustainable use of living marine resources and marine ecosystems.	PSM provisions are well reflected in the national fisheries legislation. Key initiatives include continuous inspection of fishing vessels to implement PSM within the framework of the IOTC; establishment and operationalization of the National Fisheries Observer Program; establishment of the KCGS to enforce compliance within Kenya's EEZ; construction and operationalization of the fisheries MCS complex that is fully equipped with a VMS.
FAO voluntary guidelines for flag state performance (VGFSP)	The VGFSP provides guidance to strengthen and monitor compliance by flag states with their international duties and obligations regarding the flagging and control of fishing vessels to combat IUU fishing, including monitoring, control and surveillance (MCS) activities, such as vessel monitoring systems (VMS) and observers.	VGFSP issues are addressed at the FAO committee on fisheries (COFI) sessions of which Kenya is a party. – VGFSP provisions are well reflected in the national fisheries legislation. Implementation status and indicators are the same as those of PSM.
Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (UN 1973)	CITES aims at ensuring that international trade in specimens of wild animals and plants does not threaten their survival. While the convention is legally binding on the parties, it does not take precedence over national legislation but provides a framework for each party to develop its own domestic legislation to ensure that CITES is implemented at the national level.	CITES provisions are well reflected in the national fisheries legislation and other legislations like the Wildlife Conservation and Management Act of 2013 (WCMA–2013) (National Council for Law Reporting 2013) and the EMCA –1999. Other initiatives by the government include the development of a Rapid Reference Guide To Wildlife and Fisheries Crime for use by investigators and prosecutors.
The RIO Declaration on Environment and Development (UN 1992)	Sets out goals and programs under which nations may conserve oceanic resources for their own and the benefit of the nations that share oceans with them, and international programs that may protect the	Provisions are well reflected in the national fisheries legislation and other national legislations like the EMCA – 1999 but implementation is hugely constrained by limited capacity.

(continued)

Table 2.4 (continued)

Global instrument/Convention	Aims/Objectives	Progress of implementation
	residual commons in the interests even of land-locked nations.	
Convention on biological diversity (CBD) and supplementary agreements to the CBD: The Cartagena protocol on bio-safety and the Nagoya protocol on access to genetic resources and the fair and equitable sharing of benefits arising from their utilization	The main objectives are 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. Together with its ratified supplementary agreements, the CBD is a binding agreement.	CBD provisions are well reflected in the national fisheries legislation and other legislations like the WCMA-2013 and the EMCA −1999. Key initiatives include continuous funding of research on marine and coastal ecosystems to inform conservation programs; commitment to related international treaties, e.g., the Indian Ocean and South-East Asia memorandum of understanding on conservation and Management of Marine Turtles and their habitats. Still, limited capacity and resources remain a major bottleneck to the conservation of biological diversity.
The Kyoto Declaration and Plan of Action The Bangkok Declaration and Strategy for Aquaculture Development Beyond 2000 (NACA/FAO 2000)	The first international Conference on Aquaculture organized by the FAO held in Kyoto, Japan in 1976 to address a myriad of challenges facing global aquaculture development. It focused on technology and science, networking, training and institutional development.The Parties resolved that aquaculture policies, regulations and practices should promote practical and economically viable farming and management practices that are environmentally responsible and socially acceptable and where appropriate, to build on the FAO Code of Conduct for Responsible Fisheries. (FAO 1995)	Provisions are well reflected in the national fisheries legislation and other legislations like the EMCA −1999. Aquaculture development plans are reflected in the country's Agricultural Sector Development Strategy of 2010, the National Aquaculture Policy of 2011 (Ministry of Fisheries Development 2011) and prioritized in the country's Blue Economy Sector Medium Term Plan (2018–2022). Further, A Residue Monitoring Plan for farmed fish was developed but it is yet to be implemented. –Despite its huge potential, mariculture production remains negligible without clear plans that are anchored in the country's aquaculture policy.

3 Challenges and Constraints to Implementation

As advanced above, there are positive signs that the country is on course towards meeting its international obligations. Nevertheless, there are constraints towards implementing some of the resolutions to which the country is a party. On a broader scale, the constraints revolve around the limited capacity of the country and weak policy frameworks. In 2010, the country promulgated a new constitution and adopted a two-level devolved system of governance, the national government and the county governments. Consequently, some of the national government functions were devolved to the county government level. While the assumptions behind devolving some functions to the county governments were noble, there appears to be a lack of a clear and coordinated approach to fisheries management issues between the two levels of governments. For example, while the national government has focussed on ensuring compliance by the industrial fishing vessels in the submission of catch data to inform fisheries management measures, there is little evidence to suggest that artisanal fishers are fully complying. While there appears to be an "informal consensus" that artisanal fishing catch data should be collected at the county government level, the same is not transmitted to the national government to inform overall fisheries management measures in the country. This has compounded the problem of poor fisheries data in an already fisheries data-poor country. Additionally, fisheries development programs conceptualized and funded by the county governments are not reported to the national government for sanctioning purposes. This has resulted, in some cases, in the implementation of unsustainable programs by county governments.

Other constraints to implement some resolutions include but are not limited to

1. A slow legislation process with important developed fisheries management plans taking more extended periods to be gazetted into law. Some of these management plans include the Small Scale Purse Seine Fishery Management Plan (final draft completed by a technical team in 2015) (Ministry of Agriculture Livestock and Fisheries 2015b); the Lobster Fishery Management Plan (final draft completed by a technical team in 2015) (Ministry of Agriculture Livestock and Fisheries 2015a); Marine Aquarium Fisheries Management Plan (final draft completed by a technical team in 2016) (Ministry of Agriculture Livestock and Fisheries 2016).
2. Limited national capacity to implement some resolutions of international agreements to which the country is a party.
3. Limited capacity to engage and participate effectively in the discussion of crucial straddling fish stocks and highly migratory fish stocks, including quota allocations and fisheries access arrangements.
4. Weak and inadequate legislation on aquaculture. The aquaculture legal and regulatory framework is fragmented and remains a challenge to the development of aquaculture systems. More so, there is no clear strategy for mariculture development whose potential appears to be huge along the country's coastline.
5. Uncertainty about the information regarding the current status of fisheries resources within the Kenyan Exclusive Economic Zone.

6. Inadequate infrastructure and human resource capacity in monitoring, control and surveillance resulting in ineffective enforcement of fisheries laws and regulations and an increase in IUU fishing activities.
7. Ineffective management and extension systems in the fisheries and aquaculture sector including limited commitment and involvement of stakeholders in the management of fisheries resources and protection of critical fish habitats.
8. Increased insecurity at sea, especially in the nearby coasts of the horn of Africa countries.
9. Unequal sharing of fisheries information at the international and regional level.

References

Aloo P, Munga C, Kimani E, Ndegwa S (2014) A review of the status and potential of the coastal and marine fisheries resources in Kenya. Int J Mar Sci 4(24)

Bosire JO, Okemwa G, Ochiewo J (2012) Mangrove linkages to coral reef and seagrass ecosystem services in Mombasa and Takaungu, Kenya. Participatory modelling frameworks to understand wellbeing trade-offs in coastal ecosystem services: mangrove sub-component. ESPA:45

Evans LS (2010) Ecological knowledge interactions in marine governance in Kenya. Ocean Coast Manag 53(4):180–191. https://doi.org/10.1016/j.ocecoaman.2010.01.009

FAO (1993) Agreement for the establishment of the Indian Ocean Tuna Commission. In: 105th session of the FAO conference. FAO, Rome

FAO (1995) Code of conduct for responsible fisheries. FAO, Rome, 41pp

FAO (2009) Agreement on port state measures to prevent, deter and eliminate illegal, unreported and unregulated fishing. In: 36th session of the FAO conference

Fondo NE, Kimani NE, Munga NC, Aura MC, Okemwa G, Agembe S (2014) A review on Kenyan fisheries research: 1970-2009. West Indian Ocean J Mar Sci 13(2):143–162

Hicks CC, McClanahan TR (2012) Assessing gear modifications needed to optimize yields in a heavily exploited, multi-species, seagrass and coral reef fishery. PLoS One 7(5):e36022. https://doi.org/10.1371/journal.pone.0036022

Karuga S, Abila RO (2007) Value chain market assessment for marine fish subsector in Kenya's coast region. Consultancy report for the coast development authority. Coastal Micro-enterprise development program

Kaunda-Arara B, Rose GA, Muchiri MS, Kaka R (2003) Long-term trends in coral reef fish yields and exploitation rates of commercial species from coastal Kenya. West Indian Ocean J Mar Sci 2(2):105–116

Kimani E, Okemwa G, Aura C (2018). The status of Kenya fisheries: towards sustainability exploitation of fisheries resources for food security and economic development

Le Manach F, Abunge C, McClanahan T, Pauly D (2015) Tentative reconstruction of Kenya's marine fisheries catch, 1950–2010. In Le Manach F, & Pauly D (eds.). Fisheries catch reconstructions in the Western Indian Ocean, 1950–2010. Fisheries Centre Research Reports 23(2). Fisheries Centre, University of British Columbia, pp 37–51

Malleret K (2000) A food security approach to marine protected area impacts on surrounding fishing communities: the case of Kisite marine National Park in Kenya. Cuvillier Verlag, Nonnenstieg

Mangi SC, Roberts CM, Rodwell LD (2007) Reef fisheries management in Kenya: preliminary approach using the driver-pressure-state-impacts-response (DPSIR) scheme of indicators. Ocean Coast Manag 50(5–6):463–480. https://doi.org/10.1016/j.ocecoaman.2006.10.003

McClanahan TR, Hicks CC, Darling ES (2008) Malthusian overfishing and efforts to overcome it on Kenyan coral reefs. Ecol Appl 18(6):1516–1529. https://doi.org/10.1890/07-0876.1

Ministry of Agriculture Livestock and Fisheries (2013) Kenya tuna fisheries development and management strategy (2013–2018). Government of Kenya

Ministry of Agriculture Livestock and Fisheries (2015a) The draft lobster fishery management plan. Government of Kenya

Ministry of Agriculture Livestock and Fisheries (2015b) The draft small scale purse seine fishery management plan. Government of Kenya

Ministry of Agriculture Livestock and Fisheries (2016) The draft marine aquarium fishery management plan. Government of Kenya

Ministry of Fisheries Development (2011) National aquaculture policy of 2011. Government of Kenya

Munga C, Ndegwa S (2014) A review of the status and potential of the coastal and marine fisheries resources in Kenya. Int J Mar Sci 444:1–9

NACA/FAO (2000) Aquaculture development beyond 2000: the Bangkok declaration and strategy. Conference on aquaculture in the third millennium, 20–25 February 2000, Bangkok, Thailand. NACA, Bangkok

National Council for Law Reporting (1999) Environmental management and co-ordination Act no. 8 of 1999. The judiciary, Government of Kenya

National Council for Law Reporting (2013) Wildlife conservation and management Act no. 47 of 2013. The judiciary, Government of Kenya

National Council for Law Reporting. (2016). Fisheries Management and Development Act no. 35 of 2016. The Judiciary, Government of Kenya

National Council for Law Reporting. (2017). The Kenya coast guard services bill, 2017. The Judiciary, Government of Kenya

Ochiewo J (2004) Changing fisheries practices and their socioeconomic implications in south coast Kenya. Ocean Coast Manag 47(7):389–408. https://doi.org/10.1016/j.ocecoaman.2004.07.006

Omukoto JO, Owiti H, Mwakha VA, Munga CN, Wamukota AW (2018) Participatory assessment of priority fishery profiles in an overfished urban inshore seascape in Kenya. West Indian Ocean J Mar Sci 17(2):79–92

Owiti H, Ochiewo J, Swaneerain S, Munyi F, Waiyaki E, Njiru J, Okemwa G, Aura M, Oketch R, Olela P (2018) Economic and financial impact assessment (EFIA) for marine fisheries, Kenya. Kenya Marine and Fisheries Research Institute

Samoilys MA, Osuka K, Maina GW, Obura DO (2017) Artisanal fisheries on Kenya's coral reefs: decadal trends reveal management needs. Fish Res 186:177–191. https://doi.org/10.1016/j.fishres.2016.07.025

SDFABC (2017) Blue economy sector medium term plan (2018–2022) of the Kenya vision 2030. Government of Kenya

State Department of Fisheries K (2014) Marine artisanal fisheries frame survey report

Tuda PM, Wolff M (2015) Evolving trends in the Kenyan artisanal reef fishery and its implications for fisheries management. Ocean Coast Manag 104:36–44

Tuda PM, Wolff M, Breckwoldt A (2016) Size structure and gear selectivity of target species in the multispecies multigear fishery of the Kenyan south coast. Ocean Coast Manag 130:95–106. https://doi.org/10.1016/j.ocecoaman.2016.06.001

UN (1973) Convention on international trade in endangered species of wild fauna and flora

UN (1982) United Nations convention on the law of the sea

UN (1992) The RIO declaration on environment and development

Wambiji N, Kimani E, Munga CN, Waweru G, Manyala J (2015) Stock assessment of rabbitfish (Siganus sutor) along the Kenya coast

Wamukota A (2009) The structure of marine fish marketing in Kenya:the case of Malindi and Kilifi districts. West Indian Ocean J Mar Sci 8(2):215–224

Zeller D, Booth S, Pauly D (2006) Fisheries contributions to the gross domestic product: underestimating small-scale fisheries in the Pacific. Mar Resour Econ 21(4):355–374

Chapter 3
Guatemala Case Study

Using the Marine Spatial Planning Approach to Design a Marine Protected Area in the Guatemalan Pacific

Pilar Velásquez, Vanessa Dávila, and Manuel Ixquiac

Abstract As coastal marine ecosystems are facing increasing threats associated with its unsustainable use, along with the fact that they are underrepresented within the Guatemalan protected areas system, the need to protect them through Marine Protected Areas (MPA) in the Guatemalan Pacific was prioritized since 2009. As there are no national official guidelines to design MPA, a Marine Spatial Planning approach was chosen to design "Las Lisas" MPA proposal, process that took place from 2016 until 2018. Emphasis was given to organize stakeholder participation, as "Las Lisas" proposed extent comprehended eight coastal communities and previous protected areas declarations in the country has faced several backlashes given the lack of involvement of local communities in the protected areas planning. As a result of the join planning and design process, the MPA proposal for "Las Lisas" entails 104,002.46 ha, with 96.15% of those hectares being marine. Its chosen spatial scenario is based on the current and potential activities being developed in the area and it includes within its boundaries seven out of the eight coastal communities originally considered, as one of them, La Barrona, decided not to be included within the MPA proposal. As this is the first time a Marine Spatial Planning approach was used to guide the construction of a coastal marine conservation intervention, is expected for the lessons learned from this initiative to inform future efforts for the territorial planning and ordinance of the whole Guatemalan Pacific.

Keywords Marine protected areas · "Las Lisas" · Marine spatial planning · Stakeholder participation · Marine protected areas design

P. Velásquez (✉) · M. Ixquiac
Centro de Estudios Conservacionistas (CECON), Universidad de San Carlos de Guatemala (USAC), Guatemala, Guatemala

V. Dávila
Centro de Estudios Conservacionistas (CECON), Universidad de San Carlos de Guatemala (USAC), Guatemala, Guatemala

Centro de Estudios del Mar y Acuicultura (CEMA), Universidad de San Carlos de Guatemala (USAC), Guatemala, Guatemala

M. Wolff et al. (eds.), *Challenges in Tropical Coastal Zone Management*,
https://doi.org/10.1007/978-3-031-17879-5_3

1 Background

Historically, marine conservation in Guatemala has been left aside. Going from the declaration of the Mayan Biosphere Reserve as a protected area (PA) in 1989 until the declaration of 339 PAs at year 2018 (Conap 2018) under different management categories according to the Protected Areas Law (Decree 4–89), approximately 33% of the national territory is a PA, considering mostly land. From these 339 PAs, only one (i.e. Punta de Manabique Wildlife Refuge, located in the Guatemalan Caribbean) can be considered as a Marine Protected Area (MPA).

Under such panorama and being aware about that conservation gap within the National System of Protected Areas (SIGAP by its Spanish acronym), especially in the Guatemalan Pacific, the Guatemalan State prioritized to fulfill the identified gap. In 2009, within the National Implementation Support Partnership (NISP) effort framed on the Working Plan on PA of the Convention of Biological Diversity (CBD), the National Council of Protected Areas (CONAP by its Spanish acronym) identified the ecological representation and conservation gaps and omission within SIGAP, effort that ended up in a Portfolio of Marine Sites for Conservation, which identified the polygon named “Las Lisas-La Barrona” as one of the coastal marine areas with relevant biological and social characteristics in need of the establishment of conservation measures (CONAP & Ministerio de Ambiente y Recursos Naturales MARN, 2009). Along with it, under the Global Ocean Biodiversity Initiative (GOBI), CONAP supported the eight criteria adopted by the CDB Conference of the Parties for positioning, within the Eastern Tropical Pacific, the area denominated “Sipacate Naranjo-Cañón de San José” as an Ecologically or Biologically Significant Marine Area (EBSA), which includes the marine zone of “Las Lisas-La Barrona.” Based on both efforts, Guatemala required financial support to the Global Environmental Facility (GEF) to implement, through the United Nations Development Programme (UNDP) and during 2014–2019, the project “Conservation and sustainable use of biodiversity in coastal and marine protected areas (MPAs),” which aimed, among numerous goals, for creating two new MPAs and expanding three existing coastal PAs in the Pacific region to contribute to the protection and sustainable use of marine coastal biodiversity of global, national, and local importance (Programa de las Naciones Unidas para el Desarrollo (PNUD 2014). One of these two new MPAs was “Las Lisas-La Barrona,” from now on called “Las Lisas.”[1]

1.1 “Las Lisas”

The coastal wetland and marine zone known as “Las Lisas” is located in the Guatemalan Pacific Coast, bordering to the west with El Salvador, in the Santa

[1] Reasons for the change in name are explained further in the chapter.

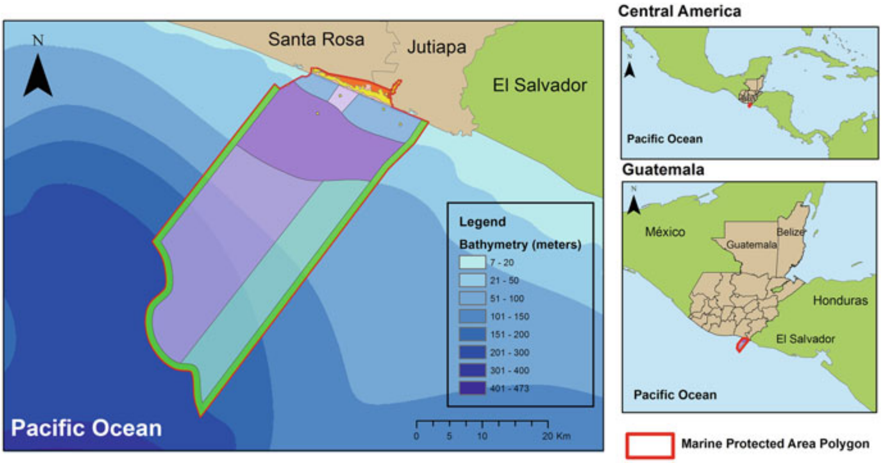


Fig. 3.1 "Las Lisas" location

Rosa and Jutiapa departments, in the Chiquimulilla and Pasaco municipalities, respectively (Fig. 3.1).

The coastal section of the wetland is constituted by an interface between the land and the ocean, where the land use and its environmental characteristics have molded the ecological conditions of the area and the living conditions of its inhabitants. It is an area of a dynamic biogeochemical activity but with a limited capacity to cope with anthropic actions like productive, commercial, and exchange processes based on the coastal marine resources that the region's nature capital provides (Boix et al. 2011). "Las Lisas" is characterized by the Chiquimulilla Channel, a series of water channels where artisanal fishing takes place all year long, surrounded by mangrove forests formed by four out of the six mangrove species reported for Guatemala (being the most common one *Rhizophora mangle*), where several Ciconiiformes and Pelecaniformes species establish their breeding colonies; by sandy beaches that are an important nesting zone for *Lepidochelys olivacea*, *Chelonia mydas agassizii,* and *Dermochelys coriacea*; and by "El Jiote" river mouth, the main connection between the coastal and marine ecosystems. Offshore, "Las Lisas" is characterized by the confirmed presence of seven species of cetaceans of the Delphinidae and Balaenopteridae families, being a common species the Humpback whale *Megaptera novaeangliae*; by the presence of several pelagic bird's species like the Pink-footed shearwater (*Ardenna creatopus*); by the presence of several fish and crustacean species of commercial and/or nutritious importance like *Lutjanus gutattus, Centropomus nigrescens,* and *L. peru;* and by the presence of an important nursing zone for Hammerhead sharks (*Sphyrna lewini*). From a socioeconomical perspective, Las Lisas is formed by seven coastal communities (i.e., Las Lisas, El Ahumado, Los Macizos, La Ginebra, Sarampaña, and La Viña del Señor in Chiquimulilla, and El Jiote Pasaco in Pasaco), totalizing around 4332 inhabitants, who develop different economic activities as a source of livelihoods like fishing and providing tourism associated services (PNUD 2017).

2 How "Las Lisas" MPA Proposal Was Designed

Even though there are official guidelines coming from CONAP for designing PAs, these are completely focused on terrestrial areas, so there was a complete lack of technical guidance concerning MPAs design coming from it. Despite these existing guidelines and the known need of consulting and socializing this kind of conservation interventions with the whole array of stakeholders, recently, the design and declaration processes of several PAs part of SIGAP did not take into consideration such fact, situation that has led to conflicts when trying to implement the actions considered as part of the management tools for these areas.

As pointed out by Lundquist and Granek (2005) successful marine conservation is the result of (a) incorporating stakeholders at all phases of the process, (b) count with defined goals and objectives at all stages of the design process, (c) including available science to guide the size and design of MPAs, and (d) guide clear monitoring strategies that assess success at scientific, social, and economic levels. Taking into consideration such factors, the recent problems that the PAs declaration has faced nationally and based on the design team extensive experience in the area, "Las Lisas" MPA proposal was designed following the principles of Marine Spatial Planning (MSP), design process that took place since August 2016 until August 2018.

MSP is a practical approach for creating and establishing a more rational organization of the different uses of the marine spaces and its interactions that seeks to equilibrate the development demand with the urgent need of protecting the marine ecosystems, looking to achieve social and economic objectives in an open and planned way (Ehler and Douvere 2009). According to the authors, MSP is a process that comprehends ten steps. As steps eight (Implementing and enforcing the spatial management plan), nine (Monitoring and evaluating performance), and ten (Adapting the spatial management process) take place once the spatial management plan is approved, only steps one to seven were applied for "Las Lisas" case as follows:

Step 1 *Identifying need and establishing authority.* At the beginning, it was established that an MSP approach was needed as the area is subject and will be subject of incompatible uses that might affect it negatively, e.g. shrimp farms versus mangrove restoration, trawling versus artisanal fishing, coastal development versus turtle's hatching locations, etc. In terms of providing authority for the MSP process, it was established that the current Guatemalan legislation was enough (at that time) to support it, as in the end, the resulting spatial management plan would be a Technical Study and a Management Plan for "Las Lisas" MPA, management tools recognized by the National Law of Protected Areas.

Step 2 *Obtaining financial support.* Financial support for developing the MSP process and to draft the management tools for "Las Lisas" was provided by the UNDP project "Conservation and sustainable use of biodiversity in coastal and marine protected areas (MPAs)." At the end of the process, the Management Plan for "Las Lisas" MPA included all the funding sources and amounts for implementing the management tools for a period of 5 years.

Step 3 *Organizing the process through pre-planning.* Conservation and management goals along with the objectives and expected outcomes of "Las Lisas" were pre-defined by the planning MSP team. Such team was formed by representatives of CONAP, UNDP, Center for Conservation Studies (CECON by its acronym in Spanish) of the San Carlos University of Guatemala (USAC by its acronym in Spanish) and Wildlife Rescue and Conservation Association (ARCAS by its Spanish acronym).

Step 4 *Organizing stakeholder participation.* This was the most important step during the whole process. Historically, lack of stakeholder participation has hindered conservation interventions along the country, i.e. scarce socialization and consultation processes with the whole array of stakeholders has led to top-bottom decisions that ended up in low acceptation and/or rejection of new terrestrial PAs. To avoid such situation, consultation and socialization of the MPA started at the very beginning of the initiative and lasted until its end. This step included numerous informative, consultation and joint work meetings and/or workshops (approximately 30) with the eight Community Development Councils (COCODEs by its Spanish acronym), five fishermen organizations and independent fishermen, three municipalities (Chiquimulilla, Pasaco, and Moyuta), seven governmental organizations (CONAP, MARN, Ministry of Agriculture, Livestock and Food—MAGA by its Spanish acronym—Fisheries and Aquaculture Normativity Direction—DIPESCA by its Spanish acronym—the National Defense Ministry—MINDEF by its Spanish acronym—the National Forestry Institute—INAB by its Spanish acronym—and the Office of the State's Land Reserves—OCRET by its Spanish acronym), non-governmental organizations, more than 20 private owners, academia (USAC, Universidad Rafael Landívar—URL—and Universidad del Valle de Guatemala—UVG) and other relevant stakeholders of the area (with a total participation of approximately 600 persons) to inform about the initiative, to collect inputs, perceptions and/or opinions regarding the coastal marine polygon to be declared as an MPA, and to discuss the guidelines that the management tools of the proposed MPA should follow in order to achieve its conservation and sustainable use objectives. Based on such consultation process, which included an exhaustive socialization effort through local mobile speakers that visited each community, public spaces for doubts solving and joint field visits to the area, seven out of the eight communities to be considered within the proposed MPA expressed their interest in being part of the MPA and their commitment to the joint work to be developed to design the area. The one community that did not agree in being part of the proposed MPA was "La Barrona," community located in the Moyuta municipality, in the Jutiapa department, that provided the second part of the MPA original name ("Las Lisas-La

Barrona) to identify the MPA proposal geographic scope. Several reasons were identified as the cause of "La Barrona" reluctancy to take part of the process and the MPA proposal. The opposition of the Moyuta Municipality Mayor appeared to be the main one, along with the siltation of the Río Paz river mouth, problematic that, according not only to the Moyuta Mayor, needs to be solved first prior declaring the area as an MPA. By the time "La Barrona" finally decided not to be included within the MPA proposal, the biological, oceanographic, and socioeconomic studies (MSP step five), the consultation process and joint work with the other seven communities was 50% completed. Socialization and consultation spaces in the seven communities that agreed on being part of the proposal were facilitated until the end of the initiative.

Step 5 *Defining and analyzing existing conditions.* In the case of "Las Lisas," step five entailed data acquisition (in the field and through literature) and the data clustering identification. Parallel to steps one to four, literature search and an exhaustive fieldwork (especially in the marine part of the area) took place to collect information regarding 43 biological, social, economic, legal, and administrative criteria that were considered as the ones defining the area. Such work included, among others, gathering information on the distribution patterns and abundance of important coastal marine taxa, artisanal fishing landings analyses, periodical analyses of physical-chemical water quality parameters, sediments analysis, tide measurements, the update of the geographic benchmarks used by the Geography National Institute (IGN by its acronym in Spanish) in the area and, with the collaboration of the Marine Affairs General Direction (DIGEMAR by its acronym in Spanish) of MINDEF, the bathymetric study of the Chiquimulilla's Channel portion considered within the boundaries of the proposed MPA and the first four nautical miles at sea included within the polygon as well, with special emphasis in the area identified as a shark nursery by previous studies (Ixquiac et al. 2009). All these biological and oceanographic data, collected over a period of 15 months, were complemented with the development of a socioeconomic study in the seven prioritized communities which was accompanied by an opinion survey regarding the acceptance of the MPA process and the area's future declaration as a protected one and an archeological study of the area since signs of its early human occupation were recorded previously by the Anthropology and History Institute (IDAEH by its acronym in Spanish).

Step 6 *Defining and analyzing future conditions.* In order to obtain a preferred scenario able to provide the basis for identifying and selecting management measures in the spatial management plan (step seven), a pattern identification process was developed. During this step, an overlap of the information layers obtained through step five was done through an integral territorial analysis on a biological, oceanographic, habitat, and socioeconomical level. By using GIS tools and geospatial analyses, based on the identified patterns and the conservation and sustainable use goals for the MPA, the adequate location and extension of the coastal marine polygon was determined.

Step 7 *Preparing and approving the spatial management plan.* To obtain a comprehensive management plan and a zoning plan for “Las Lisas,” the patterns identification result of step six was used for the characterization of the polygon and to provide scientific basis for its internal zoning proposal. The obtained polygon was presented, discussed, and analyzed in the summoned meetings with such objective. When developing meetings with communitarians and fishermen, the coastal marine polygon was printed out in an extended format for them to draw their suggestions and comments to the proposal. Once this round of meetings was concluded, the polygon was modified based on the gathered inputs and recommendations, and then taken to the following round of meetings. All this information was utilized to construct the Technical Study of the Multiple Purpose Use Area “Las Lisas,” management tool that the National Law of Protected Areas in Guatemala requires for analyzing the viability of declaring the zone as a protected one. Once the Technical Study was completed, the planning team led a process for identifying the management decisions of “Las Lisas.” Such process implied the joint and consensual identification of the finalities and permitted and non-permitted uses within the proposed polygon and in each of the zones identified within its boundaries based on the previous step results. This step required after the technical definition of the permitted and non-permitted uses of the area, a new round of consultations with the whole array of stakeholders to jointly identify the conservation elements of “Las Lisas” by using the Conservation Action Planning methodology by Granizo and Granizo (2006) and to review, analyze, and agree on the proposed uses. Once the conservation elements and the permitted and non-permitted uses were agreed upon, conservation strategies were jointly constructed to achieve “Las Lisas” conservation and sustainable use objectives. The gathered information was utilized to construct the Management Plan of the Multiple Purpose Use Area “Las Lisas,” operative tool that the National Law of Protected Areas requires for managing PAs once they are declared. Despite not being declared as a PA by that time, CONAP required to UNDP the construction of such tool. Both tools were complemented with and update of the RAMSAR informative sheet for “El Paraíso-La Barrona” and a project of Law Initiative to declare “Las Lisas” as a PA at a National Congress level.

2.1 Multiple Purpose Use Area “Las Lisas”

The regulative frame of the National Law of Protected Areas, the Governmental Agreement No. 759–90, in its article 8, considers six different categories of PAs, being the category III the selected one for “Las Lisas.” According to its definition, a Multiple Purpose Use Area is an area relatively big that might have suffered anthropogenic alteration, but still preserves a representative portion of the natural landscape. Its conservation might be primarily oriented to support productive activities or conserving the area might be an objective by itself, in any case always providing importance to its social and economic components. Being “Las Lisas” a heavily populated area with diverse anthropogenic interventions (e.g. shrimp farms, salt farms, and basic touristic infrastructure along the coastline), where productive activities like artisanal fishery and tourism take place in the representative ecosystems of the Guatemalan Pacific Coast, such category was considered as the appropriate one.

"Las Lisas" general goal is to conserve its natural capital along with the one of its adjacent zones by maintaining the integrality of the essential ecological processes that guarantee the species viability and the existing biological diversity through the management and sustainable use of its resources for the wellbeing and maintenance of the quality of life of its inhabitants. Specific objectives of the MPA are focused on dynamizing participatory and inclusive processes leading to the creation and/or reinforcement of a coastal marine culture responsible with the environment and to increase the multidisciplinary scientific-technical information of the interaction between the coastal marine ecosystems and the socioeconomic systems to inform management decisions for the area, among others. As a result of the consultation and joint construction process previously described, "Las Lisas" coastal marine polygon has a total extension of 104,002.46 hectares (ha), being 101,790.58 ha of marine nature (96.15% of its total extension) and 2211.88 ha of terrestrial nature (3.85%), which makes "Las Lisas" an eminently MPA. To the east, "Las Lisas" adjoins with the buffer zone of the National Park Hawaii, to the west includes El Jiote Pasaco municipality, and north it reaches until the boundaries of the shrimp farm Mayasal, including the mangrove forest located at its end. Its marine extension comprehends the fishing areas 12, 32, and 52, contiguous to El Salvador border, reaching until the bathymetric line of 200 meters (m) depth, which represents 27 nautical miles (nm) into the Pacific Ocean (PNUD 2017). Its orientation is given by the form of the three mentioned fishing areas, landmarks known, and regularly used by the fishermen to orientate when fishing. "Las Lisas" polygon and its internal zoning is shown in Figs. 3.2 and 3.3.

As seen in the maps, the terrestrial part of "La Barrona" was not included within the polygon given its negative to be included within the MPA proposal. Nevertheless, its marine part was included within the polygon as the Moyuta Municipality only has jurisprudence on "La Barrona" terrestrial territory. Not including "La Barrona" terrestrial part doesn't affect the MPA proposal governance and not including it now doesn't mean that it cannot be included in the future if enabling conditions for it are given.

Based on the previously described MSP steps, the actual and potential uses of the MPA zone and recommendations by its users, "Las Lisas" was internally zoned into ten different categories.

In the marine segment of the polygon, the core of "Las Lisas" design is the *Fishing Recovery Zone (1)*. It is a zone that adjoins to the coastline where artisanal fishery activities take place. Its preservation is recommended since the presence of a nursery site for sharks, especially *S. lewini*, has been reported there. Its objective is to decrease the pressure that the fishing activities possess over threatened marine species, contributing to the optimal functioning of the area as a reproduction site for sharks, what is expected to cause an overflow of prey to the rest of marine zones.

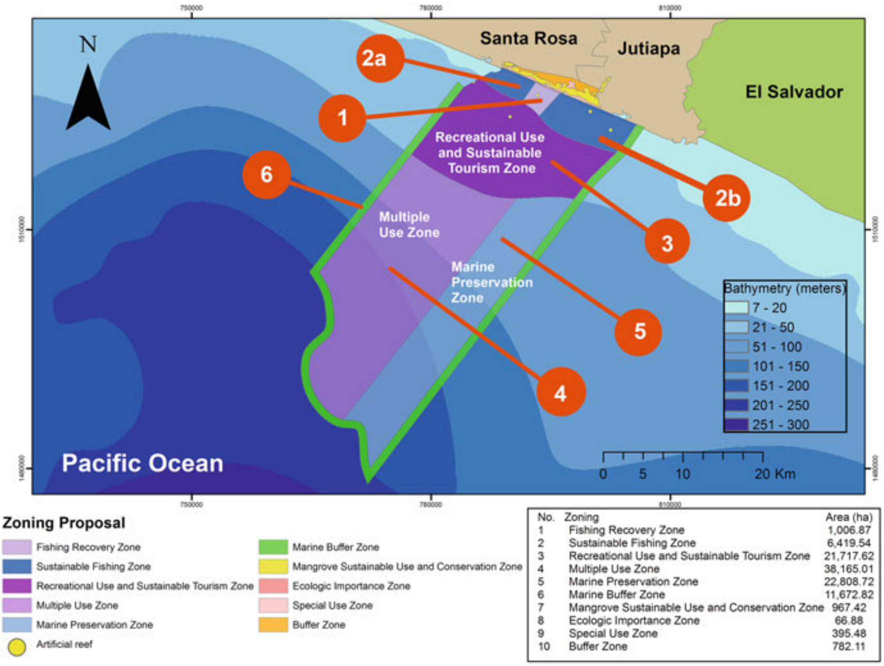


Fig. 3.2 "Las Lisas" MPA proposal

The Fishing Recovery Zone pretends to become a reproductive refuge of species with commercial importance for the artisanal fisherman, like a Core Zone or an Intangible Zone. As fishing will be not allowed during certain seasons in the Fishing Recovery Zone, it will be allowed within the *Sustainable Fishing Zone (2a and 2b)*. It corresponds to the marine zone going from the coastline until the bathymetric line of 20 m depth. For its contiguity to the mangroves, it has high importance in terms of migration of species that require both freshwater and salt water. Its objective is to promote the use of responsible fishing activities. A *Recreational Use and Sustainable Tourism Zone (3)* was identified contiguous to the previously described zones. This zone is characterized by a high primary productivity and presents the highest diversity of marine megafauna reported in "Las Lisas," especially cetaceans, biological characteristic that is currently being used by few tourism services providers in a non-lethal way as a source of livelihood. Moving forward into the ocean, a *Multiple Use Zone (4)* and a *Marine Preservation Zone (5)* were identified. The benthonic zone of the Multiple Use Zone is characterized by a high abundance of pelagic read crab (Galatheidae) and is currently used to develop navigation and fishing activities mainly focused on mahi-mahi and different shark species. While this zone has as a goal the development of ordained and controlled human activities specially when fishing will be limited within the Fishing Recovery Zone and the

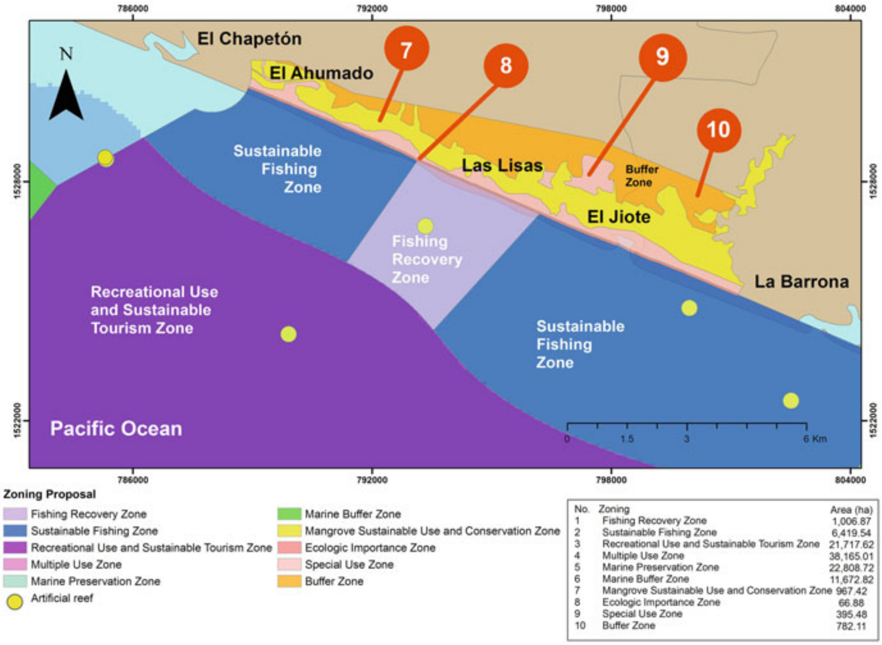


Fig. 3.3 "Las Lisas" MPA proposal in detail

Sustainable Fishing Zone, the Marine Preservation Zone has as a strategic goal to create national sovereignty in the area. One of the main concerns of the local fishermen is the illegal intrusion of fishermen coming from El Salvador, who besides representing a competition to get the fishing resource are posing a threat to "Las Lisas" marine ecosystems and species by using gillnets with very reduced mesh light (2 inches), illegal according to the Guatemalan Fishing and Aquaculture Law (Law Decree 80–2002). By stating such a goal for this zone and pointing out in the management tools for "Las Lisas" that it should be subject of special attention by the naval national authorities is expected to reduce such problematic through constant patrolling and surveillance. Scattered along the marine polygon of "Las Lisas," there are five small areas that correspond to sunk fishing vessels that are functioning as artificial reefs in the zone and/or artificial reefs deployed in the area around 2007 by DIPESCA, which are being used as fishing points by the artisanal fleet and where sizes close to the reproductive sizes of several snapper species have been reported. The use of gillnets and trawling in these areas were identified as a non-permitted activity by most of the consulted stakeholders. These five areas are specifically described within the marine zone they are located in and each of them will require a specific management plan according to DIPESCA's artificial reefs management guidelines released in 2019. A *Marine Buffer Zone (6)* was included within the design to comply with the Protected Areas Law, which requires, in its article 8, the establishment of buffer zones as a protection measure for new PAs to be declared (PNUD 2017).

In its land part, “Las Lisas” was zoned into five categories. The *Mangrove Sustainable Use and Conservation Zone (7)* is a zone of mangroves between 10 and 25 m high and, even though these mangroves are being exploited by the local population, the area still presents an acceptable conservation status. Colonial waterbirds and several Passeriformes use this area as a reproductive and/or foraging zone. Its objective is to protect the mangrove community and native species from the degradation caused by the immoderate mangrove cut down and the solid and liquid waste inadequate disposition. An *Ecologic Importance Zone (8),* comprehending sandy beaches, intertidal beaches, dunes and El Jiote river mouth was delimited. As a zone of high productivity, its objective is to preserve the intrinsic ecological processes that take place in zones under the effects of waves, currents, and wind action along with preserving the larvae and juvenile moving areas of species that require both salty and freshwater in their life cycle, mainly El Jiote river mouth. In this area, it is expected to promote the natural nesting of marine turtles, especially *C. mydas agassizii,* species with the highest nest harvest pressure during egg harvesting season in the Guatemalan Pacific Coast. To address the increase of touristic visitation to “Las Lisas”, a *Special Use Zone (9)* was delimited within the polygon. Its goal is to territorially ordain the possible increase of such services offered by the local communities and to promote/capacitate in sustainable tourism practices. Finally, a *Buffer Zone (10)* was delimitated as well. This zone includes areas heavily affected by forest clearing for cattle ranching, the Mayasal shrimp farm, and salt farms. The intensive use to which this area is subject predisposes it for productive and agricultural uses, so river contamination and watershed modification are happening. Due to such reasons, its main objective is to allow the development of the already established productive activities but limiting the forest loss, the river’s contamination, and most importantly the modification of the riverbeds, along with incentivizing the ecological restauration of the areas where possible and disincentivizing the use of exotic species and the inappropriate use of the river volume (PNUD 2017).

Taking advantage of the momentum, the level of participation during the whole process and the level of acceptance of the global MPA declaration initiative (94% according to the developed socioeconomical study) and considering that the PA’s declaration process might take an extended period of time until its official designation as a protected one at a Congress level, “Las Lisas” fishermen decided to go a step further. Using the scientific evidence and the technical tools developed by the initiative, they decided to submit a solicitude to MAGA to declare the identified Fishing Recovery Zone as a spatial-temporal no-take zone through a MAGA Ministry Agreement according to the Fishing and Aquaculture Law. If accepted, “Las Lisas” Fishing Recovery Zone will become the first no-take zone in the entire Guatemalan Pacific, opening the door for future no-take areas in the area.

3 Where "Las Lisas" Proposal Is Now, Lessons Learned and What Is Left to Be Done

After concluding the described MSP process and completing the management tools, they were submitted to CONAP in August 2018. To date, CONAP is still reviewing the proposal before proceeding at a National Congress level. Not including "La Barrona" (the area of the original proposal that decided not to take part of the initiative), within the final MPA proposal was the main point for CONAP not to fully embrace it, but as pointed out in the several meetings held with them, this is not the contextual/political moment to include it, the rest of "Las Lisas" cannot be put on hold until this moment arrives and not including it now does not mean that it cannot be included in the near future. It is important to notice that this area had been subject of serious mangrove loss due to alleged administrative and territorial discrepancies, as pointed out by national newspapers even in their cover pages (Gonzáles 2019), one of the other probable reasons why they decided to abstain from taking part of the MPA initiative. In August 2021, after a new series of technical discussions, CONAP accepted for "Las Lisas" MPA proposal to move forward with its revision process without including "La Barrona" and including a new community, "El Chapetón." Currently, this community is included within Hawaii's zoning, so such change will be included once "El Chapetón" is excluded officially from it. By 2020, the solicitude to declare the Fishing Recovery Zone as a spatial-temporal no-take zone was still under analysis by MAGA. As this area is subject of trawling by the medium scale fleet to obtain shrimp, MAGA required a consultation process with fishing cooperatives that develop this kind of fishing in the zone, even though they are not physically located within "Las Lisas" polygon. From May 2020 until April 2022, once again with financial support administered by UNDP, but this time through its Small Donations Program (PPD by its Spanish acronym), amidst the COVID-19 pandemic, a small project took place to technically revise, socialize, and discuss with the beneficiaries and the shrimping sector the Fishing Recovering Zone proposed in 2018. As a result of the project, even though lack of acceptance of this increase was shown by one sector by its end, the zone tripled its size and, along with the consulted actors, permitted and non-permitted activities within it were identified and included in a proposed Management Plan. To date, it is expected for MAGA to provide a technical opinion to the new solicitude and to proceed legally, or not, with its designation. If designated officially, the Fishing Recovery Zone will change its extension from 1006.87 ha to 2940 ha, and such change should be considered within CONAP's revision process to the whole MPA proposal, which is still ongoing.

"Las Lisas" design process led to several lessons learned, being the most relevant ones by MSP step:

Step 1 *Identifying need and establishing authority.* By using the MSP approach instead of tools like MARXAN (used for designing the only MPA declared to date—Punta de Manabique) it was intended to avoid some of the pitfalls mentioned by Agardy et al. (2011), when designing MPAs. Such authors mention that integrating

MPA planning in broader MSP and ocean zoning efforts is a way to avoid uncontextualized MPAs. Even though ocean zoning efforts are not taking place in the region, such task should become a mandatory one to be developed by the Guatemalan State if it wants to guarantee the conservation and sustainable use of the strategic marine resources present in the Guatemalan Pacific. As mentioned, to date, national legislation was enough to support the MSP process for designing this MPA but applying MSP on a national scale will require new legislation to support it and to make its results juridically binding.

Step 2 *Obtaining financial support.* In this case, funding was provided by the UNPD project mentioned above. Based on the developed MSP process, an approximation of the estimated cost to undertake an MSP process in Guatemala is available, which can be used to estimate the cost of a national scale one. In case the Guatemalan State decides to develop it, such estimation should be taken to all the sectors, e.g. sport fishing, maritime transportation, and tourism, for them to contribute financially with the process.

Step 3 *Organizing the process through pre-planning.* Lack of clear conservation and management goals, along with the lack of methodological approach coming from CONAP, led to apply five different design approaches for each of the five MPAs to be complemented and/or design with the support of the UNDP project, which resulted in a set of MPAs that might not work as a network. Such alignment should be a mandatory condition when designing a set of PAs or MPAs in the country. Given "Las Lisas" results in terms of design and stakeholder's acceptance, it is recommended for CONAP to update its guidelines for PA and MPA design including the methodological approach used for "Las Lisas."

Step 4 *Organizing stakeholder participation.* "Las Lisas" design process showed that this MPS step is the most important one and must be implemented since its very beginning until its very end. The process showed that betting on bottom-up engagement in order to increase the local stakeholder's identification and responsibility toward conservation measures might be the most appropriate approach when planning this kind of interventions in heavily populated areas as the Guatemalan Pacific Coast. Involving "Las Lisas" social capital in the entire process should increase its future involvement in the control and surveillance of the MPA and contribute to their compliance toward its management rules (Agardy et al. 2011; Bergseth et al. 2015; Campbell et al. 2012; Crawford et al. 2004; Pollnac et al. 2001, 2010). Such involvement should focus special efforts on involving even more the national authorities. To date, institutional follow-up in CONAP and DIPESCA is needed for the proposal to move forward according to the procedures established by law, which could have been avoided if counting with their even more continuous and proactive participation. Government instability during the whole process has been identified as one of the major shortcomings of the initiative and is expected to continue affecting it.

Step 5 *Defining and analyzing existing conditions.* This case has also shown that the design of MPAs in Guatemala should be a collaborative effort of different sectors based on their expertise and legal nature (e.g. DIGEMAR supporting the bathymetric study of the area), which is expected to create institutionality around national efforts, needed to provide follow-up to national interest initiatives once non-governmental funding is due. Also, "Las Lisas" effort showed that not only scientific data is needed to guide the design of PAs in the region and that this information must be shared to inform the local stakeholder's decisions on how to conserve and administer the natural resources they depend on daily for them to participate actively in planning processes.

Step 6 *Defining and analyzing future conditions.* Identifying the preferred scenario for the MPA polygon was based on the different databases and digitalized information about the 43 criteria chosen by the planning team to define the area of interest. Having all these databases organized allowed the planning team to prepare different spatial scenarios. Once they were ready and conceptualized, its viability, especially on a social and an institutional level, was analyzed to present the most viable one to the stakeholders and to refine it jointly with them. "Las Lisas" design process showed the importance of counting with solid databases regarding the criteria chosen to lead the spatial design. Also, showing graphically the overlap of the different criteria prior showing the proposed polygon helped the stakeholders to understand the rationale behind the proposal, which increased its acceptance.

Step 7 *Preparing and approving the spatial management plan.* Permanent and continuous consultation with all the relevant stakeholders and spaces for them to share their ideas and/or approaches to achieve the goals of the MPA showed to be one of the key factors for constructing a spatial management plan with a possible high level of compliance. Even though time consuming, it is necessary to focus on efforts and funding in activities leading to increase the viability of the MPA management tools. Generating a pocket version of "Las Lisas" management tools including the polygon maps and a graphic description of the permitted and non-permitted uses in each of the ten zones showed to be a good practice to increase the socialization of the initiative. As mentioned before, CONAP is still reviewing the proposal for its internal approval before proceeding at a National Congress level to declare "Las Lisas" as an MPA.

In the middle term, it is expected, besides "Las Lisas" being declared as an MPA, for the lessons learned of this MSP process to be used not only to update the CONAP guidelines for PAs design, but also to inform and guide the territorial planning of the Guatemalan Pacific as a whole. To date, the authors continue to seek funding to collect more biological and oceanographic information of "Las Lisas" polygon, to continue socializing the proposal in order to keep it in mind of "Las Lisas" stakeholders, to continue socializing the Fishing Recovery Zone, and to implement productive projects in the communities included within the MPA proposal.

Acknowledgments The authors would like to thank the stakeholders that were consulted and participated in the several discussion spaces and meetings that took place to conceptualize and jointly design "Las Lisas" MPA proposal. Many special thanks to the fishermen, communitarians, and local authorities of Las Lisas, El Ahumado, Los Macizos, La Ginebra, Sarampaña and La Viña del Señor in Chiquimulilla, and El Jiote Pasaco in Pasaco that actively participated in the whole process and keep supporting the MPA proposal to date. Participation and support coming from the authorities of the Chiquimulilla and Pasaco Municipalities, and Edwin Raxón and Hugo Recinos (DIGEMAR-MINDEF) is also thanked. Special recognition to Alva Alvarado, Colum Muccio, Luisa Ortíz, Elizabeth Yanes (ARCAS), Daunno Chew, Dora Cruz and her family and Mercedes Barrios (CECON) for their tenacious work during the process and to Raquel Sigüenza and Frendy Palma (UNDP) for their technical and administrative guidance. All this work couldn't had been possible without the financial support from the GEF project 87534 "Conservation and sustainable use of biodiversity in coastal and marine protected areas (MPAs)," administered by the UNDP. Thank you for trusting in the team to undertake this important and so needed initiative in the Guatemalan Pacific Coast.

References

Agardy T, di Sciara GN, Christie P (2011) Mind the gap addressing the shortcomings of marine protected areas through large scale marine spatial planning. Mar Policy 35(2):226–232. https://doi.org/10.1016/j.marpol.2010.10.006

Bergseth BJ, Russ GR, Cinner JE (2015) Measuring and monitoring compliance in no-take marine reserves. Fish Fish 16(2):240–258. https://doi.org/10.1111/faf.12051

Boix J, Rinze V, García J, Montiel A, Ortíz C (2011) Elementos para contribuir a la gestión integrada de zonas costeras del Pacífico de Guatemala. I. Área de trabajo: Humedal Las Lisas, Chiquimulilla, Departamento de Santa Rosa

Campbell SJ, Hoey AS, Maynard J, Kartawijaya T, Cinner J, Graham NA, Baird AH (2012) Weak compliance undermines the success of no-take zones in a large government-controlled marine protected area. PLoS One 7(11):e50074. https://doi.org/10.1371/journal.pone.0050074

CONAP (2018) Consejo Nacional de Áreas Protegidas Listado Sistema Guatemalteco de Áreas Protegidas (SIGAP) Público octubre. Recuperado mayo 8, 2019, de. http://www.chmguatemala.gob.gt/theme/integracion-y-uso-sostenible/areas-protegidas/208-listado-oficial-de-areas-protegidas-de-guatemala

Crawford BR, Siahainenia A, Rotinsulu C, Sukmara A (2004) Compliance and enforcement of community-based coastal resource management regulations in North Sulawesi Indonesia. Coast Manag 32(1):39–50. https://doi.org/10.1080/08920750490247481

Ehler C, Douvere F (2009) Marine spatial planning: a step-by-step approach toward ecosystem-based management. Intergovernmental oceanographic commission and man and the biosphere programme

Gonzáles A (2019) Manglares bajo amenaza. elPeriódico, pp. 18–19

Granizo T, Granizo T (2006) Manual de Planificación para la Conservación de Áreas PCA

Ixquiac C, Franco I, Tejeda C, Sánchez M, Sikihall J (2009) Áreas de crianza de tiburones en la plataforma continental del Pacífico de Guatemala: herramienta para el manejo y aprovechamiento sostenido del recurso tiburón. Proyecto FODECYT No. 13-2006. Guatemala: Consejo Nacional de Ciencia y Tecnología [CONCYT], Centro de Estudios del Mar y Acuicultura [CEMA]

Lundquist CJ, Granek EF (2005) Strategies for successful marine conservation: integrating socio-economic, political, and scientific factors. Conserv Biol 19(6):1771–1778. https://doi.org/10.1111/j.1523-1739.2005.00279.x

PNUD (2014) Documento de proyecto: "Conservación y uso sostenible de la biodiversidad en áreas protegidas marino costeras" [online]. http://www.gt.undp.org/content/dam/guatemala/docs/prodocs/undp_gt_marino.pdf

PNUD (2017) Estudio Técnico del Área de Uso Múltiple Marino Costera Las Lisas. Proyecto Conservación y Uso Sostenible de la Biodiversidad en Áreas Protegidas Marino Costeras (APMs). Consejo Nacional de Áreas Protegidas [CONAP], Programa de las Naciones Unidas para el Desarrollo [PNUD]. Asociación de Rescate y Conservación de Vida Silvestre [ARCAS], Centro de Estudios Conservacionistas [CECON], Guatemala

Pollnac RB, Crawford BR, Gorospe MLG (2001) Discovering factors that influence the success of community-based marine protected areas in the Visayas Philippines. Ocean Coast Manag 44(11–12):683–710. https://doi.org/10.1016/S0964-5691(01)00075-8

Pollnac R, Christie P, Cinner JE, Dalton T, Daw TM, Forrester GE, Graham NA, McClanahan TR (2010) Marine reserves as linked social-ecological systems. Proc Natl Acad Sci USA 107(43):18262–18265. https://doi.org/10.1073/pnas.0908266107

Chapter 4
Ghana Case Study One

Challenges and Opportunities in Marine Fisheries Governance in Ghana

Seth M. Abobi

Abstract Fishing is carried out along the coastline and major rivers, lakes and reservoirs of Ghana providing a major source of employment, income and food for millions of people in the country. This paper discusses issues central to marine fisheries governance in Ghana, with emphasis on the efforts and challenges towards achieving sustainable fishing practices, and consequently sustainable development. Some factors constrain current strategies for the management of Ghana's marine fisheries resources, which have led to a stagnation in total capture fisheries production in recent times. High fishing pressure leading to overexploitation and high incidences of illegal, unregulated and unreported (IUU) fishing are the key challenges confronting the marine fisheries sub-sector. The paper concludes that effective co-management structures and an increase in multisectoral and inter-ministerial engagements are needed to advance efforts towards the effective governance of marine fisheries in Ghana. The fisheries systems of Ghana are diverse, and the management of some fisheries would require decentralisation. Existing laws and regulations need amendments to achieve adequate implementation for the co-management of Ghana's marine fisheries resources as key pillar of sustainable fisheries management. Efforts of regional bodies and national institutions in enhancing the fisheries legislative framework and removing weaknesses in the monitoring, control and surveillance framework need to be supported to achieve effective marine fisheries governing systems in Ghana.

Keywords Capture fisheries production · Co-management · Ghana · Illegal, Unregulated and Unreported (IUU) · Multisectoral · Sustainable fisheries development

S. M. Abobi (✉)
Department of Fisheries and Aquatic Resources Management, Faculty of Biosciences, University for Development Studies, Tamale, Ghana

Leibniz Centre for Tropical Marine Research, Bremen, Germany
e-mail: mabobi@uds.edu.gh

M. Wolff et al. (eds.), *Challenges in Tropical Coastal Zone Management*,
https://doi.org/10.1007/978-3-031-17879-5_4

1 Introduction

Ghana is located in West Africa, along the Gulf of Guinea. The Ivory Coast borders it in the west, Burkina Faso in the north, Togo in the east, and the Gulf of Guinea and the Atlantic Ocean in the south. It has a total area of 238,535 km^2 (Fig. 4.1) and its current population is 31,072,940 (Ghana Statistical Service 2020).

Ghana's marine fisheries sub-sector is the most critical source of local fish production, delivering more than 80% of the total supply. It is a source of livelihood for over 2.4 million people and contributes significantly to the food and nutritional needs of the people, accounting for 60% of the country's animal protein consumption. It adds 4.5% to the Gross Domestic Product (GDP) and contributes to the alleviation of rural poverty and the foreign exchange of the country (FAO 2004; Sumaila 2019).

Inadequacies in Ghana's fisheries governance and management systems, such as the overlaps in roles and responsibilities of ocean governance institutions, have created conflicts at the national level (Tsamenyi 2013). Conflicts arise when groups or individuals seek the same resource using different methods of harvest or try to utilise the same space for their activities, with either party seeking dominance (Bennett et al. 2001; Charles 1992; FAO 2003). As a result of this, conflicts between

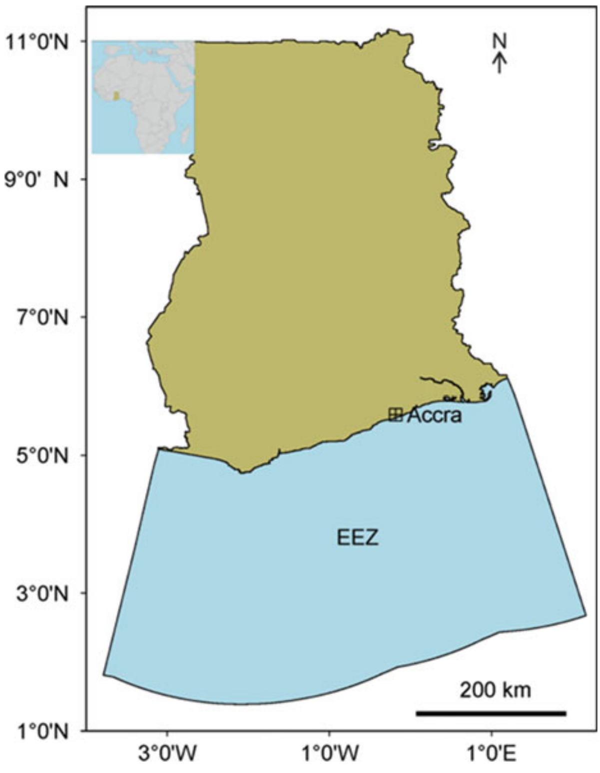


Fig. 4.1 Map of Ghana showing the national capital and the Exclusive Economic Zone (EEZ) claimed by Ghana

local and large-scale fishers, and between legitimate fishers and fishers using illegal gears, are frequent. Often, local fishers are worried about the depletion of fish resources by the large-scale fisheries and about losing their rights to fish in some areas of the sea, which may be declared as protected zones. The fisheries sector thus plays a significant role in the socio-economic development of Ghana, and good governance is imperative to reduce conflicts between resource users and other stakeholders.

Conflicts between groups can emerge due to a variety of reasons. They can arise as a function of social structure and differences in the needs of competing groups (the sociological perspective), as a function of power relations (the political perspective) or as a result of rational decision-making by an individual or group seeking to maximise personal profit from a pool of scarce resources (the economic perspective) (Bennett et al. 2001). Small-scale fishers along the coast of Ghana are impacted by the industrialisation of part of the fishery as well as by the coastal development of a booming tourism industry. As a response, local fishers have sometimes acted to secure their fishing and aquatic rights by organising themselves and implementing community-based actions inspired by sustainability principles for resource management.

The challenges to Ghana's marine fisheries sub-sector are broad and diverse and transcend ecosystemic, social and economic boundaries. The issues discussed here include fisheries resource scarcity, a possible indicator of degradation and destruction of marine ecosystems, and resource use conflicts that often occur between small-scale and industrial fishers in Ghana's Exclusive Economic Zone (EEZ). Fleet overcapacity is another critical challenge addressed, as declining catches since the year 2000 could be attributed to the availability of premix fuels, highly subsidised by the Government of Ghana. These fuels enable lower fishing operation costs, the overcapacity of fishing fleets, and consequently, the overexploitation of Ghana's marine fisheries resources. Here I discuss the state of marine fisheries governance in Ghana, factors that undermine the successful implementation of key management measures in the country's marine fisheries sub-sector, and the opportunities that could help achieve effective governance of the sector. Additionally, the paper elaborates on further suggestions for conflict resolution and sustainable marine fishing.

2 Present Status of Marine Fisheries

Analysis of capture fisheries production data shows a steady increase since the 1970s until the year 2000 (with catches varying between 350,000 and 500,000 tonnes during the period of 1996–2001). After that, catches decreased to 202,000 tons in 2014 and seem to have increased again in recent years (Fig. 4.2).

The challenges of Ghana's fisheries sector are widely known. They comprise overexploitation of fishery resources, high incidence of illegal, unregulated and unreported (IUU) fishing, open access artisanal fisheries, low economic returns,

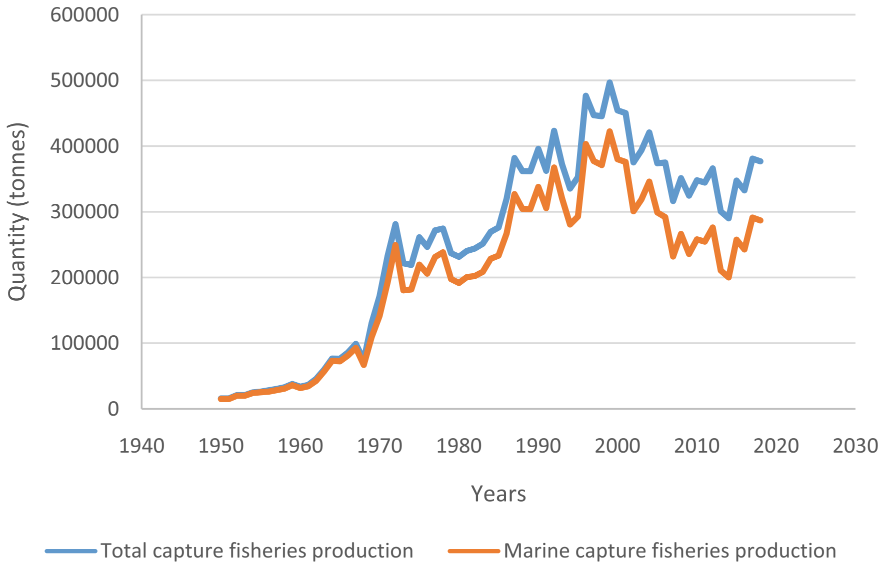


Fig. 4.2 Ghana's capture fisheries production from 1950–2018. Data source: FAO (2020)

little value addition, underdeveloped aquaculture and high demand for fish (Mills et al. 2012). In 2016, FAO (2016) reported further challenges: (1) sizable catches occur only for 3 months (usually July–September) due to seasonal fluctuations in the abundance of small pelagic fish species (especially sardinellas), implying that monthly income from fishing those species can be minimal during the rest of the year, (2) marine stocks are overexploited by the national industrial fleet, (3) poorly constructed landing sites lack infrastructure and refrigeration facilities, leading to large post-harvest losses.

Ghana's coastal fisheries are a common-pool resource (CPRs) and the above-mentioned subsidies make it easier for anyone to fish, leading to an increasing number of fishing boats and the accelerated depletion of the fish stocks (Sumaila 2019).

3 Fisheries Governance Structures and Governing Systems

Several institutions are involved in the fisheries sector of Ghana. These include the Ministry of Fisheries and Aquaculture and Development (MoFAD), the Fisheries Commission, the Parliamentary Select Committee on Food, Agriculture and Cocoa Affairs, civil society organisations (CSOs)—such as the Ghana National Canoe Fishermen Council (GNCFC), an association for small-scale fishers—the Environmental Justice Foundation (EJF), Hen Mpoano, Oxfam, Care International in Ghana and Friends of the Nation.

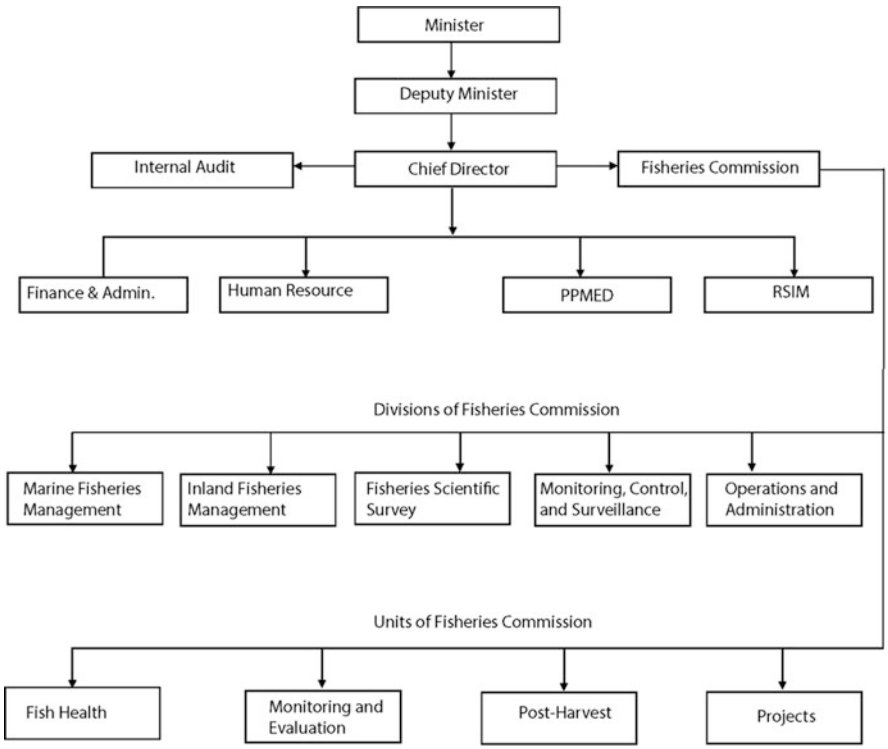


Fig. 4.3 An organisational chart illustrating the departments and agencies of Ghana's Ministry of Fisheries and Aquaculture Development (MoFAD). Developed based on information from the website of MoFAD (2020)

However, the leading regulatory authority of the sector is MoFAD (Fig. 4.3). This figure depicts the organisational structure of the Ministry. The Fisheries Commission is the primary implementing agency of the MoFAD's projects, policies and regulations. The Fisheries Commission has five divisions and four units (Fig. 4.3) to carry out its mandate effectively and efficiently. It is responsible for all monitoring, control, surveillance, evaluation and compliance control in all areas of fisheries development and management in Ghana, including fish health, post-harvest activities, safety and quality assurance.

In addition to these institutions, the Government of Ghana established the National Premix Committee (NPC) in 2009 to oversee the administration and distribution of premix fuel, a heavily subsidised petroleum product for the country's fishing vessels. The National Premix Secretariat (NPS) manages the allocation and distribution of premix fuel. The Tema Oil Refinery (TOR) receives weekly requests for the distribution of premix fuel. TOR blends and loads the product into tankers of the assigned Oil Marketing Companies (OMCs) for distribution to the various Landing Beach Committees (MoFAD 2020).

Landing Beach Committees (LBCs) were formed at the various landing beaches to empower the fishermen to run premix fuel stations at the landing beaches. Each LBC was required to select an Oil Marketing Company to supply them with premix fuel. According to the MoFAD, the proceeds from the sale of premix fuel at the landing beaches are used towards developing the fishing communities (MoFAD 2020).

4 Conflicts in Fisheries Governance

Conflicts in the governance of marine resources of Ghana are driven by (1) sudden changes in policy, (2) presence/absence of co-management organisations at the community level, (3) the state of infrastructure along the coast and (4) coastal tourism. Marine fisheries in Ghana are subject to major challenges and threats, which include resource degradation, conflicts over resources and coastal space, globalisation of markets and climate change, all shaped by the historical, economic and political contexts of the country.

Conflicts between the small-scale artisanal fleets and the inshore and semi-industrial fleets are common in Ghana (e.g. Bennett et al. 2001). There are also reported clashes between fishers of the same gear group (always from the same or neighbouring communities) chasing the same shoal of fish, a true 'struggle for fish at sea'; net entanglements (deliberate or accidental) are an additional aspect of this conflict. Some norms govern behaviour at sea in Ghana, one of which is that the crew that spots a shoal of fish (usually small pelagics) first has the right to attempt to encircle that shoal with their net. However, disagreements over who saw the shoal first are frequent. Net entanglements that result when two canoes attempt to encircle the same shoal are the obvious consequence of this type of encounter. Fishermen have reported that these types of conflicts have been rising in recent years, although there are no data to support this assertion. Lack of trust and willingness to cooperate between fishers and marine resource managers thus often impede fisheries management practices and governance.

Nyarko (2017) reported the lamentations of fishers from the Central Region of Ghana about conflicts at sea. Collisions between canoes and industrial fishing vessels, and the destruction of artisanal fishing gear, in some cases within the zone reserved for small-scale artisanal fishers (Inshore Exclusion Zone or IEZ), were identified as a key threat to these fishers in Ghana. The author indicated that in 2016 alone, the study counted thousands of cases of industrial vessels destroying nets and canoes of artisanal fishers at sea. Nevertheless, only around 5% of these cases were reported to the Fisheries Commission, and even fewer cases (around 1% of the total) resulted in compensation for the losses incurred (Nyarko 2017). Fisheries resource scarcity is another major issue that determines the outcome of fisheries management plans. Its three major drivers are a weak marine resource governance, the critical socio-economic conditions of the fishermen and ecosystem deterioration (Pomeroy et al. 2016). The institutional arrangements for the regulation of Ghana's marine resources are too limited to address the root causes of resource scarcity efficiently. Reducing the level of conflict among fishers requires strong political will and positive changes towards resource availability, competition and sustainability for all parts involved. Recently, potential attacks from pirates in the Gulf of Guinea have become a security threat to fishers and undermine fishing activities in Ghana's marine waters. According to Sow (2018), Ghana was the country with the second highest cases of boarded attacks in the Gulf of Guinea in 2018. In addition, disagreements over the implementation of the closed season for all fleets in Ghana's marine waters by the Ministry of Fisheries and Aquaculture Development are fuelling tensions between large-scale industrial fishing and small-scale artisanal fishers.

Improving relations between small-scale fishers and the Fisheries Commission of Ghana (the management authority) will be needed to reduce conflict between and among the main actors of Ghana's marine fisheries. If fishers trust each other and have good working relationships, knowledge and information about the resource (Pomeroy and Berkes 1997) will be shared, and co-operation between fishers for a well-managed fishery will be enabled (Grafton 2005). Where there is co-operation between fishers, conflict is minimal.

5 Co-Management in Governing Ghana's Marine Fisheries

In the early 1990s, the Government of Ghana identified a co-management regime as one of the pillars for achieving sustainable fisheries management (Mutimukuru-Maravanyika et al. 2013). Subsequently, the concept of Community-Based Fisheries Management Committees (CBFMC) was introduced. This concept aligns with general common-pool resources (CPRs), which, besides fish stocks, include forests, rangeland and water resources. CPRs are important for the well-being of society. These CPR share two characteristics: (1) it is costly to develop institutions to exclude potential beneficiaries from them and (2) the resource units harvested by one individual are not available to others (Ostrom 1994).

In Ghana, fishers and operators in coastal fisheries are controlled by community leaders that traditionally focus on conflict management but have not been able to halt the general degradation of the fishery (Neiland et al. 2005). Policymakers need to understand the traditionally established management rules of fisheries CPR to improve fisheries governance.

While fishing communities are among the target groups for government policy and development interventions with a focus on poverty reduction, there is still a general lack of practical knowledge and understanding of the relationships between people and CPR. This lack of knowledge poses a significant limitation when it comes to designing and implementing appropriate policies for CPR management. Consequently, many people are increasingly vulnerable to poverty associated with CPR overexploitation, degradation and privatisation (Neiland 2005).

Table 4.1 Co-management structure and roles of the different spatial levels (Adapted from Mutimukuru-Maravanyika et al. 2013)

Level	Roles in the co-management process
National	• Ensure that there is uniformity in the fisheries laws formulated and ensure every region abides by them • Formulation of fisheries law • Implementation of fisheries law • Provide input into the laws • Conflict resolution
Regional	• The region serves as a link between the district and the national level • Coordinate district level activities • Although it initially appeared that a regional level was unnecessary, benefits could be seen. Without this level, every district would have direct access to the national level and issues would not be harmonised from districts. Moreover, the regional level serves as a place where all issues coming from the various districts could be looked at and agreed upon and later channelled to the national level for action. This process would greatly facilitate work at the national level.
District	• Finance community co-management activities from the district assembly common fund • Act as a connection between co-management groups at the community level and the central government (via regional level) • Support enforcement of laws • Ensure that support from the central government gets to the community
Community	• Form a task force to enforce fisheries laws at the community level • Address issues of sanitation • Manage fisheries-related conflicts • Perform other roles related to fisheries as decided by the community

The United States Agency for International Development (USAID) through the Ghana Coastal Fisheries Governance Dialogue: Developing Options for a Legal Framework for Fisheries Co-management in Ghana (Mutimukuru-Maravanyika et al. 2013) discussed co-management frameworks for diverse fisheries systems. An effective co-management structure should involve all tiers of administration, from national, regional, district and community levels. Table 4.1 highlights the roles expected at each level of the co-management arrangement. There is a need to ensure that co-management legislations developed at the national level are devoid of politics. Such legislation and arrangements should be effectively disseminated to fishers and operators for their understanding and compliance. Moreover, co-management requires adequate financing to impact positively on fisheries governance.

Co-management requires an integrated multisectoral and ecosystem-based approach. There is a need to involve other sectors, such as water and mining. Further considerations should include fish habitats, subsidies, environmental pollution and climate change that affect the status of the fisheries (Mutimukuru-Maravanyika et al. 2013). Mutimukuru-Maravanyika et al. (2013) highlighted two possible structures for co-management (Table 4.2). The first is where authority for the management of rivers, lagoons and nearshore demersal species is delegated to local leaders. In

Table 4.2 Possible structure for a co-management arrangement in Ghana's fisheries sector (Adapted from Mutimukuru-Maravanyika et al. 2013)

Governance structure	Jurisdiction/ Ecosystem type	Fish stocks	Tools for management
Local management units (e.g. CBM) (with decentralised authorities)	Rivers, lagoons, estuaries, lakes, reservoirs Nearshore bottom-living (demersal) marine species (0–6 NM)	Tilapia, catfish, bivalves, molluscs, crustaceans, demersal marine finfish (e.g. grouper) in local management areas	MPAs, territorial user rights for fisheries (TURFs) gear prohibitions, closed seasons, mesh and species size limits
Representational co-management (with centrally retained authorities)	Pelagic upwelling ecosystems (0–200 NM) Offshore benthic ecosystems (6–200 NM)	Pelagic and offshore demersal marine species managed at the national scale	Closed seasons, gear prohibitions, mesh size limits, limited licensing, output limits

contrast, the second structure concerns the authority preserved at the national level for the management of pelagic species and offshore demersal stocks.

Ghana's fisheries Act and Regulations include the following: (1) Fisheries (Amendment) Regulations, 2015 (L.I. 2217); (2) Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (FAO 2017); (3) Fisheries Management Plan of Ghana 2015–2019 (Ministry of Fisheries and Aquaculture Development, 2015); (4) Fisheries (Amendment) Act, 2014 (Act 880); (5) Ministerial Directive Re-Implementation of Closed Seasons for Industrial Trawlers under the Fisheries Management Plan of Ghana (2015–2019); (6) Minimum Sanitary Requirement—Conditions for Renewal of Fishing Licence (2016); (7) Guidelines for the Registration and Licensing of Fishing Vessels in Ghana (Ministry of Fisheries and Aquaculture Development/Fisheries Commission, 2013); (8) Fisheries Act 2002 (Act 625); and (9) Fisheries Regulations 2010.

Although these laws and regulations are available, co-management has not been sufficiently addressed and implemented. Reviews of these legislations should thus include adequate provisions on co-management.

6 Pathways Towards Improved Marine Fisheries Governance

Achieving effective marine fisheries governance in Ghana requires broad consultations with both national and international bodies. PESCAO (Improve Fisheries Governance in West Africa) is a project funded and supported by the EU, aiming to contribute to sustainable fisheries resources development, food security and poverty alleviation in West Africa, and Ghana is one of the beneficiaries of this project. On 6 December 2018 in Accra, the Government of Ghana, the EU and its Member States met for the 2018 edition of the political dialogue. Such forums are essential in building consensus and drawing actions towards effective marine fisheries governance systems and sustainable development in Ghana's fisheries sector. During the discussion, an agreement was reached on some measures to enhance Ghana's fisheries legislative framework, combat IUU fishing and remove weaknesses in the monitoring, control and surveillance framework, among others. These actions are crucial to maintain sustainable fishing regimes in the marine sector and contribute to efforts in achieving effective fisheries governance.

The following measures should be implemented to enhance sustainable fisheries management in Ghana: closed seasons, vigorous enforcement of the rules for the large-scale industrial fishery (including no access to nearshore fisheries), prohibition of certain gears, improvement of port and landing infrastructure and market value chain, enhancement of inland fisheries production through better lake and reservoir management and investment in pond cultures to reduce marine fishing pressure. An inter-ministerial committee including the MoFAD, Ministry of Food and Agriculture, Ministry of Defence, Ministry of Interior, Ministry of Foreign Affairs and the Ministry of Employment and Labour Relations is needed to achieve the above measures. Moreover, the committee can discuss and implement measures for effective governance, and sustainable fishing regimes in the country's marine fisheries sector by (1) regularly assessing and strengthening efforts towards combating IUU fishing and (2) drawing actions towards mitigating high fishing pressure. The committee's work can be facilitated through collaboration with regional fisheries management, monitoring, control and surveillance organisations such as the Fisheries Committee for the West Central Gulf of Guinea (FCWC) and PESCAO.

Further improvements in national fisheries management strategies are needed. A recent call by Sumaila (2019) for the government to scrap fisheries subsidies is a laudable proposal. Although removing subsidies on fuels for fishing operations will reduce fisheries exploitation, in the absence of strong fisheries governing structures and legal frameworks, the abolishment of the fisheries subsidies alone will be inadequate to sustain the fisheries. Adequate governing structures are needed to combat IUU fishing and support co-management schemes. Moreover, investment in blue economy areas such as aquaculture and other alternative livelihood ventures would be more beneficial for the fishing communities and help sustain the marine fisheries sub-sector.

7 Conclusions

Ghana's marine fisheries sector provides livelihoods for about 2 million people. Effective governance, cooperative co-management and sustainable fisheries development will protect the livelihoods of vulnerable fishing communities. The key factors impeding productive fisheries include overexploitation and high fishing pressure on marine resources, and high incidences of illegal, unregulated and unreported (IUU) fishing. These challenges could be resolved by (1) engaging national experts to draw and implement measures for effective and efficient conflict management, improving compliance of regulations, and effective communication among the various stakeholders of the marine fisheries sector, (2) empowering and adequately resourcing the CBFMCs and (3) taking advantage of the existence of the MoFAD, MoFA, Ministry of Defence, Ministry of Interior, Ministry of Foreign Affairs, and the Ministry of Employment and Labour Relations, for multisectoral engagement towards improved marine fisheries governance in Ghana. Stringent enforcement of Ghana's fisheries laws is important in regulating fishing operations, especially in the nearshore waters of the country, ensuring compliance to measures that combat IUU fishing. A joint task force comprising members of the Navy Ghana Armed Forces and Marine Police Unit of Ghana Police Service will be beneficial to policing the country's waters and handling offences contained in Ghana's Fisheries Act and regulations. Support of coastal fishing communities through fisheries co-management schemes will facilitate the work of the task force. The government should take a bold decision to stop fisheries subsidies and invest the financial resources in developing aquaculture and inland fisheries production. Special courts and tribunals should be established in the coastal regions to expedite process cases involving contravention of Ghana's fisheries laws and regulations.

References

Bennett E, Neiland A, Anang E, Bannerman P, Rahman AA, Huq S, Bhuiya S, Day M, Fulford-Gardiner M, Clerveaux W (2001) Towards a better understanding of conflict management in tropical fisheries: evidence from Ghana, Bangladesh and the Caribbean. Mar Policy 25(5): 365–376

Charles AT (1992) Fishery conflicts: a unified framework. Mar Policy 16(5):379–393

FAO (2003) The ecosystem approach to fisheries FAO technical guidelines for responsible fisheries. 4(Suppl. 2):112

FAO (2004) Fishery and aquaculture country profiles, The Republic of Ghana. http://www.fao.org/fi/oldsite/FCP/en/GHA/profile.htm

FAO (2016) Fishery and aquaculture country profiles, The Republic of Ghana. http://www.fao.org/fishery/facp/GHA/en

FAO (2017) Agreement on port state measures to prevent, deter and eliminate illegal, unreported and unregulated fishing. https://www.wto.org/english/tratop_e/rulesneg_e/fish_e/2009_psma.pdf

FAO (2020) FAO. Fisheries and aquaculture software. FishStatJ–software for fishery statistical time series

Fisheries (Amendment) Act (2014) (Act 880) Republic of Ghana. https://mofad.gov.gh/wpcontent/uploads/2016/07/FISHERIES-AMENDMENTACT2014.pdf

Fisheries (Amendment) Regulations (2015) Republic of Ghana. Fisheries (Amendment) regulations (L.I. 2217). http://rhody.crc.uri.edu/gfa/wp-content/uploads/sites/10/2018/04/Ghana-Fisheries-Amendment-Regulations-2015-L.I.-2217.pdf

Fisheries Act (2002) Act 625. Accra, Ghana: Government Printer, Assembly Press. https://www.mofad.gov.gh/wpcontent/uploads/2016/05/Fisheries-Act-2002-Act-625.pdf

Fisheries Regulations (2010) Republic of Ghana, Fisheries Regulations, Government of Ghana. GPCL, Assembly Press, Accra. https://www.mofad.gov.gh/wp-content/uploads/2016/05/Fisheries-Regulations-2010.pdf

Ghana Statistical Service (2020) 2020 population projection by sex, 2010–2020. Archived from the original on 24 April 2018. Retrieved 2 May 2018. https://statsghana.gov.gh/nationalaccount_macros.php?Stats=MTA1NTY1NjgxLjUwNg==/webstats/s679n2sn87

Grafton RQ (2005) Social capital and fisheries governance. Ocean Coast Manag 48(9–10):753–766

Mills DJ, Mutimukuru-Maravanyika T, Ameyaw G, Asare C (2012) Ghana coastal fisheries governance dialogue: presentations, discussions and outcomes from a stakeholder forum on issues for reforming governance of Ghana's coastal fisheries. WorldFish Center, USAID Hɛn Mpoano Initiative, Ghana, p 57

Minimum Sanitary Requirement – Conditions for Renewal of Fishing License (2016) https://www.mofad.gov.gh/wpcontent/uploads/2016/06/Ministerial-Directive-on-Minimum-Sanitary-For-Vessels-31-5-2016.pdf

Ministerial Directive Re: -Implementation of Closed Seasons for Industrial Trawlers under the Fisheries Management Plan of Ghana (2015–2019) http://extwprlegs1.fao.org/docs/pdf/gha168932.pdf

Ministry of Fisheries and Aquaculture Development (2015) Republic of Ghana, fisheries management plan of Ghana. A national policy for the management of the marine fisheries sector 2015–2019. http://rhody.crc.uri.edu/gfa/wp-content/uploads/sites/10/2018/04/Fisheries-Management-Plan-of-Ghana-Marine-Sector-2015-2019.pdf

Ministry of Fisheries and Aquaculture Development/Fisheries Commission (2013) Guidelines for the registration and licensing of fishing vessels in Ghana. https://www.mofad.gov.gh/wp-content/uploads/2016/05/Final-Guidelines-for-Acquiring-Fishing-Licence.pdf

MoFAD (2020) Ministry of fisheries and aquaculture development. Republic of Ghana. https://www.mofad.gov.gh/

Mutimukuru-Maravanyika T, Asare C, Ameyaw G, Mills D, Agbogah K (2013) Ghana coastal fisheries governance dialogue: developing options for a legal framework for fisheries co-management in Ghana. USAID, Coastal Resources Center of University of Rhode Island and WorldFish Center, Ghana, p 59

Neiland AE (2005) Common pool resources and fisheries management (1). Key sheet no. 1. https://assets.publishing.service.gov.uk/media/57a08c8340f0b6497400127a/R8467_Ann3-1.pdf

Neiland AE, Lewins R, Bennett E (2005) Incorporating common pool resource (CPR) issues into fisheries management in developing countries: key lessons and best practice. Report. DFID/MRAG FMSP project no. R8467. www.fmsp.org.uk; www.onefish.org/id/281385

Nyarko RK (2017) Fishermen from the central region lament conflicts at sea. JoyNews. https://fcwc-fish.org/other-news/ghana-fishermen-from-the-central-region-lament-conflicts-at-sea

Ostrom E (1994) Institutional analysis, design principles and threats to sustainable community governance and management of commons. ICLARM Conf Proc 45:34–50

Pomeroy RS, Berkes F (1997) Two to tango: the role of government in fisheries co-management. Mar Policy 21(5):465–480

Pomeroy R, Parks J, Mrakovcich KL, LaMonica C (2016) Drivers and impacts of fisheries scarcity, competition, and conflict on maritime security. Mar Policy 67:94–104

Sow M (2018) Figures of the week: piracy increasing in the Gulf of Guinea. https://www.brookings.edu/blog/africa-in-focus/2018/08/02/figures-of-the-week-piracy-increasing-in-the-gulf-of-guinea/

Sumaila UR (2019) Global trends in fisheries in the context of the blue economy; implications for Ghana. In Donkor (2019): Govt urged to scrap fuel, subsidies to fisher folks. http://www.ghanaiantimes.com.gh/%EF%BB%BFgovt-urged-to-scrap-fuel-subsidies-to-fisher-folks/

Tsamenyi M (2013) Analysis of the adequacy of legislative framework in Ghana to support fisheries co-management and suggestions for a way forward. Coastal resources center, University of Rhode Island. USAID integrated coastal and fisheries governance program for the western region of Ghana. 29pp

Chapter 5
Pacific Island Case Study

Impact of Tourism on Small Island Marine Ecosystems: Insights from Two Pacific Archipelagos

Natalie Prinz and Jonas Letschert

Abstract Many Pacific Island Countries and Territories (PICTs) are characterised by unique marine ecosystems which attract millions of international visitors every year, creating a profitable business for tourist operators. On the downside, the rising tourist numbers are associated with changes in these ecosystems. We performed a literature search and reviewed 43 studies with a geographic scope covering the central Pacific, of which 16 focused on direct impacts of tourism on the marine environment. All but one study found negative or neutral effects of tourism on the marine environment. Only five studies present results from 2014 until present, which is insufficient, given the rapid increase in tourism numbers. Moreover, the majority of the studies focused on popular tourism destinations, indicating a spatial bias of the current knowledge about tourism impacts in the Pacific. In addition to the review, we highlight direct and indirect effects of tourism on marine ecosystems in the area by discussing two case studies. One case study relates to the feeding of reef fish in the Cook Islands by tourists, and the other to the introduction of invasive species in Galapagos. In both cases, species compositions at tourist sites differed from non-visited sites. Based on our review and discussion, we conclude that tourism can be responsible, and tourists may be willing to engage in conservation. We formulate four recommendations that suggest increased: (1) monitoring of the marine environment, (2) citizen science projects to include stakeholder observations for monitoring environmental change, (3) reciprocal knowledge exchanges among tourists, scientists and residents and (4) spatially balanced research on the effect of tourism on marine ecosystems with methods applicable to many PICTs.

N. Prinz (✉)
Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany

School of Science, University of Waikato, Tauranga, New Zealand
e-mail: nprinz@waikato.ac.nz

J. Letschert
Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany

Thünen-Institute of Sea Fisheries, Bremerhaven, Germany

M. Wolff et al. (eds.), *Challenges in Tropical Coastal Zone Management*,
https://doi.org/10.1007/978-3-031-17879-5_5

Keywords Island states · Ocean environment · Invasive species · Fish feeding · Disturbance · Stakeholder knowledge exchange

1 Introduction

The Pacific Ocean contains vast and complex marine ecosystems, including the world's most extensive coral reefs (Morrison 2012). Coral reefs and other pristine ecosystems in the Pacific are of high economic value, with over 500 million residents of the Pacific rim countries depending on them (Wilkinson and Souter 2008). Inhabitants of Pacific islands have always used their coasts as a source of nutrition and have applied locally managed harvesting and conservation schemes (Connor et al. 1996; Johannes 2002). These islands have few resources due to their colonial history, small size and distance from major markets (Berno 1999). In many of these small island developing states, which often self-identify as large ocean island states, people are dependent upon marine areas and resources for food security (Gillett 2009). In the course of the twentieth and twenty-first century, tourism has developed as a new source of income, complementing the ongoing fishing activity (Higham and Luck 2007; Lachs and Onate-Casado 2020). All island states of Oceania (including Australia and New Zealand) experienced a 15% increase of tourists since 2015 (UNWTO 2019). Tourism represents a crucial part of the Oceania economy stating 12% of the GDP and 13% of the employment (WTTC 2017).

The pristine marine environment of many Pacific Island Countries and Territories (PICTs) is a major attraction for tourism (Asch et al. 2018) and access to remote places linked to aquatic environments is increasingly provided (Nicoll et al. 2016). The exceptional growth of the global marine tourism industry (Asch et al. 2018; Orams 2002) is reflected in steadily increasing tourism numbers in some PICTs, and very rapidly in other PICTs, over the last two decades (Fig. 5.1). In line with those numbers, the type of dependence on marine areas, like reefs, is shifting from fishing to tourism in some countries and more specifically on some islands of these countries (Diedrich 2007; Hunter et al. 2018). Globally, nearly half of the net benefits of coral reefs were derived from tourism and recreation already in 2003 (Cesar et al. 2003), whilst in 2017 coral reefs were estimated to generate 2.2% of all global ecosystem service values for tourism (Spalding et al. 2017). In particular, marine wildlife tourism generates substantial income for reef-rich country economies and local tour operators (Higham and Luck 2007) consisting of a diverse range of businesses, from one person to large, multinational companies (Orams 2002). Popular activities are animal catching, viewing, feeding and interacting with fish, turtles, sharks, rays and marine mammals (Newsome et al. 2005).

Alongside other anthropogenic activities impacting tropical marine environments (Earp et al. 2018), tourism activities can have various effects on the marine environment, most of these considered negative impacts, such as a loss of biodiversity (Morrison 2012). The mechanisms of impact can be categorised as direct, i.e. physical damage by boats' anchors, divers, trampling and harvesting of resources or indirect, i.e. sedimentation, pollution, behavioural change of species and

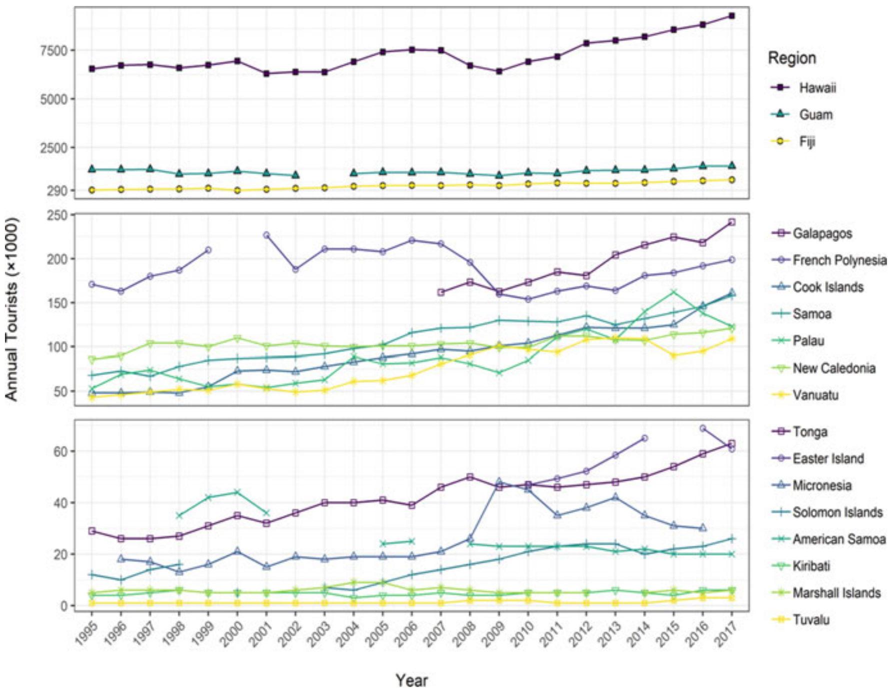


Fig. 5.1 Annual tourism numbers for Pacific Islands from 1995 to 2017. Numbers were derived from the World Tourism Organization (UNWTO 2019) as well as online resources for Galapagos (de Galápagos 2019), Hawaii (State of Hawaii DBEDT 2019) and Easter Island (www.subturismo.gob.cl/)

introduction of non-indigenous species (NIS) (Table 5.1). In a review, Morrison (2012) identified habitat destruction, marine site overcrowding, disruption of nesting or breeding and increased coastal erosion due to tourism development as the main dangers to threatened marine species in the Pacific. Based on IUCN (2010) data, tourism had a negative impact on 15% of all species listed as endangered in the Pacific region of which the majority were corals (83%). There is no correlation between the number of tourists and the number of endangered species, however there is a correlation when the permanent population is added to the number of tourists (Hall 2010). Even the least intrusive efforts for the establishment of small-scale ecotourism can have substantial alterations of the environment (De Haas 2002). Overall, number of tourists, intensity of boat traffic and management of activities on the PICTs are the factors that influence the magnitude and extent of alterations to the ecosystems. These alterations may cause the ecological integrity of coral reefs to be compromised, affecting their ecological functioning (Phillips 2015). For this study we focused on the impacts of marine tourism on marine ecosystems in PICTs. Tourism activities refer to all smaller-scale activities which are provided to tourists coming to the islands via larger vessels or airplanes. This study does not include the impacts on cultural or social-ecological systems.

Table 5.1 Studies investigating the direct impact of tourism on the marine ecosystem and factors analysed in this literature review

Country/ region	Tourism types	Impact types	Method	Study period	Reference
French Polynesia	Shark feeding	Higher number of parasites in 1 out 6 fish species around shark-feeding sites	Fish sampling	2010	Vignon et al. (2010)
French Polynesia	Shark feeding	Change in behaviour of sharks	Monitoring	2010	Clua et al. (2010)
French Polynesia	Not stated	Water pollution; littering	Literature review	1969–1994[a]	Hutchings et al. (1994)
Fiji	Shark feeding	More individuals; less species richness	Monitoring	2003–2012	Brunnschweiler et al. (2014)
Fiji	Shark feeding	Increased long-term abundance over feeding years	Monitoring	2011	Brunnschweiler and Baensch (2011)
Palau	Snorkelling	Negative effects of snorkelling for corals (rubble, coral fragments)	Monitoring	2015	Otto et al. (2015)
Easter Island	Not stated	Littering (although most is affiliated to fisheries)	Monitoring, interviews, literature review	2012–2016	Kiessling et al. (2017)
Easter Island	Not stated	Boat collision with turtles; illegal turtle meat consumption	Interviews; monitoring	2011	Álvarez-Varas et al. (2015)
Hawaii	Whale watching	Whales avoid boat traffic	Monitoring	2008–2010	Cartwright et al. (2012)
Hawaii	Consumption	Increasing pressure on reef fish	Investigating restaurant menus	1928–1974	Van Houtan et al. (2013)
Cocos	Not stated	Littering	Monitoring	2006–2015	Naranjo-Elizondo and Cortes (2018)
New Caledonia	Not stated	Corals; tourism as a potential threat for reefs	Literature review	1946–2006[a]	Wantiez (2008)
Galapagos	Not stated	Corals; tourism as a potential threat for reefs	Monitoring, coral cores, literature review	1965–2011[b]	Glynn et al. (2018)
Galapagos	Marine traffic	Increasing rates of NIS	Monitoring; literature review	1902–2015[a]	Keith et al. (2016)
Galapagos	Diving	Contact with corals	Monitoring	2012–2019	Moity et al. (2018)
Guam	Diving	Contact with corals		2004–2007	Burdick et al. (2008)

(continued)

Table 5.1 (continued)

Country/ region	Tourism types	Impact types	Method	Study period	Reference
			Monitoring; literature review		

[a]The study period was set starting from the first mentioned article
[b]The study period was set to the range of the oceanographic data

Despite the burgeoning literature concerning the impact of tourism on marine ecosystems, knowledge on most of the PICTs (excluding Australia, New Zealand and Papua New Guinea in this review) is still incipient. In this chapter, we discuss the influence of tourism on marine ecosystems in PICTs based on a literature review and two case studies[1]: (a) snorkelling tours and feeding of fish communities in the Cook Islands and (b) marine tourism influencing non-indigenous species (NIS) dispersal in the Galapagos archipelago. The aim of this review is to provide an understanding of the current impacts of marine tourism activities on coastal marine environments of Pacific islands. Lastly, we discuss efforts to tackle these effects with a focus on regulated ecotourism approaches and stakeholder engagement.

2 Methods

First, we performed a search in *web of knowledge* with the following set of keywords: (Touris*) AND (Pacific) AND (island OR archipelago OR isla OR île) AND (marine OR "salt water" OR aquatic) AND (ecosystem OR environment OR system OR "food chain" OR biodiversity OR species OR organism OR biota). The search resulted in 43 studies published up until 2019, which we screened for their relevance. We selected studies that match our study area, the Pacific Ocean (Fig. 5.2), and investigated the impact of tourism on marine ecosystems. During this step we also considered relevant references within these studies if available. Secondly, literature collected for the two case studies were revised and added to our pool of literature items. We extracted numbers for annual tourists from the database of the World Tourism Organization (UNWTO 2019), as well as from reports and online resources for Galapagos (de Galápagos 2019), Hawaii (State of Hawaii DBEDT 2019) and Easter Island (Fig. 5.1). The UNWTO (2019) summarises all incoming tourism numbers, including arrivals via air and sea per country.

[1]ISATEC Master theses case studies by J. Letschert 2017, as well as N. Prinz (published in Prinz et al. 2020)

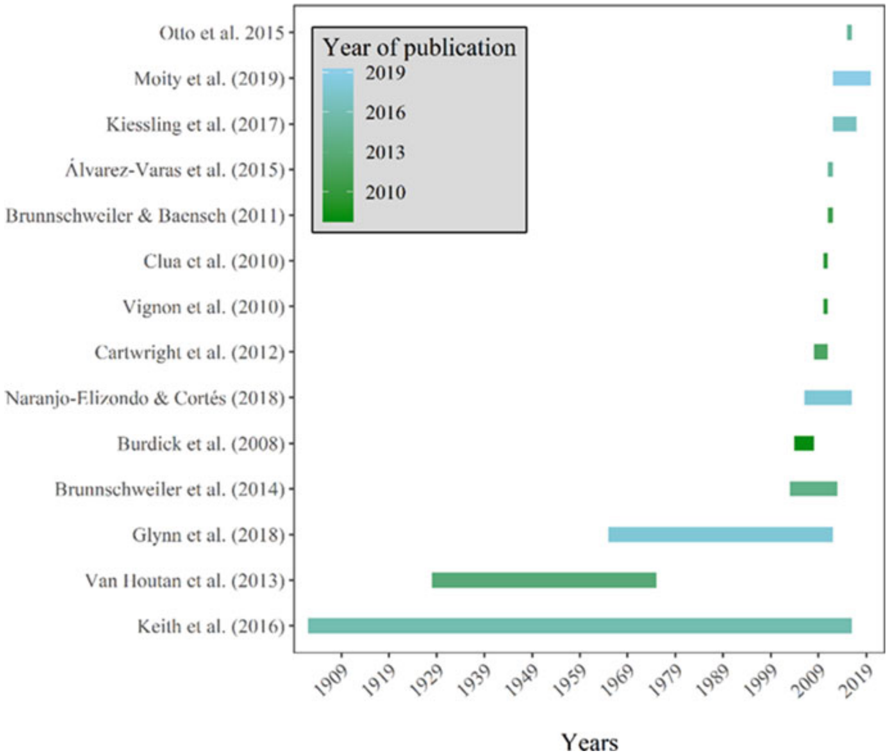


Fig. 5.2 Range of the study period for each reviewed literature item. Each bar is colour-coded to reflect the publication date of the study

3 Results

The pooled literature search yielded 16 articles that investigated the direct effects of tourism on marine ecosystems of islands and archipelagos in the Pacific Ocean (Table 5.1). The focus of the selected studies are the effects of tourism on corals (Burdick et al. 2008; Glynn et al. 2018; Moity et al. 2018; Otto et al. 2015; Wantiez 2008), sharks (Brunnschweiler et al. 2014; Brunnschweiler and Baensch 2011; Clua et al. 2010; Vignon et al. 2010), other fish (Vignon et al. 2010), fish consumption (Van Houtan et al. 2013), sea turtles (Álvarez-Varas et al. 2015), whales (Cartwright et al. 2012), introduced species (Keith et al. 2016), litter (Hutchings et al. 1994; Kiessling et al. 2017; Naranjo-Elizondo and Cortes 2018) and water pollution (Hutchings et al. 1994).

Only one study was published in 1994 (Hutchings et al. 1994) and all others between 2008 and 2019. The study period of the reviewed literature varies between 1 year and more than a 100 years, although most studies focus on time ranges within the last decade (Fig. 5.2). The majority of PICTs with high numbers of visitors in

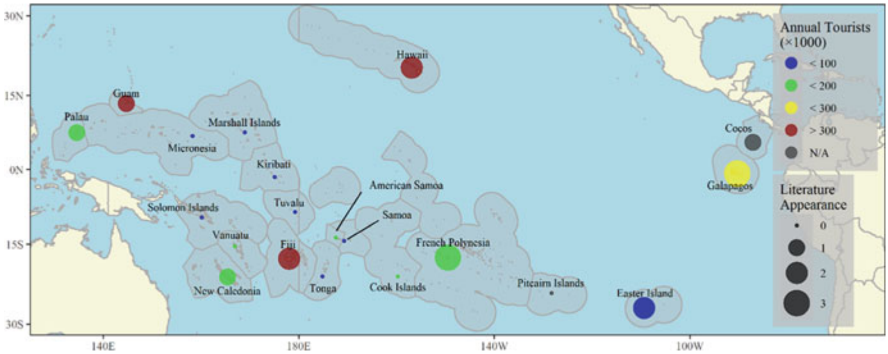


Fig. 5.3 Study area with all small island states, territories and regions included in this review. Colour and size of the points indicate the number of tourists in 2017 and the number of appearances in our literature selection

2017 show more publications in our review when compared to PICTs with fewer tourists (Fig. 5.3).

The majority of studies conducted in-water monitoring (8), followed by literature reviews (4), interviews (2), fish sampling (1) and unconventional methods (1), i.e. investigating restaurant menus. Naranjo-Elizondo and Cortes (2018) pose a tourist-including method, as they did not analyse the effect of tourism directly, but used an opportunistic sampling design, searching seabeds for litter during recreational, touristic trips with a submersible. A second example for a citizen science approach are recreational divers encouraged to report observed megafauna, which so far resulted in 7000 sightings of 15 different species (Moity et al. 2019).

Almost all studies mentioned or detected negative effects of tourism on marine ecosystems. The effects range from an individual scale, e.g. higher amount of parasites on fish (Vignon et al. 2010), boat collisions with turtles (Álvarez-Varas et al. 2015) and changed behaviour of sharks (Brunnschweiler and Baensch 2011; Clua et al. 2010) and whales (Cartwright et al. 2012), over broader effects, e.g. the physical contact of divers and snorkelers with corals (Moity et al. 2018; Otto et al. 2015), and depleting of reef fish populations through higher demand of tourists (Van Houtan et al. 2013), to an ecosystem-wide scale, e.g. littering of beaches (Hutchings et al. 1994; Kiessling et al. 2017) and deep sea areas (Naranjo-Elizondo and Cortes 2018), increased rates of introduced species (Keith et al. 2016) and water pollution (Hutchings et al. 1994).

Only one study by Kiessling et al. (2017) mentions a positive influence of marine tourism, as tourism on Easter Island leads to an increased demand of souvenirs without plastic bags, which represents an incentive for local tourist operators to practice their businesses in a more sustainable fashion. In fact, the results of Kiessling et al. (2017) show that local engagement to clean beaches is higher, and litter pollution lower on Easter Island than on the mainland of Chile.

Not all studies identified tourism as the main threat for marine ecosystems. In particular, literature focussing on beached or dumped litter describes how a large portion of marine debris is associated with fisheries (Kiessling et al. 2017; Naranjo-Elizondo and Cortes 2018). In the case of Kiessling et al. (2017), this makes up 64% of collected debris. Furthermore, it was mentioned that the remaining debris is unlikely to have originated only from tourism. In the case of Naranjo-Elizondo and Cortes (2018) on the Cocos Islands, almost all plastic debris could be associated with fisheries. However, other debris, such as cans and fabrics, were found in relatively good state, indicating that it has near-coastal origins. Given the fact that there are no permanent inhabitants on Cocos, it is likely that this debris originates from tourists.

3.1 Cook Islands Case Study

In the Cook Islands, tourism has become the dominant sector of the economy and is largely supported through activities on reefs (Mellor 2003). The total number of tourists to the Cook Islands has increased steadily over the last half of the century, from less than 10,000 in 1976 to about 168,700 visitors in 2018 (Cook Island Tourism 2019; Mellor 2003; UNWTO 2019). Reef tourism is dominated by boating, snorkelling and diving activities (Prinz et al. 2020), but also increases the sales of marine resource products such as high-value food fish and farmed pearls (Mellor 2003). In part to maintain the value for the tourism sector, Island Councils undertake efforts such as the creation of protected areas (ra'ui), bans, restrictions on destructive fishing techniques and harvesting control of shellfish and marine mammals (Pinca et al. 2009). Yet, tourism may still increase stress on the lagoon and reef resources. Tourists are supplied with pelagic fish in order to spread the revenue from tourism among fishermen and lessen the fishing pressure on lagoonal reef resources ((Pinca et al. 2009); N. Prinz pers. observation). As an example, the sustainable management of the touristic flagship lagoon Aitutaki is an objective shared by the entire community due to its increasing dependency on tourism that is based on the lagoon's attractions (SCUBA, snorkelling, excursions to motu, fishing, etc.) (Pinca et al. 2009).

To quantify tourism impact on lagoonal reef fish, Prinz et al. (2020) conducted research on the island of Aitutaki, which is inhabited by about 2000 people (Hoffmann 2002). In 2015, it was estimated that 29,261 tourists visited Aitutaki (Cook Island Tourism 2019). Feeding fish with bread, among other foods, to attract them for tourists has been a common practice for over 15 years during daily snorkelling tours. Two sites within the lagoon were chosen where fish feeding for and by tourists occured on a daily basis near an anchor buoy, and compared to two adjacent sites, with similar substrate composition where feeding does not normally occur, but experimental fish feeding was carried out for this study. To quantify the fish density and taxonomic richness at bread feeding events, stationary visual censuses (Bohnsack and Bannerot 1986) were conducted within a 3 m radius for 15 min while counting all non-cryptic fish. Censuses were done 1 h before bread feeding, during feeding and 1 h after feeding at all sites over 5 days. To estimate the effect of bread in the water on the feeding behaviour of two model species, 5 min focal follows were conducted on five individuals per species, also before, during and after feeding events.

Direct and indirect effects of bread supply on fish community composition and behaviour were observed. Mean fish abundance and diversity were higher at sites where fish were regularly fed artificially, compared to sites where fish were not fed before. This is likely due to the habituation of bread-liking species to human food. Overall, 25% of the 71 fish species found were attracted to bread and fed on it. Main feeding groups were omnivores and piscivore-invertivores. During feeding events, taxonomic richness decreased at all sites, as compared to 1 h before and after feeding. This could be explained by the fact that only certain fish species are attracted to the bread.

The first model species *Chaetodon auriga* fed readily on bread at the tourism sites. Whilst bread was supplied, *C. auriga* was observed to cease feeding on natural substrate and instead fed on bread. At the comparative sites however, no individual of this species was observed to feed on bread. The second model species *Ctenochaetus striatus*, a detritivore, was observed to test the bread but not feed on it. Instead, their feeding rates on natural substrate decreased while bread was supplied, compared to an hour before or after bread supply. This led to the assumption that bread feeding may indirectly affect the natural foraging behaviour of certain fish species, as vigilance increases due to the accumulation of fish in the water column, during artificial feeding (Milazzo 2011). This practice, as common as it is, may therefore contribute to shaping the concept of the "ecology of fear" in reef fish (Brown 2019).

To investigate the social perception of this practice among local stakeholders (local and foreign residents, compared to tourists), questionnaires were collected (Prinz et al. 2020, supplementary material). The social-ecological approach was included to better understand why tourists around the world partake in the artificial feeding of animals "in the wild" and whether/why it is considered necessary. Local stakeholders considered feeding fish an essential part of the lagoon cruise experience for tourists. Tourists, in contrast, considered artificial feeding of fish not important to the enjoyment of their visit, would appreciate the cruise without feeding, and argued that fish feeding can be stopped (54% of responses, Fig. 5.4). This result poses an opportunity for local management of lagoon cruises. The incorporation of stakeholder perceptions, in this case, the perception of tourists that fish feeding may be superfluous, is crucial to effectively develop management practices for marine conservation. Therefore, the Aitutaki management plan is being developed to incorporate these results which are in line with other regulations around the globe having targeted controlled or banned fish feeding (Authority 1994).

3.2 Galapagos Case Study

The Galapagos Islands are a globally renowned destination for extraordinary marine fauna and a high degree of endemism (Bustamante et al. 2002; Tye et al. 2002). The

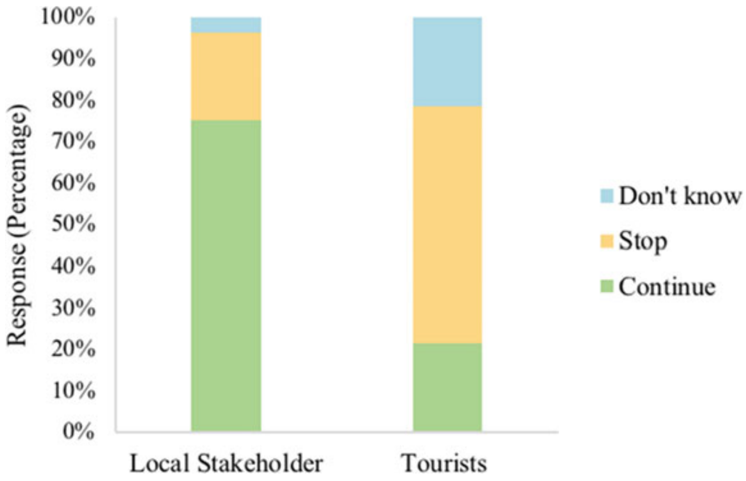


Fig. 5.4 Stakeholder responses to the question of whether to continue or stop fish feeding in the Aitutaki Lagoon (Cook Islands). Total number of responses $n = 104$ with responses from local stakeholders $n = 52$ and tourists $n = 52$. Figure adapted from Prinz et al. (2020)

marine and terrestrial ecosystems have been the subject to anthropogenic influence since the eighteenth century when whalers and pirates used the islands as shelter and stop-off (Eibl-Eibesfeldt 2001). In the following centuries Galapagos became a destination for research cruises and in the early twentieth century also for the first touristic journeys. The ever-increasing number of yearly visitors reached its peak in 2017 with 241,800 (de Galápagos 2019). The Galapagos Marine Reserve (GMR) was founded in 1998 and prohibits industrial fisheries, which is why tourism is the largest source of income in the GMR. The large amounts of people visiting the islands require more transportation and imported goods (i.e. food and water). This has led to a higher frequency of arrivals of cargo ships and airplanes. In 2005, 100 cargo ships and 1100 airplanes journeyed to Galapagos (Rogg et al. 2005), each arrival representing a potential risk for the introduction of NIS. During the last decades, the touristic fleet of the Galapagos Islands grew from 40 to more than 190 ships (de Galápagos 2019; Epler 2007), partly due to a shift in the tourism behaviour which is steering towards more day-tour and less cruise tourism (Mejia and Brandt 2015; Watkins and Cruz 2007). Thus, remote locations become increasingly connected to hub ports and popular visitor sites in the Galapagos archipelago.

One of the main conservation goals of the GMR is the prevention of NIS introductions, and to this end the Galapagos Biosecurity Agency (ABG) performs hull checks on newly arrived ships and prohibits ballast water discharge of ships coming from outside the GMR (ABG 2013; Campbell et al. 2015). Despite all efforts, the amount of NIS in the Galapagos is still increasing and is also positively related to increasing urbanisation (Toral-Granda et al. 2017). The biodiversity of marine NIS is usually underestimated in the tropics due to the difficulty of performing in-situ monitoring and the taxonomic challenges posed by marine

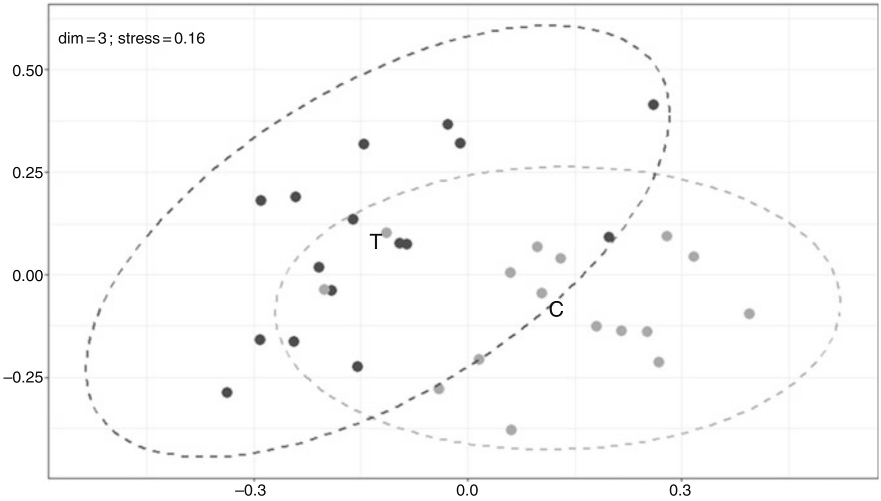


Fig. 5.5 Non-metric multidimensional scaling (NMDS) with each point representing a sample of a settlement community of conservation (C, grey) or tourism sites (T, black). Samples from conservation sites were more similar to each other than to samples from tourism sites and vice versa

invertebrates (Carlton et al. 2019). This is showcased by studies published in the past 4 years: Keith et al. (2016) reported seven marine NIS and 3 years later Carlton et al. (2019) reported 53 marine NIS and 33 marine cryptogenic (origin unknown) species for Galapagos.

To study the impact of tourism on benthic NIS, PVC settlement plates were installed at four marine tourism sites and four conservation sites, the latter prohibiting all anthropogenic activities. Settlement plates were floating about 1 m below lowest low tide, which is a well-established method for the monitoring of sessile port communities. After a settlement period of 3 months, identifications of settled animals were made to the lowest possible taxonomic level (Fig. 5.5). Additionally, water temperatures were measured at each study site every 30 min, enabling the detection of upwelling events whilst boat traffic was quantified using vessel movement data based on automatic identification system (AIS). Multivariate statistics (i.e. Permanova and SIMPER) revealed differences in species community composition between study sites based on boat traffic, conservation status and confounding factors such as temperature and upwelling events.

A total of 76 species were differentiated, of which seven were identified to species, ten to genus and the rest to a higher taxonomic level. Of the identified species, three are presumably non-indigenous and one cryptogenic in Galapagos. The conservation status of the study site (tourism or conservation) significantly influenced the community structure ($p = 2\text{e-}05$), as all tourism sites were more similar to each other than to conservation sites and vice versa. In general, marine NIS occurred more frequently at tourism than at conservation sites. Boat traffic was only slightly significant in affecting species compositions ($p = 0.04$) and therefore cannot be identified as the major reason for different species compositions. However, previous studies from Australia and the Mediterranean have shown the importance of small-scale boating as an important vector for marine NIS dispersal (Anderson et al. 2015; Ferrario et al. 2017; Marchini et al. 2015; West et al. 2007). Other marine NIS vectors, such as species trade, ballast water discharge and aquaculture, are absent at the study sites due to their remote location and the strong conservation regulations in Galapagos. Moreover, it is rather unlikely that any reported NIS arrived at the study sites by drifting of early life-stages in currents, because the pelagic time of eggs and larvae of sessile species is only seconds to minutes limiting their natural dispersal range. Therefore, the only possible vector apart from boat traffic in Galapagos is species rafting on either natural debris, larger marine organisms, or anthropogenic litter. However, the fact that species communities differ between marine visitor and conservation sites (Fig. 5.5) and marine NIS diversity was systematically higher at marine visitor sites argues against a random NIS dispersal such as rafting and in favour of vessel-induced NIS dispersal. The results are in line with other studies (Anderson et al. 2015; Letschert et al. 2021; Marchini et al. 2015) and represent a strong argument to consider the effect of marine tourism on marine NIS introductions in marine conservation plans.

4 Discussion

Despite the importance of tourism for local livelihoods (Hunter et al. 2018), the industry's cumulative effects on the ecosystem's health are apparent in many parts of the world. This literature review and both case studies summarise various effects of tourism on marine ecosystems in PICTs (Table 5.1). Except for one study, all literature mentioned here described negative or neutral effects of tourism on marine ecosystems. These tourism-related impacts range from individual-scale (feeding, contact, disease risk, harvesting) to ecosystem-scale changes (pollution, introduction of NIS). These impacts can provoke direct or indirect shifts in animal behaviour and loss of biodiversity. In both case studies, species compositions at sites frequently visited by tourists differed from non-visited sites (Prinz et al. 2020). In the case of feeding aquatic fauna, the direct observations of a change in community structure or behavioural patterns may lead to regulations of feeding practices (Brookhouse et al. 2013; Brunnschweiler et al. 2014). Direct impacts of touristic activities can be mitigated via restrictions and management strategies. In contrast, the introduction of NIS into an area with distinct endemic diversity is initially not an obvious process to tourists and, therefore, not negatively perceived. However, we argue that these changes may affect tourism in the long term, as endemic fauna may be more appreciated than introduced species, or a shift in ecological functioning may ensue due to NIS. Hence, it is critical to develop holistic strategies to account for direct as well as indirect changes in touristic hotspots.

The geographic focus of the discussed studies is dispersed throughout the central Pacific Ocean. However, the majority of the PICTs with high numbers of visitors are also subject to increased research when compared to PICTs with fewer tourists (Fig. 5.3). This may be due to the fact that countries with a higher reliance on visitors focus more on ecological impact as sustaining tourism is of priority. Alternatively, countries with higher income through tourism may have more available financial capacity to conduct research. Planning, managing and monitoring is critical for understanding the severity and types of impacts from different activities (Trave et al. 2017) since the number of annual tourists is constantly rising up until 2017 in most PICTs (Fig. 5.1). Yet, our findings may indicate a bias in the current knowledge of the impact of tourism on the marine environment in the central Pacific towards more popular tourist destinations.

From the reviewed literature items, more than half included, at least partially, the last decade in their study periods, but only five show results after 2014 (Table 5.1). However, given the fast increase of annual tourists in some places, this is not a suitable representation of monitoring and scientific values from the end of this decade. Hence, it is important to generate more recent data in order to recognise potential effects of visitors on marine environments early on. Given the examples of negative effects of tourism on marine habitats and the relatively few locations investigated, further research on that topic across the central Pacific is paramount. The interaction between coastal human activity of PICTs and ecological change has to be investigated simultaneously in order to manage marine tourism sustainably, find ecosystem-based regulations and ensure ecological resilience alongside touristic activities (Phillips 2015). Furthermore, institutional frameworks allocated to plan and administer sustainable development and conservation programs can eliminate poor public and political awareness of conservation principles and practices (Baines et al. 2002; Morrison and Buckley 2010). The development of sustainable tourism in the Pacific region is possible, yet the implementation of such plans may be the real challenge, as many of the PICTs are lower-income countries with priorities on other socio-economic issues and therefore less emphasis on environmental management. The main aim in future years should be to develop adaptive co-management systems that combine top-down strategic frameworks with bottom-up decision-making as has been suggested before (Lachs and Onate-Casado 2020). With the our review we only focused on effects of tourism on marine ecosystems and thus excluded studies researching tourism impacts on the socio-cultural system of PICTs. Therefore, further literature reviews with a broader focus are necessary to describe the impacts of tourism on the socio-ecological system.

4.1 Tourism Fostering Conservation?

Despite many studies highlighting the negative effects of marine tourism activities on marine flora and fauna, tourism can promote visitor awareness and create an incentive for nature conservation efforts (Higginbottom 2004; Higham and Luck 2007; Kiessling et al. 2017; Newsome et al. 2005). Marine waste is a good example; tourist activities may lead to an exacerbation of littering, which could decrease the location's attractiveness to tourists (Gregory 1999). Thus, littering by visitors has a negative feedback effect on tourism. Yet, obvious pollution can encourage visitors and tourism operators to engage in anti-littering campaigns and increase behavioural awareness (Kiessling et al. 2017). Tourism has long been cited as a justification for the conservation of biodiversity and the establishment of MPAs and parks throughout the Pacific Ocean (Morrison 2012).

The change from a fishing livelihood towards tourism-based income is one example for a change in people's perceptions. Large reef fish may have great value on the market but also for various ecological roles and for reef tourism (Fenner 2014). The direct comparison between income from fishing versus tourism activity may shift the interest towards live animals and protected marine environments (Fenner 2014; Graham and Idechong 1998). Over the past three decades, tourism has influenced island economies, such as Palau's, and their focus on protecting valuable resources in order to maintain its aesthetic value for visitors (Graham and Idechong 1998). This example shows that tourism is an option for an alternative sustainable livelihood, however, its feasibility depends on several other factors than simply annual tourist numbers and may be more difficult to implement in other PICTs.

4.2 Tourists Willing to Go Eco-Friendly

Campaigns, restrictions and targeted education on tourist trips may increase awareness and be important for successful ecotourism to occur (Patroni et al. 2018; Prinz et al. 2020; Wiener et al. 2009). Communicating scientific findings whilst engaging in the tourism sector may be key to make conservation a part of the touristic experience (Wiener et al. 2009) through the development of effective education programmes (Patroni et al. 2018). For instance, analysing the tourist diver's ecological perception can help to inform managers and justify conservation as well as increase their support for nature conservation restrictions by, in this case, applying a carrying capacity for dive trails (Ríos-Jara et al. 2013). Arguably, well-designed, themed experiences during ecotourism trips can target the tourist's conservation beliefs and enhance their understanding of a certain area or species (Higginbottom et al. 2001), behaviour and/or philanthropic support for conservation (Powell and Ham 2008). With conservation as a reason, tourists may be willing to pay more for a better and more sustainable experience (Grafeld et al. 2016).

4.3 Remarks on the COVID-19 Pandemic

This chapter was written prior to the Covid-19 pandemic, which had serious consequences for tourism due to travel restrictions worldwide. After the outbreak of the virus in late 2019, the Pacific region was one of the first to suffer from a drop in overseas arrivals (Abbas et al. 2021) with up to 100% decrease of visitors from the year before by April 2020 in some regions (Westoby et al. 2021). As tourism contributed to up to 70% of some of the PICTs economies, the socio-economic impact of the disappearance of touristim revenue on these states and territories is unprecedented (Connell and Taulealo 2021; Scheyvens et al. 2020). Connell and Taulealo (2021) argue that tourism as we knew it may not restart in the immediate future and PICTs inhabitants are forced to return to other businesses as a source of income. The over-dependence on tourism resulted in various negative impacts on the economic and social wellbeing of some of the PICTs (Connell and Taulealo 2021; Scheyvens et al. 2020; Westoby et al. 2021). The fact that alternative economic development opportunities are scarce (Connell and Taulealo 2021) and the future uncertain adds to the complex situation for PICTs inhabitants. Instead, the attention is drawn to adapt to the situation and focus on the transformational potential and recovery of the travel and leisure industry (Scheyvens et al. 2020). The effect of this almost immediate reduction in tourism pressure on marine environments was recorded to be positive (reduction of boat traffic, CO_2 emissions, pollution and increase in fish population density of functionally important species, for example) as well as negative (increase in illegal fishing, poaching) (Edward et al. 2021; Spalding et al. 2021). Yet, there may be cascading effects of complex dynamics between the local tourism industries and marine environmental protection (Bates et al. 2021). Therefore, tourism impacts on some areas of the marine environment in many PICTs will have to be further explored in the context of the change caused by the pandemic.

5 Recommendations

Based on our findings we propose four recommendations to enhance the understanding of tourism impact in different tourism locations. These recommendations can be adapted and used among PICTs to avoid irreversible changes in regularly-visited marine tourism locations.

1. *Monitoring the effects*: Alongside tourism development and through its revenue, we suggest to increase ongoing concomitant impact monitoring and incorporate results into ecosystem management.
2. *Citizen Science & Integrative approach*: By integrating tourists in citizen science projects, they contribute to the monitoring of the respective marine environment in a cost-effective way. Moreover, environmental citizen science projects raise tourists' awareness for conservation, which may directly lead to a less harmful behaviour during their visit.
3. *Knowledge exchange*: Communicating scientific findings whilst engaging in the tourism sector may be key to make conservation a part of the tourism experience. Tourist businesses and their employees can be trained to understand ecosystem dynamics. In addition, scientists can be informed by local community leaders about perceived environmental changes from the tourism operators.

4. *Balanced research design*: Research should be more equally distributed among PICTs and include sites with less tourists. Scientific studies should apply uniform sampling designs to be able to make temporal and spatial comparisons.

Acknowledgements We thank the editors and the reviewer for their valuable comments which improved the quality of this paper.

References

Abbas J, Mubeen R, Iorember PT, Raza S, Mamirkulova G (2021) Exploring the impact of COVID-19 on tourism: transformational potential and implications for a sustainable recovery of the travel and leisure industry. Curr Res Behav Sci 2:100033
ABG (2013) El directorio de la Agencia de Regulación y Control de la Bioseguridad y Cuarentena para Galápagos
Álvarez-Varas R, Petitpas R, Stowhas P, Fuentes-Hurtado M (2015) Conservation research needs of Easter Island (Rapa Nui) marine turtles. Chelonian Conserv Biol 14(2):184–192
Anderson LG, Rocliffe S, Haddaway NR, Dunn AM (2015) The role of tourism and recreation in the spread of non-native species: a systematic review and meta-analysis. PLoS One 10(10) https://doi.org/e014083310.1371/journal.pone.0140833
Asch RG, Cheung WWL, Reygondeau G (2018) Future marine ecosystem drivers, biodiversity, and fisheries maximum catch potential in Pacific Island countries and territories under climate change. Mar Policy 88:285–294. https://doi.org/10.1016/j.marpol.2017.08.015
Authority G B R M P (1994) Guidelines for fish feeding in the great barrier reef (brochure). Great Barrier Reef Marine Park Authority, Townsville, QLD
Baines G, Hunnam P, Rivers M.J, Watson B (2002) South Pacific biodiversity conservation programme: terminal evaluation mission. UNDP, New York, USA
Bates AE, Primack RB, Biggar BS, Bird TJ, Clinton ME, Command RJ, Richards C, Shellard M, Geraldi NR, Vergara V (2021) Global COVID-19 lockdown highlights humans as both threats and custodians of the environment. Biol Conserv 263:109175
Berno T (1999) When a guest is a guest: Cook Islanders view tourism. Ann Tour Res 26(3): 656–675
Bohnsack JA, Bannerot SP (1986) A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA/National Marine Fisheries Service
Brookhouse N, Bucher DJ, Rose K, Kerr I, Gudge S (2013) Impacts, risks and management of fish feeding at Neds Beach, Lord Howe Island Marine Park, Australia: a case study of how a seemingly innocuous activity can become a serious problem. J Ecotour 12(3):165–181
Brown JS (2019) Ecology of Fearq. Ency Anim Behav:196
Brunnschweiler JM, Baensch H (2011) Seasonal and long-term changes in relative abundance of bull sharks from a tourist shark feeding site in Fiji. PLoS One 6(1) https://doi.org/e1659710.1371/journal.pone.0016597
Brunnschweiler JM, Abrantes KG, Barnett A (2014) Long-term changes in species composition and relative abundances of sharks at a provisioning site. PLoS One 9(4):e86682. https://doi.org/e9414810.1371/journal.pone.0094148
Burdick D, Brown V, Asher J, Gawel M, Goldman L, Hall A, Kenyon J, Leberer T, Lundblad E, & McIlwain, J (2008) The state of coral reef ecosystems of Guam. The state of coral reef ecosystems of the United States and Pacific freely associated states, pp 465–509
Bustamante R, Wellington G, Branch G, Edgar G, Martinez P, Rivera F, Smith F, Witman J (2002) Outstanding marine features of the Galàpagos

Campbell ML, Keith I, Hewitt CL, Dawson TP, Collins K (2015) Evolving marine biosecurity in the Galapagos Islands. Manag Biol Invasions 6(3):227–230. https://doi.org/10.3391/mbi.2015.6.3.01

Carlton JT, Keith I, Ruiz GM (2019) Assessing marine bioinvasions in the Galapagos Islands: implications for conservation biology and marine protected areas. Aquat Invasions 14(1):1–20. https://doi.org/10.3391/ai.2019.14.1.01

Cartwright R, Gillespie B, LaBonte K, Mangold T, Venema A, Eden K, Sullivan M (2012) Between a rock and a hard place: habitat selection in female-calf humpback whale (*Megaptera novaeangliae*) pairs on the Hawaiian breeding grounds. PLoS One 7(5) https://doi.org/e3800410.1371/journal.pone.0038004

Cesar H, Burke L, Pet-Soede L (2003) The economics of worldwide coral reef degradation. International Coral Reef Action Network

Clua E, Buray N, Legendre P, Mourier J, Planes S (2010) Behavioural response of sicklefin lemon sharks *Negaprion acutidens* to underwater feeding for ecotourism purposes. Mar Ecol Prog Ser 414:257–266. https://doi.org/10.3354/meps08746

Connell J, Taulealo T (2021) Island tourism and COVID-19 in Vanuatu and Samoa: an unfolding crisis. Small States Territor 4(1):105–124

Connor R, Houlbrook R, Tarihao F (1996) Local conservation area ownership and traditional management. In: Developing alternatives: community development strategies and environmental issues in the Pacific, Victoria University, Melbourne

Cook Island Tourism (2019) Ministry of finance and economic management government of the Cook Islands statistical bulletin migration, June 2019. http://www.mfem.gov.ck/images/Mig_Statistics_Report_201906.pdf

de Galápagos ODT (2019) Estadistísticas del turismo en Galápagos 2018. In: Galápagos-Ecuador: Ministerio de Turismo del Ecuador

De Haas HC (2002) Sustainability of small-scale ecotourism: the case of Niue South Pacific. Curr Issue Tour 5(3–4):319–337

Diedrich A (2007) The impacts of tourism on coral reef conservation awareness and support in coastal communities in Belize. Coral Reefs 26(4):985–996. https://doi.org/10.1007/s00338-007-0224-z

Earp HS, Prinz N, Cziesielski MJ, Andskog M (2018) For a world without boundaries: connectivity between marine tropical ecosystems in times of change. In: YOUMARES 8–Oceans across boundaries: learning from each other, pp 125–144

Edward JP, Jayanthi M, Malleshappa H, Jeyasanta KI, Laju R, Patterson J, Raj KD, Mathews G, Marimuthu A, Grimsditch G (2021) COVID-19 lockdown improved the health of coastal environment and enhanced the population of reef-fish. Mar Pollut Bull 165:112124

Eibl-Eibesfeldt I (2001) Galápagos-Die Arche Noah im Pazifik. Piper, 2001, https://books.google.co.nz/books/about/Gal%C3%A1pagos.html?id=IiVYPgAACAAJ&redir_esc=y

Epler B (2007) Tourism, the economy, population growth, and conservation in Galapagos. Charles Darwin Foundation, p 55

Fenner D (2014) Fishing down the largest coral reef fish species. Mar Pollut Bull 84(1–2):9–16. https://doi.org/10.1016/j.marpolbul.2014.04.049

Ferrario J, Caronni S, Occhipinti-Ambrogi A, Marchini A (2017) Role of commercial harbours and recreational marinas in the spread of non-indigenous fouling species. Biofouling 33(8):651–660. https://doi.org/10.1080/08927014.2017.1351958

Gillett R (2009) Fisheries in the economies of the Pacific island countries and territories. Asian Development Bank

Glynn PW, Feingold JS, Baker A, Banks S, Baums IB, Cole J, Colgan MW, Fong P, Glynn PJ, Keith I, Manzello D, Riegl B, Ruttenberg BI, Smith TB, Vera-Zambrano M (2018) State of corals and coral reefs of the Galapagos Islands (Ecuador): past, present and future. Mar Pollut Bull 133:717–733. https://doi.org/10.1016/j.marpolbul.2018.06.002

Grafeld S, Oleson K, Barnes M, Peng M, Chan C, Weijerman M (2016) Divers' willingness to pay for improved coral reef conditions in Guam: an untapped source of funding for management and conservation? Ecol Econ 128:202–213. https://doi.org/10.1016/j.ecolecon.2016.05.005

Graham T, Idechong N (1998) Reconciling customary and constitutional law: managing marine resources in Palau. Micronesia Ocean Coast Manag 40(2–3):143–164. https://doi.org/10.1016/S0964-5691(98)00045-3

Gregory MR (1999) Plastics and South Pacific Island shores: environmental implications. Ocean Coast Manag 42(6–7):603–615. https://doi.org/10.1016/S0964-5691(99)00036-8

Hall CM (2010) An island biogeographical approach to island tourism and biodiversity: an exploratory study of the Caribbean and Pacific Islands. Asia Pac J Tour Res 15(3):383–399. https://doi.org/10.1080/10941665.2010.503628

Higginbottom K (2004) Wildlife tourism. Common Ground publishing, Altona, p 302

Higginbottom K, Rann K, Moscardo G, Davis D, Muloin S (2001). Status assessment of wildlife tourism in Australia: an overview. CRC for Sustainable Tourism Gold Coast

Higham J, Luck M (2007) Marine wildlife and tourism management: insights from the natural and social sciences. CABI. 389pp

Hoffmann TC (2002) Coral reef health and effects of socio-economic factors in Fiji and Cook Islands. Mar Pollut Bull 44(11):1281–1293. https://www.sciencedirect.com/science/article/pii/S0025326X02002606?via%3Dihub

Hunter CE, Lauer M, Levine A, Holbrook S, Rassweiler A (2018) Maneuvering towards adaptive co-management in a coral reef fishery. Mar Policy 98:77–84. https://doi.org/10.1016/j.marpol.2018.09.016

Hutchings P, Payri C, Gabrie C (1994) The current status of coral-reef Management in French-Polynesia. Mar Pollut Bull 29(1–3):26–33. https://doi.org/10.1016/0025-326x(94)90422-7

IUCN (2010) IUCN Red list of threatened species. Version 2010.3. www.iucnredlist.org

Johannes RE (2002) The renaissance of community-based marine resource management in Oceania. Annu Rev Ecol Syst 33:317–340. https://doi.org/10.1146/annurev.ecolsys.33.010802.150524

Keith I, Dawson TP, Collins KJ, Campbell ML (2016) Marine invasive species: establishing pathways, their presence and potential threats in the Galapagos marine reserve. Pac Conserv Biol 22(4):377–385

Kiessling T, Salas S, Mutafoglu K, Thiel M (2017) Who cares about dirty beaches? Evaluating environmental awareness and action on coastal litter in Chile. Ocean Coast Manag 137:82–95. https://doi.org/10.1016/j.ocecoaman.2016.11.029

Lachs L, Onate-Casado J (2020) Fisheries and tourism: social, economic, and ecological trade-offs in coral reef systems. In: Youmares 9–The oceans: our research, our future, pp 243–260. https://doi.org/10.1007/978-3-030-20389-4_13

Letschert J, Wolff M, Kluger LC, Freudinger C, Ronquillo J, Keith I (2021) Uncovered pathways: modelling dispersal dynamics of ship-mediated marine introduced species. J Appl Ecol 58(3): 620–631

Marchini A, Ferrario J, Minchin D (2015) Marinas may act as hubs for the spread of the pseudo-indigenous bryozoan *Amathia verticillata* (Delle Chiaje, 1822) and its associates. Sci Mar 79(3): 355–365. https://doi.org/10.3989/scimar.04238.03A

Mejia CV, Brandt S (2015) Managing tourism in the Galapagos Islands through price incentives: a choice experiment approach. Ecol Econ 117:1–11. https://doi.org/10.1016/j.ecolecon.2015.05.014

Mellor CS (2003) Towards new tourism development strategies in Cook Islands. Pacific Economic Bulletin 18(1):100–107

Milazzo M (2011) Evaluation of a behavioural response of Mediterranean coastal fishes to novel recreational feeding situation. Environ Biol Fish 91(1):127–132. https://doi.org/10.1007/s10641-011-9784-4

Moity N, Izurieta JC, Araujo E, Casafont M (2018) DiveStat: a new tool for managing dive tourism. In: Galapagos report 2017, pp 72–77

Moity N, Izurieta J, Araujo E, Casafont M (2019) DiveStat: a new tool for managing dive tourism. In: Galapagos report 2017–2018. GC, Fairfax, pp 72–77
Morrison C (2012) Impacts of tourism on threatened species in the Pacific region: a review. Pac Conserv Biol 18(4):227–238
Morrison C, Buckley R (2010) Conservation tourism, Cambridge edn. CABI Publishing, Cambridge
Naranjo-Elizondo B, Cortes J (2018) Observations of litter deposited in the deep waters of Isla del coco National Park, eastern tropical Pacific. Front Mar Sci 5:91. https://doi.org/9110.3389/fmars.2018.00091
Newsome, D, Dowling, RK, Moore, SA (2005) Wildlife tourism. Channel view publications, England. https://doi.org/10.21832/9781845410087
Nicoll R, Vick C, Laffoley D, Hajduk T, Zuccarino-Crowe C, Bianco M, Russell S, Flood K, Parry L, Keenleyside K (2016) MPAs, aquatic conservation and connecting people to nature. Aquat Conserv Mar Freshw Ecosyst 26:142–164. https://doi.org/10.1002/aqc.2678
Orams M (2002) Marine tourism: development, impacts and management. Routledge, London
Otto, EI, Gouezo, M, Koshiba, S, Mereb, G, Jonathan, R, Olsudong, D, Golbuu, Y (2015) Impact of snorkelers on shallow coral reef communities in Palau. Palau International Coral Reef Center
Patroni J, Simpson G, Newsome D (2018) Feeding wild fish for tourism: a systematic quantitative literature review of impacts and management. Int J Tour Res 20(3):286–298. https://doi.org/10.1002/jtr.2180
Phillips WN (2015) Tourism threats to coral reef resilience at Koh Sak, Pattaya bay. Environ Nat Resour J 13(1):47–60
Pinca S, Ribanataake A, Kronen M, Chapman L, Lasi F (2009) Cook Islands country report: profiles and results from survey work at Aitutaki, Palmerston, Mangaia and Rarotonga (February and October 2007). Pacific Regional Oceanic and Coastal Fisheries Development Programme (PROCFish/C/CoFish)/Secretariat of the Pacific Community, Noumea
Powell RB, Ham SH (2008) Can ecotourism interpretation really lead to pro-conservation knowledge, attitudes and behaviour? Evidence from the Galapagos islands. J Sustain Tour 16(4): 467–489. https://doi.org/10.2167/jost797.0
Prinz N, Story R, Lyon S, Ferse SCA, Bejarano S (2020) To feed or not to feed? Coral reef fish responses to artificial feeding and stakeholder perceptions in the Aitutaki lagoon, Cook Islands. Front Mar Sci 7. https://doi.org/14510.3389/fmars.2020.00145
Ríos-Jara E, Galván-Villa CM, Rodríguez-Zaragoza FA, López-Uriarte E, Munoz-Fernández VT (2013) The tourism carrying capacity of underwater trails in Isabel Island National Park Mexico. Environ Manag 52(2):335–347
Rogg H, Buddenhagen C, Causton C (2005) Identification of risks and management of invasive alien species. In: Identification of risks and management of invasive alien species using the IPPC framework. Proceedings of the workshop on invasive alien species and the international plant protection convention. International plant protection convention secretariat, Brau, p 798–807
Scheyvens R, Movono A, Strickland D, Bibi P, Tasere A, Hills G, Rihai N, & Teama F (2020). Development in a world of disorder: tourism, COVID-19 and the adaptivity of South Pacific people
Spalding M, Burke L, Wood SA, Ashpole J, Hutchison J, Ermgassene PZ (2017) Mapping the global value and distribution of coral reef tourism. Mar Policy 82:104–113. https://doi.org/10.1016/j.marpol.2017.05.014
Spalding M, Burke L, Fyall A (2021) Covid-19: implications for nature and tourism. Anatolia 32(1):126–127
State of Hawaii DBEDT (2019). https://dbedt.hawaii.gov/. Accessed 11 Mar 2019
Toral-Granda MV, Causton CE, Jager H, Trueman M, Izurieta JC, Araujo E, Cruz M, Zander KK, Izurieta A, Garnett ST (2017) Alien species pathways to the Galapagos Islands Ecuador. PLoS One 12(9) https://doi.org/e018437910.1371/journal.pone.0184379

Trave C, Brunnschweiler J, Sheaves M, Diedrich A, Barnett A (2017) Are we killing them with kindness? Evaluation of sustainable marine wildlife tourism. Biol Conserv 209:211–222. https://doi.org/10.1016/j.biocon.2017.02.020

Tye A, Snell H, Peck S, Adsersen H (2002) Outstanding terrestrial features of the Galapagos archipelago. A biodiversity vision for the Galapagos Islands:12–23

UNWTO (2019) All countries: inbound tourism: arrivals by region 1995–2017 (01.2019). https://www.e-unwto.org/doi/abs/10.5555/unwtotfb0000270519952017201901

Van Houtan KS, McClenachan L, Kittinger JN (2013) Seafood menus reflect long-term ocean changes. Front Ecol Environ 11(6):289–290

Vignon M, Sasal P, Johnson RL, Galzin R (2010) Impact of shark-feeding tourism on surrounding fish populations off Moorea Island (French Polynesia). Mar Freshw Res 61(2):163–169. https://doi.org/10.1071/Mf09079

Wantiez L (2008) Coral reefs of New Caledonia in 2006: status report and monitoring network. Revue D Ecologie-La Terre Et La Vie 63(1–2):117–132

Watkins G, Cruz F (2007) Galapagos at risk: a socioeconomic analysis of the situation in the archipelago. Charles Darwin Foundation, Puerto Ayora, Province of Galapagos, Ecuador

West EJ, Bames PB, Wright JT, Davis AR (2007) Anchors aweigh: fragment generation of invasive *Caulerpa taxifolia* by boat anchors and its resistance to desiccation. Aquat Bot 87(3):196–202. https://doi.org/10.1016/j.aquabot.2007.06.005

Westoby R, Gardiner S, Carter RW, Scott N (2021) Sustainable livelihoods from tourism in the "10 new Balis" in Indonesia. Asia Pac J Tour Res 26(6):702–716

Wiener CS, Needham MD, Wilkinson PF (2009) Hawaii's real life marine park: interpretation and impacts of commercial marine tourism in the Hawaiian islands. Curr Issue Tour 12(5–6): 489–504. https://doi.org/10.1080/13683500902736855

Wilkinson CR, Souter D (2008) Status of Caribbean coral reefs after bleaching and hurricanes in, p 2005

WTTC (2017) Travel and tourism economic impact 2017 Oceania, World Travel and Tourism Council (WTTC), London

Chapter 6
Saudi Arabia Case Study

The Development of Saudi Arabia's Red Sea Coastline: Challenges Facing Sustainable Resource Use

Vanessa Robitzch, Alexander Kattan, Aislinn Dunne, and Darren J. Coker

Abstract Determined to advance toward a post-oil era, the Kingdom of Saudi Arabia is rapidly transforming its economy and social structures. The country is targeting new industries, investing in large-scale development projects, and opening its borders for tourism. Through these ambitious projects, the Kingdom envisions an economic and environmentally sustainable future independent of petroleum export. However, these plans also pose major challenges to terrestrial and marine ecosystems, particularly because much of this effort focuses on development along remote coastal regions with historically low human populations. Here, we present the historical use, current state, and future projections of coastal marine resources of the Saudi Arabian Red Sea. Focusing on fisheries, aquaculture, and tourism, we discuss the potential challenges and opportunities of increasing coastal developments in light of Saudi Arabia's Vision 2030.

Keywords Aquaculture · Artisanal fisheries · Climate change · Development · Tourism

V. Robitzch (✉)
Red Sea Research Center, King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia

Instituto de Ciencias Ambientales y Evolutivas, Universidad Austral de Chile, Campus Isla Teja, Valdivia, Chile
e-mail: Vanessa.RobitzchSierra@kaust.edu.sa

A. Kattan · A. Dunne · D. J. Coker
Red Sea Research Center, King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia

M. Wolff et al. (eds.), *Challenges in Tropical Coastal Zone Management*,
https://doi.org/10.1007/978-3-031-17879-5_6

1 Introduction to the Kingdom of Saudi Arabia and Its Red Sea Coastline

Covering 80% of the Arabian Peninsula, the Kingdom of Saudi Arabia (KSA) is a vast expanse of land largely composed of desert, rock, and sparsely-vegetated biomes amidst a hot and arid climate. The nation's harsh terrestrial environments, however, contrast greatly with its surrounding seas (Vincent 2008). Flanked by the Gulf to the east and the Red Sea to the west, KSA is home to some of the most unique and biodiverse marine ecosystems on the planet. The Red Sea coast alone is home to mangrove forests, seagrass beds, salt marshes, coastal lagoons, and coral reefs. Together, these habitats form a network of ecosystems that support immense biodiversity (Jawad 2021). Oceanographic features shape the Red Sea's environment with prominent latitudinal gradients in temperature, salinity, and nutrients. Salinity increases from approximately 36 in the south to 41 in the north, while temperatures decrease from south to north with maximum annual temperatures of 33 °C in the south and 27 °C in the north (Chaidez et al. 2017). Nutrients and chlorophyll-*a* concentrations are also highest in the south, mainly due to the input of nutrient-rich waters with lower salinities from the Gulf of Aden via the Bab El-Mandeb Strait (Raitsos et al. 2015; Sofianos and Johns 2002) (Fig. 6.1). These environmental gradients have been shown to impact various processes among Red Sea ecosystems such as mangroves or coral reefs, and marine megafauna and plankton dynamics (Racault et al. 2015; Sofianos and Johns 2003; Voolstra and Berumen 2019). Despite the unique and biodiverse Red Sea ecosystems, research in the region has been historically low compared to other tropical areas of the world. A review on the research output from the Red Sea indicated six to eight times higher research activity in Australia's Great Barrier Reef and the Caribbean, respectively, over the same time period (Berumen et al. 2013). Nonetheless, this trend has been steadily changing in

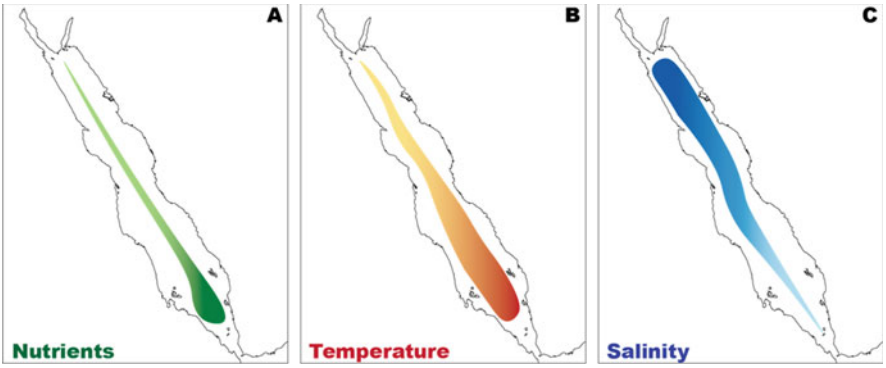


Fig. 6.1 Illustration of the environmental gradients in the Red Sea. (**a**) Nutrient concentrations (green) and (**b**) sea surface temperature (red) are highest in the South; (**c**) salinity (blue) is highest in the North of the Red Sea. Color and width indicate the intensity of the respective environmental factor

the past two decades due to increased interest in marine and coastal biodiversity and available resources for exploring the Red Sea provided by the Kingdom (Voolstra and Berumen 2019).

The Kingdom of Saudi Arabia has undergone monumental social and economic changes in less than a century driven by a rapidly growing economy and population. Given the scarcity of local food and natural water resources on land, the mostly nomadic population of Saudi Arabia traditionally relied on a subsistence economy built around trading goods along pilgrim routes, artisanal fisheries, and agricultural practices mainly limited to herding camels, goats, and sheep (Al-Rasheed 2010). The discovery of its vast petroleum reserves in 1938 rapidly transformed Saudi Arabia's economy (Lackner 1978). Saudi Arabia is now the biggest exporter of petroleum and has the second largest proven reserves worldwide (usatoday.com, 22/05/2019). From the 1990s up to 2014, petroleum exports and associated industries account for approximately 90% of the budget revenue of Saudi Arabia (Presley and Westaway 2017; Sultan and Haque 2018). Closely linked to the rise in oil exports and increasing global oil demands, the gross domestic product of Saudi Arabia has grown by more than 100-fold in the last five decades (Samargandi et al. 2014). However, the discovery of oil not only propelled the economic development of Saudi Arabia but also drastically altered demographics and the culture within the country. The population of Saudi Arabia has steadily increased from three million in 1950 to over 30 million in 2013 (Forstenlechner and Rutledge 2011; Howarth et al. 2017). Among these, more than 8 million foreign workers were employed in Saudi Arabia as part of the oil and the service sector (Baruch and Forstenlechner 2017). The recent opening of KSA to tourism in 2019 will also change, at least temporarily, the Kingdom's demography. Hence, despite its solid economic development rapid population growth, demographic changes, and the need for increased new infrastructures will likely drive many of the future challenges in the country.

In this context, the Kingdom proposed a new roadmap for economic and social development in 2016 termed "Vision 2030," this plan aims to implement a series of reforms and investments to prepare Saudi Arabia's economy for a post-oil era (Fattouh and Sen 2016; Khan 2016). As such, the government is looking for new ways to diversify its economy, foster foreign investment, and reduce dependence on foreign labor (Hvidt 2013; Moser et al. 2015). In its search for new opportunities toward sustainable economic growth, Saudi Arabia is turning to the Red Sea coastline and its marine resources. In this context, the Red Sea has great potential for sustainable exploitation and development across many branches of the economy. Vision 2030 seeks to promote and expand established industries such as cargo transport and fisheries, but also to develop new avenues of income including mining, aquaculture, and ecotourism (Cappelen and Choudhury 2017; Ekiz et al. 2017). Several large giga-projects are being developed along the northern Red Sea coastline, including NEOM (a planned futuristic city), the Red Sea Project (by the Red Sea Development Company, TRSDC), and AMAALA (luxury resorts and ecotourism destinations). These projects are mostly coastal with large areas of land planned for development. NEOM is planning to exist across 26,500 km^2 (NEOM 2021), and the Red Sea Project will cover 200 km of coastline and 90 currently undeveloped islands (TRSDC 2021). Moreover, these projects promise to make large-scale developments in a way that is not only minimally invasive to the environment, but in some cases "regenerative" by enhancing the biota and increasing the biodiversity that is currently there (TRSDC 2021). Naturally, the premise of large-scale development and exploitation of the coastal environments poses not only great opportunities but also major challenges and environmental risks for the development of Saudi Arabia.

2 Red Sea Fisheries in Saudi Arabia

For centuries, small, subsistence fisheries were the mainstay for villages along the Saudi Arabian coast of the Red Sea. In addition to cooler temperatures, abundant and diverse fishery resources (in pelagic, coral reef, and neritic environments) along the Red Sea influenced traditionally nomadic peoples, enduring harsh terrestrial landscapes and climate, to settle and establish coastal towns (Neve and Al-Aiidy 1973). Historically, the subsistence fisheries of these maritime villages encompassed few, small, and rudimentary vessels, known locally as *sambuks* or *huris*, with fishers harvesting primarily from nearshore reefs using simple techniques such as hook-and-line and small traps (Tesfamichael and Pauly 2016). While fish remain an important source of protein in KSA (Burger et al. 2014), contemporary fishing practices in Saudi Arabia continue to be mostly artisanal (64% of total catch). Industrial fishing practices (i.e., trawling; 23% of total catch) are limited to the far southern coastline around Jazan and the Farasan islands, the only region with significant area of soft-bottom hábitat (Tesfamichael and Pauly 2012). However, the artisanal fishing fleet underwent widespread motorization in the 1980s (Tesfamichael and Pauly 2012) and further benefited from cheap fuel prices, refrigeration at-sea, and low-wage labor immigration from nearby countries (Jin et al. 2012; Richards and Waterbury 1996; Tesfamichael and Pauly 2016). The hiring of cheap foreign labor enabled Saudi fishing families to stop harvesting themselves, a practice sometimes termed "investor fishing" (Tesfamichael and Pauly 2016). These factors, coupled with a rapidly growing population and demand for seafood, allowed Saudi fishermen to expand their artisanal businesses, moving from subsistence to commercial fishing. Between 1990 and 2005 the number of registered traditional fishing vessels tripled. Moreover, improved coastal infrastructure and transportation to large fish markets and a growing number of restaurants have further fueled the increasing demand for seafood. This pattern of unmitigated development and exploitation has doubtlessly had a significant impact on Red Sea fisheries in Saudi Arabia across and along the entirety of its coastline.

While data regarding the status of Saudi Red Sea fishery stocks remains limited, the available information and evidence point to high and largely unregulated fishing pressure over the past several decades. In reconstructing fishery landings from 1950 to 2010, Tesfamichael and Pauly (2012) report peak catch occurred in the mid-1990s, while Jin et al. (2012) conclude artisanal fisheries in the Kingdom have been overharvested since the early 1990s. A number of additional and more recent fishery-dependent studies also indicate overfishing, in particular for higher trophic level taxa such as groupers (Hassanien 2021) and sharks (Spaet and Berumen 2015). By far, the most popular Serranids (groupers) for consumption in Saudi Arabia are the roving coral grouper (*Plectropomus pessuliferus marisrubri*) and the congeneric squaretail grouper (*Plectropomus areolatus*). These similar-looking fish, both known locally as *najel*, have nearly doubled in market value over the past decade from 15 USD/kg (DesRosiers 2011) to more than 25 USD/kg (Shellem et al. 2021). The rising prices of highly-desired fishery species may also suggest reduced catches despite stable or increasing effort.

Several fishery-independent studies in the Saudi Arabian Red Sea, namely those employing underwater visual census (UVC) techniques, further support the overfishing hypothesis. For example, Roberts et al. (2016) only recorded two sharks (both *Triaenodon obesus*) during the course of extensive survey effort (40 sites and 4 depths) along 8 ° of latitude, while Khalil et al. (2017) report the near-absence of top predators and low abundance of commercially valuable fishes on reefs in the central Red Sea. Large predators were similarly undocumented in eight sites using UVC around the Al Wajh bank (Atta et al. 2019). While historic baseline data informing what "pristine" reef fish assemblages look like are lacking for the Saudi Arabian Red Sea, remote and relatively unexploited reefs in Sudan offer some context. Taking advantage of similar benthic and oceanographic conditions on either side of the Red Sea, Kattan et al. (2017) conducted UVC surveys at similar latitudes in both Saudi Arabia and Sudan. This study revealed healthier reef fish assemblages on Sudanese reefs compared to those in Saudi Arabia. This was characterized by greater overall fish biomass as well as abundance and mean size of top predators. Biomass of top predators (such as larger groupers, snappers, and jacks) was strikingly different between the two countries, with three times greater biomass recorded on remote Sudanese reefs compared to analogous sites in KSA. These results suggest heightened fishing pressure in Saudi Arabia, particularly for commercially important species.

Perhaps the most compelling evidence for unsustainable fishing practices in the Saudi Arabian Red Sea comes from studies on sharks and rays, high trophic level taxa whose absence is indicative of general overexploitation (Pauly et al. 1998). Despite a 2008 royal decree outright banning the harvest of these animals, they continue to be landed and sold at KSA fish markets along the coast. Worryingly, fish market surveys for elasmobranchs suggest both growth and recruitment overfishing for many species as well as the direct targeting of shark nursery áreas (Spaet and Berumen 2015). Baited Remote Underwater Video (BRUV) and longline survey efforts have likewise found depauperate numbers of sharks in the Saudi Red Sea, especially when compared to neighboring Sudan and other regions of the global ocean where reef sharks are considered common (MacNeil et al. 2020; Spaet et al. 2016).

The plight of sharks and rays in the Saudi Arabian Red Sea highlights the fundamental challenge to a future of sustainable marine resource exploitation: the advancement and enforcement of regulations. As pointed out by Spaet and Berumen

(2015), financial and human resources should not be a limiting factor in a nation with the world's largest proven oil reserves. Moreover, as border regulations strictly require all vessels to check in and out with local coast guard stations each time they go to sea, enforcement infrastructure is already in place. With minimal training, coast guard personnel could ensure that elasmobranchs (or any other protected taxa) do not make their way to market (Spaet and Berumen 2015). Spearfishing is another banned practice that openly continues to occur, as evidenced by the sale of spearguns and related equipment at dive shops along the coast (authors' personal observations). Left unchecked, heavy spearfishing activity has the potential to visibly deplete large target species, especially those exhibiting high site fidelity, as are groupers (Oakley 1984).

Importantly, protection of spawning aggregations, a fundamental approach to sustainable management of aggregating species, appears to be lacking in KSA. For example, to supply the high demand for parrotfish, fishers target a large and predictable annual aggregation of *Hipposcarus harid* in the Farasan Islands, typically harvesting the aggregation in its entirety (Gladstone 1996; Spaet 2013). Moreover, seasonal aggregations of *Plectropomus pessuliferus marisrubri* and *Plectropomus areolatus,* which had experienced seasonal closures between 1985 and 1995 (DesRosiers 2011) are seemingly unregulated despite their high value. While some management efforts are arbitrarily disseminated, typically via cryptic social media posts circulated within the fishing community, the impact and reception of these announcements appear suspect at best (AK personal observation). Further inhibiting regulatory efforts is the paucity of scientific knowledge to inform management (Berumen et al. 2013) and the waning of local taboos and any self-enforcement as Saudis have largely left the fisher workforce (DesRosiers 2011).

Despite the challenges Saudi Arabia faces for a future of sustainable fishery management in the Red Sea, the Kingdom is well-poised to make progress. Fundamental to meaningful change is education of and support from the Saudi public, which has shown encouraging progress in recent years. Results of a recent survey of more than 1500 Saudi nationals indicate that, while the issue of overfishing remains a lower priority, there exists meaningful awareness of marine environmental issues and, more importantly, widespread support for government action as well as trust in university and government scientists to address these threats (Almahasheer and Duarte 2020). Also encouraging is the importance KSA is placing on environmental protection in the pursuit of its goals of Vision 2030. The development of the marine tourism industry, in particular, presents a strong incentive to promote healthy reefs to be enjoyed by the likes of snorkelers, divers, and recreational fishers (see Sect. 6.4). Finally, the creation of large giga-projects placing environmental protection and enhancement at the core of their mission holds potential for the creation of large marine protected areas in the northern reaches of the Saudi Red Sea.

3 Aquaculture in the Saudi Arabian Red Sea: A Case Study in the City of Al Lith

Aquaculture development in Saudi Arabia dates back to 1980 with the establishment of the first aquaculture project at the Saudi Arabian National Center for Science and Technology and subsequent founding of a national fish farming center in Jeddah (Salama et al. 2016). In 1982, the National Prawn Company (now, National Aquaculture Group—NAQUA) was founded to benefit the economy of Saudi Arabia and to meet the market's demand for seafood. Today, NAQUA operates the largest aquaculture facility in Saudi Arabia on the shores of Al Lith, a small town on the central coast of Saudi Arabia (Berumen et al. 2019) (Fig. 6.2). The large facility in the north of Al Lith spans over 65 km of coastline and occupies 40 km^2 of land for pond farms and hatcheries predominantly of prawns but also of finfish, sea cucumbers, algae, and beta-carotene (produced in hypersaline ponds cultivating *Dunaliella* spp.) (Fig. 6.2). The facilities harbor more than 500 inland ponds, feed production and handling systems, and a fully integrated facility for all post-harvesting processes (NAQUA 2021). Since 2010, NAQUA has intensified its finfish aquaculture by farming barramundi (*Lates calcarifer*) in the Red Sea (Berumen et al. 2019). These fish are stocked in cage cultures positioned offshore from the large on-land prawn farm (Fig. 6.1b). In 2021, NAQUA reported an annual growth capacity of 90,000 t of white prawn (*Litopenaeus vannamei*) and produced 15,000 t of barramundi (*Lates calcarifer*) per year (NAQUA 2021). Thereby, the facilities in Al Lith are among the largest aquaculture operations of their type in the world (NAQUA 2021).

While the facility is a source of food and monetary income to the Kingdom, it is also regarded as a critical source of anthropogenic wastewater to Al Lith's coast and

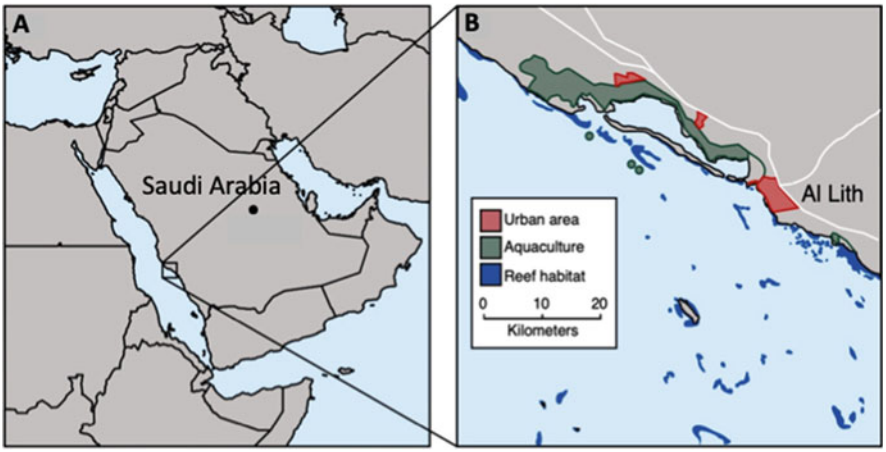


Fig. 6.2 Overview of the Al Lith area. (**a**) Al Lith is a coastal town of Saudi Arabia in the Central Red Sea. (**b**) Aquaculture facilities cover a large portion of the Al Lith coastline and are close to coral reef habitats.

a threat through the introduction of alien species. Escaped barramundi have been reported in Israeli waters of the Gulf of Aqaba, 800 km north of the farms (Stern and Rothman 2021); and effluents from both the on-land prawn farm and the offshore cage cultures have been detected in nearby coastal waters by various monitoring efforts. The intake of water from the Red Sea to the on-land prawn aquaculture facility has an estimated flow of 42−48 $m^3 s^{-1}$ (Hozumi et al. 2018). Wastewater from the ponds merges to one main effluent plume that, apart from a settling basin, receives no additional treatment (Hozumi et al. 2018). An assessment from 2009 revealed that the outfall site had elevated concentrations of ammonium and phosphate (5–75 times and 4–14 times higher at the outfall compared to other sites, respectively), along with significant changes in the microbial communities, including the presence of potential pathogens (e.g., *Francisella* spp. and *Rickettsiales*) (Becker et al. 2017). As the plume is further characterized by elevated levels of salinity, density, and turbidity, it sinks and travels along paths determined by the bathymetry to form a dense 1–3 m thick layer above the seafloor (Hozumi et al. 2018). Thereby, this dense, bottom-flowing plume can be observed as far as 8 km from the discharge point and may have a detrimental impact on benthic and demersal communities (Hozumi et al. 2018). Sawall et al. (2014) found that impacted reefs near the outfall in Al Lith have less coral cover, a shift in community composition toward bigger, more stress-tolerant species, and a greater fraction of non-living substrate than its corresponding offshore reefs. The spatial coverage of harmful algal blooms as well as the higher concentrations of chlorophyll-*a* near Al Lith was also seen to increase with annual production of the shrimp farm from 2002–2010, which could be a biological response to the nutrient-rich effluent from the facility (Gokul et al. 2020). In addition to the outflow from the on-land prawn farm, effluent from offshore finfish cage cultures have also been detected. In a 2016/2017 survey of the offshore barramundi cage cultures, elevated levels of chlorophyll-*a* and heterotrophic bacteria were detected down-current from cages, as were altered ratios of nitrogen:phosphorus (Dunne et al. 2021). This study also detected higher levels of ammonium, particulate matter, and phosphate in the waters close to or down-current from the fish farm cages after fish in the cages were fed, with elevated ammonium levels detected in water up to 800 m from the farm. These studies all point to water quality impacts by various aquaculture activities in the area, which must be managed in order to mitigate the effects on adjacent marine ecosystems.

The potential conflict between coastal development and ecological conservation is a global issue. However, the Red Sea, like many tropical regions, may be particularly sensitive to water pollution due to naturally low-nutrient conditions. The waters around Al Lith are generally characterized by oligotrophic conditions (0.1–0.2 μm phosphate, $<$ 0.1 μm ammonium, and $<$ 0.7 μm nitrate + nitrite) (Furby et al. 2014; Hozumi et al. 2018) and are also home to diverse marine habitats including coral reefs, mangrove, and seagrass beds (Hozumi et al. 2018). Aquaculture runoff is known to introduce significant amounts of nitrogen, phosphate, and organic solids into the surrounding water, thereby having an impact on many biological and biogeochemical processes (Nogales et al. 2011). Plumes from aquaculture sites can impact the survivorship of juvenile corals (Villanueva et al. 2005) and impair coral reproduction (Loya et al. 2004). Impacts of eutrophication in general have been observed on coral reefs in the Red Sea, highlighting the need to properly manage the effluent from Red Sea aquaculture. Naumann et al. (2015) found that hard coral decline and increased turf algae cover was correlated with higher ambient phosphate and ammonium concentrations on coral reefs in South Sinai, Egypt, and Karcher et al. (2020) demonstrated that nitrogen-limited turf algae benefited more than hard corals from experimental eutrophication in the central Red Sea. If effluent from future Red Sea aquaculture is not well managed or treated, the ensuing nutrient enrichment could have negative impacts on the surrounding benthic habitats.

Demand for fresh fish is growing in Saudi Arabia, with annual fish consumption per capita increasing from 3 kg in 1977 to 8 kg in 2007 (FAO 2021). Despite recent expansions of the NAQUA facility in Al Lith, Saudi Arabia still imported 85% of its total fish food supply in 2017 (FAO 2020). Saudi Arabia's economic development plan, Vision 2030, lists increased funding for aquaculture development as one of its priorities, and the Ministry of Environment, Water, and Agriculture proposed to develop aquaculture facilities along the whole coast of the Red Sea (MEWA 2021). NEOM, Saudi Arabia's largest giga-project located on the Red Sea, plans to create the largest fish farm and hatchery in the Middle East and North Africa Region, envisioning aquaculture development on a grand scale (NEOM 2021). As Saudi Arabia develops its aquaculture production ambitions, mitigation of the eutrophication impacts will be needed in order to preserve the unique habitats along the Red Sea coast.

Facilities around the world have developed management techniques to mitigate the polluting effects of aquaculture. Recent studies have highlighted the role of positioning offshore cages in deep waters with sufficient current to disperse nutrients and to prevent water quality impacts (Price et al. 2015). The selection of suitable sites with good water exchange and quality plays a significant role in the economic viability and ecological impacts of aquaculture operations (Pérez et al. 2003) and should be considered in the implementation of future fish farms in the Red Sea. Criteria such as sufficient water depth and current speed for waste dispersal, as well as avoiding sensitive habitats like mangroves, are crucial for aquaculture site selection (Benetti et al. 2010). Situating fish farms in deeper water farther from shore is associated with lower levels of pollution but higher operational costs (Cardia et al. 2017), and Saudi Arabia will need to assess its unique benthic and oceanographic environment (many coral reefs in an enclosed basin with limited water exchange or storm and wave action) in order to choose appropriate aquaculture sites that are commercially viable. A site suitability survey for cage farming sites was performed in the Red Sea region of Saudi Arabia, considering several physical, chemical, and biological parameters as well as possible conflicts of interest with other users such as industry and local fisheries (Salama et al. 2016). Potential impacts to the surrounding environment were not the focus of this survey and should be part of future assessments. Managing the operations of aquaculture facilities can limit their impacts through approaches that for instance limit the density of animals in farms (Gentry et al. 2017) or through effective feeding rates that reduce the amount of uneaten food leaving fish farms (Dauda et al. 2019). Another promising technique is integrated multi-trophic aquaculture (IMTA), where waste generated by organisms at higher trophic levels (e.g., carnivorous fish) is absorbed by organisms of lower trophic levels (e.g., algae or filter feeding bivalves) growing next to them. IMTA has been successfully established in places such as Sangguo Bay, China, since the late 1980s, and grows a large array of finfish, seaweeds, and molluscs to improve economic and environmental quality of the aquaculture operations (Fang et al. 2016). Modeling of fish farms in Gokasho Bay, Japan, predicted that planting seaweed could reduce surface phytoplankton near fish farms by up to 30%, and that bottom dissolved oxygen concentrations could be increased by up to 35% via the ingestion of organic wastes by sea cucumbers (Zhang and Kitazawa 2016). While IMTA has a long history in Asia, it has been less readily implemented in other parts of the world (Chan 1993; Hughes and Black 2016). As IMTA is not widely practiced in Saudi Arabia, research would need to be conducted to identify appropriate native species and trophic links that would thrive in Red Sea coastal waters. This, in addition to other management and operational strategies, might be employed as Saudi Arabia moves forward with its aquaculture development goals.

As this industry expands in the coming decades, continued research to understand and model the complex interactions of aquaculture systems in the oligotrophic Red Sea will help operators and regulatory agencies assess the carrying capacity of Saudi Arabia's coastal areas. With Vision 2030, Saudi Arabia has the chance to apply the newest concepts and modern operating procedures to develop a framework for sustainable aquaculture. Marine aquaculture operations in the Red Sea have a high potential to be an integral part of a holistic coastal zone management that considers both multiple stakeholders' needs and the concept of marine stewardship. However, without a careful development plan, an expansion of this industry could have large-scale detrimental impacts on the environment.

4 Tourism in the Kingdom of Saudi Arabia

Prior to 2019, Saudi Arabia was largely inaccessible to international tourists. Historically, visas to enter the country were only issued for employment, business consulting, education, or religious pilgrimage, but citizens of other member states party to the Gulf Cooperation Council (GCC; Kuwait, Qatar, Bahrain, United Arab Emirates, and Oman) could also enter the country. Given these circumstances, tourism in KSA has long been limited to GCC nationals, pilgrims, and expats residing in the Kingdom. This has, to a large extent, stunted the development of the tourism and hospitality sector in KSA. Marine-based tourism in particular has been generally uncommon among the Saudi populace. Most marine tourism activity in KSA's Red Sea has historically been limited to the coastal metropolis of Jeddah and a few other urban centers around the Farassan Banks and Yanbu. However, the ambitious agenda of Vision 2030 seeks to fundamentally transform the country's tourism sector. In September 2019, tourist visas were formally introduced, allowing international visitors a year-long, multiple entry pass to spend up to 90 days in the Kingdom (New York Times 2019). Complementing this announcement has been a concerted effort by the government to rebrand KSA as a welcoming and exciting destination, home to a special culture, fascinating history, and rich natural wonders.

Central to the tourism-related goals of Vision 2030 is the large-scale development of entertainment and hospitality hubs to attract visitors, particularly those interested in luxurious and exclusive destinations. To this end, several giga-projects have been launched throughout the country, such as in Al-'Ula (a UNESCO World Heritage archeological site) in the Medinah Region or in Soudah and Rijal Alma'a in the mountains of the Asir Region (to be launched in 2023 and completed by 2030) (The nationalnews.com 2021).

Three massive giga-projects along the Red Sea coast, already underway, will have lasting impacts to the Kingdom's coastal marine resources. These projects, all situated along the sparsely-populated stretches of the northern coast, are NEOM, AMAALA, and the Red Sea Project (https://www.amaala.com/; https://www.neom.com/en-us; https://www.theredsea.sa/en/project/master-plan). These three projects aim to deliver innovative and hyper-luxurious tourist destinations and economic hubs with environmental protection and responsibility at the core of their missions, promoting minimal environmental footprints and net-zero carbon emissions. Developers aim to leverage the natural beauty of the Red Sea coastline, pristine islands, and the rich diversity of marine life inhabiting azure tropical waters to attract wealthy tourists from around the world. The ambitious environmental agenda of the Red Sea Project goes a step further, with goals to restore and even enhance biodiversity of their jurisdiction through strict and sweeping measures such as large-scale fishery closures and the elimination of livestock grazing (pers. comm.).

While large-scale development along the Red Sea coast represents a unique opportunity for Saudi Arabia, it may pose severe risks to the environment and marine life. Severe shoreline alterations due to infrastructure development at the Saudi coast have already been reported (Alharbi et al. 2017). This includes dredging and construction on shallow coastal structures, which can reduce water quality and water flow along with smothering nearby shallow habitats. Road construction and coastal development can lead to a higher sedimentation rate in the proximate marine ecosystems, affecting seagrass meadows, coral reefs, and mangrove forests (Brodersen et al. 2017; Ellison 1999; Ryan et al. 2008). Many of these shallow coastal habitats provide key nursery habitats for juvenile reef fish, sharks, and dugongs. Emerging sea turtle hatchlings can be affected by the light pollution coming from buildings and street lights along the coast and modifications to nesting beaches, increasing their mortality (Harewood and Horrocks 2008).

Coral reef tourism is a critical, undervalued economic resource, which depends strongly on healthy coral reef ecosystems (Spalding et al. 2017). Tourists are attracted to regions with healthy coral cover, clear warm water, and charismatic megafauna (e.g., whale sharks, manta rays) along with endemic species. Therefore, maintaining healthy reef ecosystems is key to a thriving tourism industry. Taking steps to manage reef fisheries to promote healthy fish populations, reduce marine pollution and debris, and reduce carbon emissions would help to reduce stress on the ecosystem. Many species that are commonly susceptible to overfishing are valued by scuba divers (e.g., large groupers, napoleon wrasse, bumphead parrotfish, sharks) and are generally worth more to the tourism sector than to the fishery (Huveneers et al. 2017; Vianna et al. 2012). Therefore, understanding the economic benefits for ecotourism is vital to install local value to this ecosystem. Approximatly 13% of reef fish and 5.5% corals are endemic to the Red Sea (Bogorodsky and Randall 2019; DiBattista et al. 2016), providing a strong drawcard to those seeking to observe unique species. Citizen science is gaining popularity in vulnerable regions to engage locals and tourists to assist in actively participating in conservation by instilling a sense of ownership and connection with marine life and educating them about the threats to the wildlife that inhabit these vulnerable ecosystems. By promoting cooperation with the government to reduce environmental impact by human activities, countries like Indonesia have shown that the tourism industry may help to achieve a sustainable use of coral reef ecosystems (Huang and Coelho 2017). Such integrated governance to protect coral reefs, while at the same time promoting the local economy, is a system that has been established in many other places worldwide and may be helpful in the Saudi Arabian Red Sea as well (Mumby and Steneck 2008).

The introduction of tourism in KSA means that additional stress will be placed on coastal marine ecosystems and the species that inhabit them. To avoid a significant decline of the value of coral reefs, tourist activities must be regulated, public awareness of environmental issues must be increased, and the political system must be maneuvered for support (Olsson et al. 2008). Taken together, Saudi Arabia has the unique chance to monitor and plan in detail from the very beginning to avoid a potential drawback from the coastal development envisioned. This opportunity can be used to develop coastal ecotourism and establish a solid coral reef protection system, collaborating with local people as well as accounting for global threats, such as climate change. Large-scale coastal development, as planned in Vision 2030, deeply relies on strict regulations over a long-term period and, if not executed well, may threaten tourist attractions along the Saudi Arabian Red Sea coast.

5 Future Projections, Impacts, and Climate-Driven Challenges for the Red Sea Coastal Development in Saudi Arabia

To accomplish ambitious development goals of Vision 2030, the various giga-projects have been developed to accommodate a rising population and new tourism venues, while simultaneously establishing an increasingly sustainable image, away from an oil dependent economy. NEOM, AMAALAA, and the Red Sea Project are some of the examples that will have the most impact on the Saudi Arabian Red Sea.

Fig. 6.3 Coral reefs especially in the Southern Red Sea were strongly affected by the third global bleaching event, in 2015

However, climate change is likely to pose a fundamental challenge for many developmental goals, especially along the Red Sea coastline. Understanding how multiple stressors compound and interact on an already vulnerable system is imperative going forward. Unfortunately, climate change assessments in the Red Sea are scarce. Meanwhile, mass coral bleaching events due to elevated sea surface temperatures have been experienced on a global scale in recent years (Hughes et al. 2017). These events are expected to increase in frequency and severity, especially in regions previously considered low risk. The Red Sea is known as a region that harbors extraordinarily thermotolerant corals compared to other regions of the world (Fine et al. 2013; Hume et al. 2016; Osman et al. 2018) and was for a long time thought to be unaffected by climate change (Pineda et al. 2013), but recent coral bleaching in the basin has challenged this concept (DeCarlo 2020; DeCarlo et al. 2021; Monroe et al. 2018).

In 2015, a devastating bleaching event, declared as the third global bleaching event by the United States National Oceanic and Atmospheric Administration (NOAA), took its toll on the inshore reefs in the central-southern Red Sea (Monroe et al. 2018) (Fig. 6.3). This resulted in a general decrease in coral cover and species richness across all reefs investigated in the central región (Monroe et al. 2018) and further corroborated previously identified trends in reef composition, where branching, fast-growing species were increasingly heavily affected compared with more massive coral species (Baird et al. 2009; Fitt et al. 2001; Loya et al. 2001; Stimson et al. 2002). Using coral skeleton cores to identify periods of thermal stress, DeCarlo (2020) also found evidence for significant bleaching events in the central Red Sea during 1998 and 2010, which had remained unrecorded. In addition, widespread coral bleaching was observed in 2020 (DC personal observation), making it clear that the Red Sea is no longer an exception to the increased frequency of bleaching events observed globally (Hughes et al. 2018).

Due to the urgency and economic ramifications of coral reef decline, it is important to understand the drivers and mechanisms of the heightened thermotolerance and the observed differences in bleaching susceptibility within the

Red Sea. The northern reaches of the Red Sea are thought to harbor corals with an increased thermotolerance compared to the southern reaches (Osman et al. 2018), but these waters are also much cooler than those in the southern Red Sea. Hence, different bleaching susceptibilities are likely influenced by the environmental gradients (temperature, salinity, and nutrients) (DeCarlo et al. 2020; Genevier et al. 2019) (Fig. 6.1) and currents that characterize the Red Sea waters (such as upwellings and eddies). Hypotheses as to why we find increased thermotolerance include distinct genetic thermal filters due to the high temperature in the south that is followed by a northward dispersion of thermally selected coral larvae (Fine et al. 2013), and environmental factors such as salinity itself that influence the thermotolerance directly (Gegner et al. 2017).

Despite the heightened thermotolerance of corals in certain regions of the Red Sea, it is clear that climate change is affecting Red Sea reefs, regardless of their unique evolutionary or environmental circumstances. Climate-induced coral bleaching and death are known to be exacerbated by local stressors such as macroalgal growth or sedimentation (Donovan et al. 2021; Good and Bahr 2021), so future coral bleaching along the Saudi Arabian coastline might be mitigated by local environmental protections. Climate change will interact with multiple local stressors across the región (Ellis et al. 2019) and will certainly undermine the basis of all related industries, e.g., fisheries, tourism, aquaculture, and coastal development. In addition to coral loss, it is expected that tropical storms, heatwaves, and sea level will increase globally, adding pressure on biodiversity and coastal development in the region. Therefore, it is no longer sufficient to understand the impact of specific stressors but rather their combined effect. The Kingdom will need to manage local stressors in order to lessen degradation to its coral reefs. Joining the global challenge of reducing greenhouse gas emissions to tackle the omnipresent effects of climate change is a good step forward, but regulations on issues such as water pollution and overfishing are still needed and might further temper the projected impacts of climate change to Saudi Arabia's reefs and the economic activities to which they are tied.

6 Conclusion

While the Red Sea is a major component of the desert Kingdom's natural resource portfolio, its full utility has yet to be realized. Fishing and commercial coastal development have so far comprised the bulk of economic activity along the coast. The aspirations of Vision 2030, however, are poised to spur economic diversification and herald progress for Saudi Arabia. Nascent but growing industries such as aquaculture and eco-tourism offer great potential in the pursuit of sustainable development.

A sustainable approach to expanding existing industries while pursuing novel ones will be a significant challenge. To date, exploitation of Red Sea resources has gone largely unregulated. Short-minded or nonexistent policies have to a large extent failed to properly manage Red Sea fisheries, mitigate damaging coastal development, or reduce local impacts from aquaculture facilities. Moreover, continued impacts of global climate change will fundamentally test the resiliency of Red Sea ecosystems, namely the coral reefs that underpin them. Hence, the long-term viability of a sustainable marine-based economy will depend on active management to minimize local environmental impacts, mitigate the widespread effects of climate change, and balance the often conflicting needs of multiple industries. Policies and spatial planning, informed through the continued investment in Red Sea science, should jointly pursue a strategic transition from a purely growth-based economy to a regenerative one that supports human well-being without exceeding the carrying capacity of coastal environments.

Coastal development and increased exploitation of Saudi Arabia's Red Sea resources, as planned and underway at several sites along the coast, are inevitable. Yet, doing so in a science-based and sustainability-driven manner will be crucial for the Kingdom to meet its development goals while ensuring the well-being of both people and nature. The success of Vision 2030 will depend in no small part on a new approach to valuing, utilizing, and conserving the country's natural resources in a way that meets the growing demands of a diverse range of stakeholders.

Acknowledgments We are thankful for the contributions by Hagen M. Gegner, Sabrina K. Roth, Florian Roth, and Nils Rädecker, including written sections and figures.

References

Alharbi OA, Phillips MR, Williams AT, Thomas T, Hakami M, Kerbe J, Niang AJ, Hermas E, Al-Ghamdi K (2017) Temporal shoreline change and infrastructure influences along the southern Red Sea coast of Saudi Arabia. Arab J Geosci 10(16):1–21. https://doi.org/36010.1007/s12517-017-3109-7

Almahasheer H, Duarte CM (2020) Perceptions of marine environmental issues by Saudi citizens [original research]. Front Mar Sci 7:600. https://doi.org/10.3389/fmars.2020.00600

Al-Rasheed M (2010) A history of Saudi Arabia. Cambridge University Press, p 317

Atta CJ, Coker DJ, Sinclair-Taylor TH, DiBattista JD, Kattan A, Monroe AA, Berumen ML (2019) Conspicuous and cryptic reef fishes from a unique and economically important region in the northern Red Sea. PLoS One 14(10):e0223365. https://doi.org/e022336510.1371/journal.pone.0223365

Baird AH, Bhagooli R, Ralph PJ, Takahashi S (2009) Coral bleaching: the role of the host. Trends Ecol Evol 24(1):16–20. https://doi.org/10.1016/j.tree.2008.09.005

Baruch Y, Forstenlechner I (2017) Global careers in the Arabian gulf understanding motives for self-initiated expatriation of the highly skilled, globally mobile professionals. Career Dev Int 22(1):3–22. https://doi.org/10.1108/Cdi-12-2015-0164

Becker C, Hughen K, Mincer TJ, Ossolinski J, Weber L, Apprill A (2017) Impact of prawn farming effluent on coral reef water nutrients and microorganisms. Aquac Environ Interact 9:331–346. https://doi.org/10.3354/aei00238

Benetti DD, Benetti GI, Rivera JA, Sardenberg B, O'Hanlon B (2010) Site selection criteria for open ocean aquaculture. Mar Technol Soc J 44(3):22–35. https://doi.org/10.4031/Mtsj.44.3.11

Berumen ML, Hoey AS, Bass WH, Bouwmeester J, Catania D, Cochran JEM, Khalil MT, Miyake S, Mughal MR, Spaet JLY, Saenz-Agudelo P (2013) The status of coral reef ecology research in the Red Sea. Coral Reefs 32(3):737–748. https://doi.org/10.1007/s00338-013-1055-8

Berumen ML, Roberts MB, Sinclair-Taylor TH, DiBattista JD, Saenz-Agudelo P, Isari S, He S, Khalil MT, Hardenstine RS, Tietbohl MD, Priest MA, Kattan A, Coker DJ (2019) Fishes and connectivity of Red Sea coral reefs. Coral Reefs Red Sea 11:157-+. https://doi.org/10.1007/978-3-030-05802-9_8

Bogorodsky SV, Randall JE (2019) Endemic fishes of the Red Sea. In: Oceanographic and biological aspects of the Red Sea. Springer, Cham, pp 239–265. https://doi.org/10.1007/978-3-319-99417-8_14

Brodersen KE, Hammer KJ, Schrameyer V, Floytrup A, Rasheed MA, Ralph PJ, Kuhl M, Pedersen O (2017) Sediment resuspension and deposition on seagrass leaves impedes internal plant aeration and promotes phytotoxic H_2S intrusion. Front Plant Sci 8:657. https://doi.org/10.3389/fpls.2017.00657

Burger J, Gochfeld M, Batang Z, Alikunhi N, Al-Jandali R, Al-Jebreen D, Aziz MAM, Al-Suwailem A (2014) Fish consumption behavior and rates in native and non-native people in Saudi Arabia. Environ Res 133:141–148. https://doi.org/10.1016/j.envres.2014.05.014

Cappelen Å, Choudhury R (2017) The future of the Saudi Arabian economy possible effects on the world oil market. In: Oil in the Gulf: obstacles to democracy and development. Routledge, London, pp 41–62

Cardia, F, Ciattaglia, A, Corner, RA (2017) Guidelines and criteria on technical and environmental aspects of cage aquaculture site selection in the Kingdom of Saudi Arabia

Chaidez V, Dreano D, Agusti S, Duarte CM, Hoteit I (2017) Decadal trends in Red Sea maximum surface temperature. Sci Rep 7(1):1–8

Chan GL (1993) Aquaculture, ecological engineering–lessons from China. Ambio 22(7):491–494

Dauda AB, Ajadi A, Tola-Fabunmi AS, Akinwole AO (2019) Waste production in aquaculture: sources, components and managements in different culture systems. Aquac Fish 4(3):81–88

DeCarlo TM (2020) Treating coral bleaching as weather: a framework to validate and optimize prediction skill. Peerj 8. https://doi.org/10.7717/peerj.9449

DeCarlo TM, Gajdzik L, Ellis J, Coker DJ, Roberts MB, Hammerman NM, Pandolfi JM, Monroe AA, Berumen ML (2020) Nutrient-supplying ocean currents modulate coral bleaching susceptibility. Sci Adv 6(34) https://doi.org/eabc549310.1126/sciadv.abc5493

DeCarlo TM, Carvalho S, Gajdzik L, Hardenstine RS, Tanabe LK, Villalobos R, Berumen ML (2021) Patterns, drivers, and ecological implications of upwelling in coral reef habitats of the southern Red Sea. J Geophys Res Oceans 126(2) https://doi.org/e2020JC01649310.1029/2020JC016493

DesRosiers, N (2011) Growth and maturation of *Plectropomus* spp. in the Saudi Arabian Red Sea

DiBattista JD, Roberts MB, Bouwmeester J, Bowen BW, Coker DJ, Lozano-Cortes DF, Howard Choat J, Gaither MR, Hobbs JPA, Khalil MT, Kochzius M, Myers RF, Paulay G, Robitzch VSN, Saenz-Agudelo P, Salas E, Sinclair-Taylor TH, Toonen RJ, Westneat MW et al (2016) A review of contemporary patterns of endemism for shallow water reef fauna in the Red Sea. J Biogeogr 43(3):423–439. https://doi.org/10.1111/jbi.12649

Donovan MK, Burkepile DE, Kratochwill C, Shlesinger T, Sully S, Oliver TA, Hodgson G, Freiwald J, van Woesik R (2021) Local conditions magnify coral loss after marine heatwaves. Science 372(6545):977-+. https://doi.org/10.1126/science.abd9464

Dunne A, Carvalho S, Moran XAG, Calleja ML, Jones B (2021) Localized effects of offshore aquaculture on water quality in a tropical sea. Mar Pollut Bull 171. https://doi.org/11273210.1016/j.marpolbul.2021.112732

Ekiz E, Oter Z, Stephenson ML (2017) Tourism development in the Kingdom of Saudi Arabia determining the problems and resolving the challenges. In: International Tourism Development and the Gulf Cooperation Council States: challenges and opportunities, pp 124–139

Ellis JI, Jamil T, Anlauf H, Coker DJ, Curdia J, Hewitt J, Jones BH, Krokos G, Kurten B, Hariprasad D, Roth F, Carvalho S, Hoteit I (2019) Multiple stressor effects on coral reef ecosystems. Glob Chang Biol 25(12):4131–4146. https://doi.org/10.1111/gcb.14819

Ellison JC (1999) Impacts of sediment burial on mangroves tidal swamp accretion. Mar Pollut Bull 37(8–12):420–426
Fang JG, Zhang J, Xiao T, Huang DJ, Liu SM (2016) Integrated multi-trophic aquaculture (IMTA) in Sanggou Bay, China introduction. Aquac Environ Interact 8:201–205. https://doi.org/10.3354/aei00179
FAO (2020) FAO. Fisheries and aquaculture software. FishStatJ–software for fishery statistical time series
FAO. (2021). National Aquaculture Sector overview. Kingdom of Saudi Arabia. National Aquaculture Sector overview fact sheets. Text by Odaiby, M. FAO Fisheries and Aquaculture Division [online], Rome (updated)
Fattouh, B, Sen, A (2016) Saudi Arabia's vision 2030, oil policy and the evolution of the energy sector. Oxford Institute for Energy Studies, Oxford Energy Comment, July https://www.oxfordenergyorg/wpcms/wpcontent/uploads/2016/07/Saudi-Arabias-Vision-2030-Oil-Policy-and-the-Evolutionof-the-Energy-Sector.pdf
Fine M, Gildor H, Genin A (2013) A coral reef refuge in the Red Sea. Glob Chang Biol 19(12): 3640–3647
Fitt WK, Brown BE, Warner ME, Dunne RP (2001) Coral bleaching: interpretation of thermal tolerance limits and thermal thresholds in tropical corals. Coral Reefs 20(1):51–65. https://doi.org/10.1007/s003380100146
Forstenlechner I, Rutledge EJ (2011) The GCC's "demographic imbalance": perceptions, realities and policy options. Middle East Policy 18(4):25–43. https://doi.org/10.1111/j.1475-4967.2011.00508.x
Furby KA, Apprill A, Cervino JM, Ossolinski JE, Hughen KA (2014) Incidence of lesions on Fungiidae corals in the eastern Red Sea is related to water temperature and coastal pollution. Mar Environ Res 98:29–38. https://doi.org/10.1016/j.marenvres.2014.04.002
Gegner HM, Ziegler M, Radecker N, Buitrago-Lopez C, Aranda M, Voolstra CR (2017) High salinity conveys thermotolerance in the coral model Aiptasia. Biology Open 6(12):1943–1948. https://doi.org/10.1242/bio.028878
Genevier LGC, Jamil T, Raitsos DE, Krokos G, Hoteit I (2019) Marine heatwaves reveal coral reef zones susceptible to bleaching in the Red Sea. Glob Chang Biol 25(7):2338–2351. https://doi.org/10.1111/gcb.14652
Gentry RR, Lester SE, Kappel CV, White C, Bell TW, Stevens J, Gaines SD (2017) Offshore aquaculture: spatial planning principles for sustainable development. Ecol Evol 7(2):733–743. https://doi.org/10.1002/ece3.2637
Gladstone W (1996) Unique annual aggregation of longnose parrotfish (*Hipposcarus harid*) at Farasan Island (Saudi Arabia, Red Sea). Copeia (2):483–485
Gokul EA, Raitsos DE, Gittings JA, Hoteit I (2020) Developing an atlas of harmful algal blooms in the Red Sea: linkages to local aquaculture. Remote Sens 12(22) https://doi.org/369510.3390/rs12223695
Good AM, Bahr KD (2021) The coral conservation crisis: interacting local and global stressors reduce reef resiliency and create challenges for conservation solutions. Sn Appl Sci 3(3) https://doi.org/31210.1007/s42452-021-04319-8
Harewood A, Horrocks J (2008) Impacts of coastal development on hawksbill hatchling survival and swimming success during the initial offshore migration. Biol Conserv 141(2):394–401. https://doi.org/10.1016/j.biocon.2007.10.017
Hassanien H (2021) Status of commercial fisheries in the Umluj, Red Sea, Saudi Arabia. Fresen Environ Bull 30:494–504
Howarth N, Galeotti M, Lanza A, Dubey K (2017) Economic development and energy consumption in the GCC: an international sectoral analysis. Energy Transit 1(2):1–19
Hozumi A, Hong PY, Kaartvedt S, Rostad A, Jones BH (2018) Water quality, seasonality, and trajectory of an aquaculture-wastewater plume in the Red Sea. Aquac Environ Interact 10:61–77. https://doi.org/10.3354/aei00254

Huang YT, Coelho VR (2017) Sustainability performance assessment focusing on coral reef protection by the tourism industry in the coral triangle region. Tour Manag 59:510–527. https://doi.org/10.1016/j.tourman.2016.09.008

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. https://doi.org/10.3354/aei00174

Hughes TP, Kerry JT, Alvarez-Noriega M, Alvarez-Romero JG, Anderson KD, Baird AH, Babcock RC, Beger M, Bellwood DR, Berkelmans R, Bridge TC, Butler IR, Byrne M, Cantin NE, Comeau S, Connolly SR, Cumming GS, Dalton SJ, Diaz-Pulido G et al (2017) Global warming and recurrent mass bleaching of corals. Nature 543(7645):373-+. https://doi.org/10.1038/nature21707

Hughes TP, Anderson KD, Connolly SR, Heron SF, Kerry JT, Lough JM, Baird AH, Baum JK, Berumen ML, Bridge TC, Claar DC, Eakin CM, Gilmour JP, Graham NAJ, Harrison H, Hobbs JPA, Hoey AS, Hoogenboom M, Lowe RJ et al (2018) Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. Science 359(6371):80-+. https://doi.org/10.1126/science.aan8048

Hume BCC, Voolstra CR, Arif C, D'Angelo C, Burt JA, Eyal G, Loya Y, Wiedenmann J (2016) Ancestral genetic diversity associated with the rapid spread of stress-tolerant coral symbionts in response to Holocene climate change. Proc Natl Acad Sci U S A 113(16):4416–4421. https://doi.org/10.1073/pnas.1601910113

Huveneers C, Meekan MG, Apps K, Ferreira LC, Pannell D, Vianna GMS (2017) The economic value of shark-diving tourism in Australia. Rev Fish Biol Fish 27(3):665–680. https://doi.org/10.1007/s11160-017-9486-x

Hvidt M. (2013) Economic diversification in GCC countries: past record and future trends

Jawad LA (2021) The Arabian seas: biodiversity , environmental challenges and conservation measures. Springer Nature, Cham

Jin D, Kite-Powell H, Hoagland P, Solow A (2012) A bioeconomic analysis of traditional fisheries in the Red Sea. Mar Resour Econ 27(2):137–148. https://doi.org/10.5950/0738-1360-27.2.137

Karcher DB, Roth F, Carvalho S, El-Khaled YC, Tilstra A, Kurten B, Struck U, Jones BH, Wild C (2020) Nitrogen eutrophication particularly promotes turf algae in coral reefs of the Central Red Sea. Peerj 8. https://doi.org/e873710.7717/peerj.8737

Kattan A, Coker DJ, Berumen ML (2017) Reef fish communities in the Central Red Sea show evidence of asymmetrical fishing pressure. Mar Biodivers 47(4):1227–1238. https://doi.org/10.1007/s12526-017-0665-8

Khalil MT, Bouwmeester J, Berumen ML (2017) Spatial variation in coral reef fish and benthic communities in the central Saudi Arabian Red Sea. Peerj 5:e3410. https://doi.org/e341010.7717/peerj.3410

Khan MUH (2016) Saudi Arabia's vision 2030. Defence J 19(11):36

Lackner H (1978) A house built on sand: a political economy of Saudi Arabia. Ithaca Press, England

Loya Y, Sakai K, Yamazato K, Nakano Y, Sambali H, van Woesik R (2001) Coral bleaching: the winners and the losers. Ecol Lett 4(2):122–131. https://doi.org/10.1046/j.1461-0248.2001.00203.x

Loya Y, Lubinevsky H, Rosenfeld M, Kramarsky-Winter E (2004) Nutrient enrichment caused by in situ fish farms at Eilat, Red Sea is detrimental to coral reproduction. Mar Pollut Bull 49(4):344–353. https://doi.org/10.1016/j.marpolbul.2004.06.011

MacNeil MA, Chapman DD, Heupel M, Simpfendorfer CA, Heithaus M, Meekan M, Harvey E, Goetze J, Kiszka J, Bond ME, Currey-Randall LM, Speed CW, Sherman CS, Rees MJ, Udyawer V, Flowers KI, Clementi G, Valentin-Albanese J, Gorham T et al (2020) Global status and conservation potential of reef sharks. Nature 583(7825):801–806. https://doi.org/10.1038/s41586-020-2692-z

MEWA (2021) Investment in aquaculture. https://www.mewa.gov.sa/en/Ministry/Agencies/AgencyforEconomicAffairsandInvestment/topics/Pages/topc232020.aspx

Monroe AA, Ziegler M, Roik A, Rothig T, Hardenstine RS, Emms MA, Jensen T, Voolstra CR, Berumen ML (2018) In situ observations of coral bleaching in the central Saudi Arabian Red Sea during the 2015/2016 global coral bleaching event. PLoS One 13(4) https://doi.org/e019581410.1371/journal.pone.0195814
Moser S, Swain M, Alkhabbaz MH (2015) King Abdullah Economic City: engineering Saudi Arabia's post-oil future. Cities 45:71–80. https://doi.org/10.1016/j.cities.2015.03.001
Mumby PJ, Steneck RS (2008) Coral reef management and conservation in light of rapidly evolving ecological paradigms. Trends Ecol Evol 23(10):555–563. https://doi.org/10.1016/j.tree.2008.06.011
NAQUA (2021) Aquaculture in Saudi Arabia|shrimp farming|fish farming. https://www.naqua.com.sa/en/core-business#fish-business
Naumann MS, Bednarz VN, Ferse SCA, Niggl W, Wild C (2015) Monitoring of coastal coral reefs near Dahab (Gulf of Aqaba, Red Sea) indicates local eutrophication as potential cause for change in benthic communities. Environ Monit Assess 187(2) https://doi.org/4410.1007/s10661-014-4257-9
NEOM (2021) tabuk fish and neom. https://www.neom.com/en-us/newsroom/tabuk-fish-and-neom
Neve P, Al-Aiidy H (1973) The Red Sea fisheries of Saudi Arabia. Marine Research Centre
New York Times (2019) Saudi Arabia invites tourists: what you need to know. https://www.nytimes.com/2019/09/27/travel/saudi-tourist-visa-questions.html
Nogales B, Lanfranconi MP, Pina-Villalonga JM, Bosch R (2011) Anthropogenic perturbations in marine microbial communities. FEMS Microbiol Rev 35(2):275–298. https://doi.org/10.1111/j.1574-6976.2010.00248.x
Oakley S (1984) The effects of spearfishing pressure on grouper (Serranidae) populations in the eastern Red Sea. Proc Symp Coral Reef Environ Red Sea. Jeddah,
Olsson P, Folke C, Hughes TP (2008) Navigating the transition to ecosystem-based management of the great barrier reef, Australia. Proc Natl Acad Sci U S A 105(28):9489–9494. https://doi.org/10.1073/pnas.0706905105
Osman EO, Smith DJ, Ziegler M, Kurten B, Conrad C, El-Haddad KM, Voolstra CR, Suggett DJ (2018) Thermal refugia against coral bleaching throughout the northern Red Sea. Glob Chang Biol 24(2):E474–E484. https://doi.org/10.1111/gcb.13895
Pauly D, Christensen V, Dalsgaard J, Froese R, Torres F (1998) Fishing down marine food webs. Science 279(5352):860–863. https://doi.org/10.1126/science.279.5352.860
Pérez O, Ross L, Telfer T, del Campo Barquin L (2003) Water quality requirements for marine fish cage site selection in Tenerife (Canary Islands): predictive modelling and analysis using GIS. Aquaculture 224(1–4):51–68
Pineda J, Starczak V, Tarrant A, Blythe J, Davis K, Farrar T, Berumen M, da Silva JCB (2013) Two spatial scales in a bleaching event: corals from the mildest and the most extreme thermal environments escape mortality. Limnol Oceanogr 58(5):1531–1545. https://doi.org/10.4319/lo.2013.58.5.1531
Presley JR, Westaway T (2017) A guide to the Saudi Arabian economy. Springer, cham
Price C, Black KD, Hargrave BT, Morris JA (2015) Marine cage culture and the environment: effects on water quality and primary production. Aquac Environ Interact 6(2):151–174. https://doi.org/10.3354/aei00122
Racault MF, Raitsos DE, Berumen ML, Brewin RJW, Platt T, Sathyendranath S, Hoteit I (2015) Phytoplankton phenology indices in coral reef ecosystems: application to ocean-color observations in the Red Sea. Remote Sens Environ 160:222–234. https://doi.org/10.1016/j.rse.2015.01.019
Raitsos DE, Yi X, Platt T, Racault MF, Brewin RJW, Pradhan Y, Papadopoulos VP, Sathyendranath S, Hoteit I (2015) Monsoon oscillations regulate fertility of the Red Sea. Geophys Res Lett 42(3):855–862. https://doi.org/10.1002/2014gl062882
Richards A, Waterbury J (1996) A political economy of the Middle East. Westview Press, Nevada
Roberts MB, Jones GP, McCormick MI, Munday PL, Neale S, Thorrold S, Robitzch VS, Berumen ML (2016) Homogeneity of coral reef communities across 8 degrees of latitude in the Saudi

Arabian Red Sea. Mar Pollut Bull 105(2):558–565. https://doi.org/10.1016/j.marpolbul.2015.11.024
Ryan KE, Walsh JP, Corbett DR, Winter A (2008) A record of recent change in terrestrial sedimentation in a coral-reef environment, La Parguera, Puerto Rico: a response to coastal development? Mar Pollut Bull 56(6):1177–1183. https://doi.org/10.1016/j.marpolbul.2008.02.017
Salama AJ, Satheesh S, Balqadi AA, Kitto MR (2016) Identifying suitable fin fish cage farming sites in the eastern Red Sea coast Saudi Arabia. Thalassas 32(1):1–9. https://doi.org/10.1007/s41208-015-0001-7
Samargandi N, Fidrmuc J, Ghosh S (2014) Financial development and economic growth in an oil-rich economy: the case of Saudi Arabia. Econ Model 43:267–278. https://doi.org/10.1016/j.econmod.2014.07.042
Sawall Y, Al-Sofyani A, Kürten B, Al-Aidaroos A, Hoang Xuan B, Marimuthu N, Khomayis H, Sommer U, Gharbawi W, Wahl M (2014) Coral communities, in contrast to fish communities, maintain a high assembly similarity along the large latitudinal gradient along the Saudi Red Sea coast. J Ecosyst Ecogr 4(003):1–7
Shellem CT, Ellis JI, Coker DJ, Berumen ML (2021) Red Sea fish market assessments indicate high species diversity and potential overexploitation. Fish Res 239. https://doi.org/10.1016/j.fishres.2021.105922
Sofianos SS, Johns WE (2002) An oceanic general circulation model (OGCM) investigation of the Red Sea circulation, 1. Exchange between the Red Sea and the Indian Ocean. J Geophys Res Oceans 107(C11) https://doi.org/319610.1029/2001jc001184
Sofianos SS, Johns WE (2003) An oceanic general circulation model (OGCM) investigation of the Red Sea circulation: 2. Three-dimensional circulation in the Red Sea. J Geophys Res Oceans 108(C3)
Spaet J (2013) Predictable annual aggregation of longnose parrotfish (Hipposcarus harid) in the Red Sea. Mar Biodivers 43(3):179–180. https://doi.org/10.1007/s12526-013-0162-7
Spaet JLY, Berumen ML (2015) Fish market surveys indicate unsustainable elasmobranch fisheries in the Saudi Arabian Red Sea. Fish Res 161:356–364. https://doi.org/10.1016/j.fishres.2014.08.022
Spaet JLY, Nanninga GB, Berumen ML (2016) Ongoing decline of shark populations in the eastern Red Sea. Biol Conserv 201:20–28. https://doi.org/10.1016/j.biocon.2016.06.018
Spalding M, Burke L, Wood SA, Ashpole J, Hutchison J, Ermgassene PZ (2017) Mapping the global value and distribution of coral reef tourism. Mar Policy 82:104–113. https://doi.org/10.1016/j.marpol.2017.05.014
Stern N, Rothman SBS (2021) An alarming mariculture breach in a coral reef: alien barramundi Lates calcarifer (Bloch, 1790) at the northern Red Sea. Bioinvasions Records 10(1):181–187. https://doi.org/10.3391/bir.2021.10.1.19
Stimson J, Sakai K, Sembali H (2002) Interspecific comparison of the symbiotic relationship in corals with high and low rates of bleaching-induced mortality. Coral Reefs 21(4):409–421. https://doi.org/10.1007/s00338-002-0264-3
Sultan ZA, Haque MI (2018) Oil exports and economic growth: an empirical evidence from Saudi Arabia. Int J Energy Econ Policy 8(5):281
Tesfamichael D, Pauly D (2012) Catch reconstruction for the Red Sea large marine ecosystem by countries (1950–2010)
Tesfamichael D, Pauly D (2016) The Red Sea ecosystem and fisheries preface and acknowledgements. Red Sea Ecosyst Fish 7:Vii–Viii. https://doi.org/10.1007/978-94-017-7435-2
The nationalnews.com (2021) Saudi Arabia's Asir region to become tourist hotspot with $13bn investment. https://www.thenationalnews.com/gulf-news/saudi-arabia/2021/09/28/saudi-arabias-asir-region-to-become-tourist-hotspot-with-13bn-investment/. Retrieved 28 Sep 2021
TRSDC (2021) The master plan. https://www.theredsea.sa/en/project/master-plan
Vianna GMS, Meekan MG, Pannell DJ, Marsh SP, Meeuwig JJ (2012) Socio-economic value and community benefits from shark-diving tourism in Palau: a sustainable use of reef shark

populations (vol 145, p 267, 2012). Biol Conserv 156:147–147. https://doi.org/10.1016/j.biocon.2012.11.010

Villanueva RD, Yap HT, Montano MNE (2005) Survivorship of coral juveniles in a fish farm environment. Mar Pollut Bull 51(5–7):580–589. https://doi.org/10.1016/j.marpolbul.2005.04.033

Vincent P (2008) Saudi Arabia: an environmental overview. CRC, Boca Raton, FL

Voolstra CR, Berumen ML (2019) Coral reefs of the Red Sea, vol 11. Springer, Cham

Zhang JB, Kitazawa D (2016) Assessing the bio-mitigation effect of integrated multi-trophic aquaculture on marine environment by a numerical approach. Mar Pollut Bull 110(1): 484–492. https://doi.org/10.1016/j.marpolbul.2016.06.005

Chapter 7
Philippines Case Study One

Balayan Bay Short-Term Fisheries Closure: A Case of a Successful Execution of Inter-agency and Multi-sectoral Partnerships for Integrated Fisheries Management in the Philippines

Regina T. Bacalso, Ian J. Tajonera, Rina M. Rosales, James Kho, Marlito Guidote, Loretta Sollestre, and Nygiel B. Armada

Abstract In 2014 a closed season for the commercial fishery of small pelagics was implemented for the first time in Balayan Bay, Philippines. The fishery closure was identified as a strategic regulation to protect the small pelagics during their peak spawning period, and subsequently, as a measure to promote fisheries sustainability. Within a year immediately following the inaugural closed season, fishers in Balayan Bay reported increases in their catches of not only the small pelagics, but also of the intermediate-sized predatory pelagic fishes. The results of the fish catch monitoring surveys and reproductive biology studies from before and after the closed season appear to corroborate the fishers' observations. They also yielded additional information that prompted specific policy modifications. Hence, the scientific findings were explicitly included in a provincial resolution to extend the seasonal fishery closure for another six years. With the Bureau of Fisheries and Aquatic Resources taking a central role in the succeeding fisheries monitoring and stock assessments, survey results from Balayan Bay and adjacent bays were integrated recently, and they provided the basis for the expansion of the geographic scope of the closed season. This case study shall describe the processes that led to the successful implementation of the Balayan Bay closed season. The roles and critically active participation of multiple sectors and government agencies are highlighted.

R. T. Bacalso (✉) · I. J. Tajonera · J. Kho · M. Guidote · N. B. Armada
Ecosystems Improved for Sustainable Fisheries (ECOFISH) Project, Cebu City, Philippines
e-mail: regina.bacalso@leibniz-zmt.de

R. M. Rosales
Ecosystems Improved for Sustainable Fisheries (ECOFISH) Project, Cebu City, Philippines

Resources, Environment and Economics Center for Studies (REECS), Cebu City, Philippines

L. Sollestre
Provincial Government – Environment and Natural Resources Office (PG-ENRO), Province of Batangas, Batangas, Philippines

M. Wolff et al. (eds.), *Challenges in Tropical Coastal Zone Management*,
https://doi.org/10.1007/978-3-031-17879-5_7

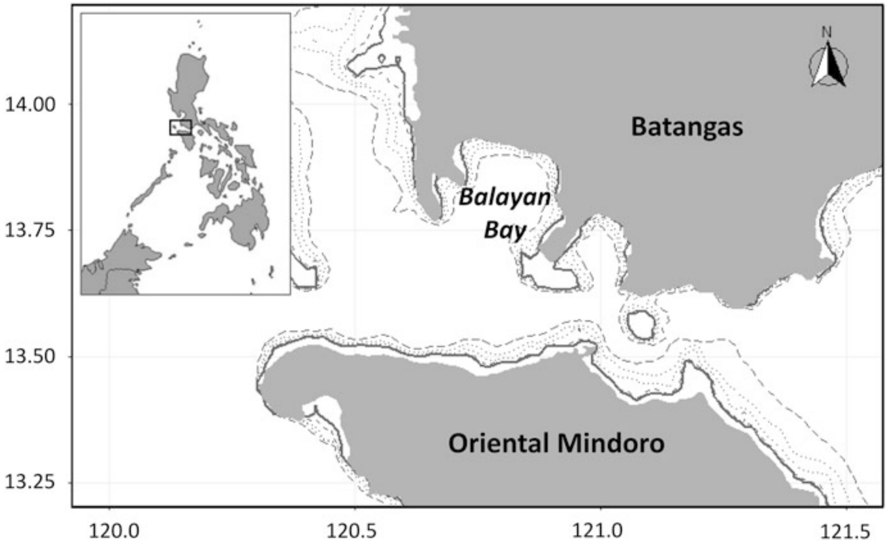


Fig. 7.1 Location of Balayan Bay showing the adjacent waters and the 20- to 200-m isobaths. Bathymetric data were sourced from NOAA's Global Relief Model (Amante and Eakins 2009)

Participatory data collection, effective science communication, participatory rule-making, engaging the local champions, and an innovative application of incentives to promote voluntary compliance are identified as key success factors.

Keywords Artisanal fisheries · Closure · Comanagement · Participation

1 Introduction

The Balayan Bay (Fig. 7.1) is one of 3 major bays comprising the Verde Island Passage (VIP) Marine Key Biodiversity Area that forms part of the Philippines' internal waters. Nine coastal municipalities within the Province of Batangas surround Balayan Bay, with a combined total water area of approximately 1 559 km2. It is located along the south-western edge of mainland Luzon and forms part of what is known as the Southern Tagalog Region (Region IV-A) or the Calabarzon area.

Extensive coral reefs, seagrass beds, and mangrove forests provide a rich habitat that supports both demersal and pelagic fisheries species (ECOFISH 2014b). These include, among others, several species of snappers, jacks, emperor fish, scads, mackerels, and sardines. In a fisheries survey conducted in 2014 by the Ecosystems Improved for Sustainable Fisheries (ECOFISH) Project, small pelagics comprised over 80% of the total recorded catches landed within Balayan Bay (ECOFISH 2014a). About 55% of the landed catch are marketed locally, i.e., within local communities ("*barangays*") and in municipal markets, while some 22% are exported to other nearby urban areas such as the populous centers of Batangas, Cavite, and Metro Manila (ECOFISH 2015).

The capture fisheries sector in Balayan Bay is further classified into commercial and municipal sectors. The commercial sector refers to fishing operations that utilize fishing vessels with 3 gross tons or more. The main gear types are purse seines, ring nets, and bag nets. On the other hand, the municipal sector refers to fishing operations that utilize fishing vessels with less than 3 gross tons and includes the subsistence-level type of fishing activities. The main gear types are simple hook and lines, multiple handlines, surface gillnets, bottom-set gillnets, and jigs. Over 87% of the total fisher population in Balayan Bay belong to the municipal fisheries sector (ECOFISH 2015), which is estimated to contribute about half of the total annual fisheries yield in Balayan Bay (unpublished data).

2 Management Context and Statement of the Problem

The Provincial Government of Batangas applies an Integrated Coastal Management (ICM) framework in the management of its coastal and fisheries resources (Eng 2006; Thia-Eng 2008). The nine local government units (LGUs) of Balayan Bay have also recently adopted the Ecosystems Approach to Fisheries Management (EAFM) (FAO 2003, 2005; Garcia 2003) in order to addresses the trans-boundary nature of the fishery resources and their associated habitats and ecosystems (Province of Batangas 2015). Inherent to both the ICM framework and EAFM is the acknowledgment of the intricate interdependence between the fishery sector's human and environmental dimensions. Governance-wise, both frameworks also recognize the different scales of management from the local communities or villages (called *barangays*), to the municipalities/cities (or LGUs), and the provincial and national government agencies. They both highlight the need for partnerships between the different offices and levels of government (Bermas and Chua 2018) as well as other relevant sectors of civil society.

The Balayan Bay LGUs have a long history of inter-local coordination largely due to numerous marine environmental protection initiatives undertaken by both government and non-governmental organizations. Since the 1990s, they have received assistance from various groups such as the World Wildlife Fund (WWF), Conservation International (CI), Partnerships in Environmental Management for the Seas of East Asia (PEMSEA), and later with the Coral Triangle Initiative (CTI) under the USAID and other UN-supported programs (ADB 2011; DENR-PAWB 2009; Oglethorpe 2009; PEMSEA 2006, 2009; Province of Batangas 2015; Vergara et al. 2008; Weeks et al. 2014; White et al. 2006; WWF-SSME Program 2004). In 2011, the Provincial Government of Batangas developed its Comprehensive Coastal Resources Management Plan. It involved a series of studies to determine the status of the coastal and fisheries resources in the Verde Island Passage and to identify priority areas for management. The issue of declining catches was highlighted, thus prompting the province to set resource conservation and fisheries sustainability as a major priority. To help identify possible management actions, the University of the Philippines in the Visayas Foundation, Inc. (UPVFI) through the non-governmental organization Conservation International conducted further detailed biological and fisheries assessments. Two recommendations that were particularly relevant for Balayan Bay are (1) strategic regulations to protect important stocks and/or critical life stages (e.g., through seasonal fisheries closures) and (2) a comprehensive and regular monitoring of the catches and fishing effort. Incidentally, the Philippines' Bureau of Fisheries and Aquatic Resources of the Department of Agriculture (DA-BFAR) is promoting seasonal fishing closures as one proactive strategy to sustain fish stocks. With its inclusion as a major criterion in the Bureau's national fisheries awards program, seasonal fishing closures or "closed seasons" have become quite popular across the country even in the absence of any objective basis for their establishment.

With the assessment results as initial basis, the Province of Batangas considered establishing a closed season for the small pelagics in Balayan Bay. The small pelagics herein referred to are primarily the scads (*Decapterus* spp., *Selar* spp.), mackerels (*Rastrelliger* spp.), and sardines and herrings (family Clupeidae). They may also include the anchovies (family Engraulidae) and other schooling pelagics such as the bullet and frigate tunas (*Auxis*). Due to the inherent biological productivity of these species, it was anticipated that their protection during close seasons will yield immediate and perceptible results. Thus, a closed season was incorporated in the Inter-LGU Fisheries Resources Management (IFRM) Plan of the 9 Balayan Bay coastal LGUs as a management action to increase particularly the small pelagic stock populations and improve the overall catches of the fishers in the bay (Province of Batangas 2015).

This case study shall describe the processes leading to the implementation of the inaugural closed season in Balayan Bay and highlight the innovations and key ingredients that led to its successful implementation. Some main results from the assessment and subsequent monitoring surveys will also be presented to provide the biological context of the management initiative, show the potential impacts to the fisheries, and to underscore their importance in informing the stakeholders' decision to continue the implementation of the closed season on a regular basis.

3 Promoting Multi-sectoral Participation and Science-Informed Decision-Making

3.1 Reproductive Biology Study

In order to provide an objective basis for the scope and design of the temporal fishing closure, the Ecosystems Improved for Sustainable Fisheries (ECOFISH) Project worked with the Provincial Government of Batangas and Conservation International to conduct a reproductive-biology study in the waters of the Verde Island Passage with a focus on the small pelagic fishes found in Balayan Bay. Literature on the reproductive biology of important small pelagic stocks in other Philippine fishing grounds shows variations in the seasonality of the spawning activity (Aripin and Showers 2000; Armada 2004; Campos et al. 2015; Dalzell et al. 1990; Guanco et al. 2009). These identified peak spawning months are often used as basis for determining the time and duration of temporal fishing closures to significantly reduce the fishing pressure on the spawning stocks.

Ideally, a reproductive biology study is conducted for one year. However, resource limitations prevented the execution of a year-long study in VIP. Thus, the ECOFISH first consulted both the municipal and commercial fishers in the area to glean valuable local knowledge about the seasonality of the different pelagic stocks and the observed appearance of mature and spawning individuals. The fishers reported that small pelagics occur within Balayan Bay and the adjacent waters of the Verde Island Passage all throughout the year. Critically, the fish are most often observed to have mature and gravid gonads from October to December of each year, though they may also be observed outside of these months, albeit less frequently. Based on this information, ECOFISH conducted a reproductive biology study for six months from September 2013 to February 2014 to coincide with the observed peak spawning months of the small pelagics in the area.

Unique to the study was the employment of local members of the community as fisheries enumerators who were trained in fish gonad staging following a standard scale suggested by (Bucholtz et al. 2008). They were also tasked to conduct a fisheries-dependent survey to collect information on the catch and fishing effort of the various fishing gears using a standardized data collection method (ECOFISH 2014a). The fisheries-dependent survey data gathered from both the commercial and municipal fishing activities. It identified the commercial fishing operations, namely the purse seines (*pangulong*), ring nets (*pukotan*) and bag nets (*basnig*) with the highest average catch rates of 156, 154, and 73 kg/vessel/day, respectively, during the survey period. The CPUE of the municipal fishing gears, on the other hand, ranged between 5 and 30 kg/vessel/day. The catch data showed that small pelagics comprised about 90% of the total landings during the survey period, with the species *Decapterus macrosoma* and *Selar crumenophthalmus* comprising nearly half of the total landings.

Based on the reproductive biology survey, mature individuals of *Decapterus macrosoma* were already observed in September 2014. However, their frequency of occurrence along with individuals with gravid gonads was highest during the third quarter of November 2014 until the 1st quarter of December 2014, and again in the third quarter of January 2015 (Fig. 7.2a). For *Selar crumenophthalmus*, mature gonads were also recorded from September 2014 and with the highest frequency of occurrence of gravid gonads during the first quarter of November 2014 and again a few months later in February 2015 (Fig. 7.2b). Results from the other small pelagic species are presented separately in Fig. 7.3, which shows variable peaks in the frequency of occurrence of mature (Stage III) and gravid (Stage IV) gonads.

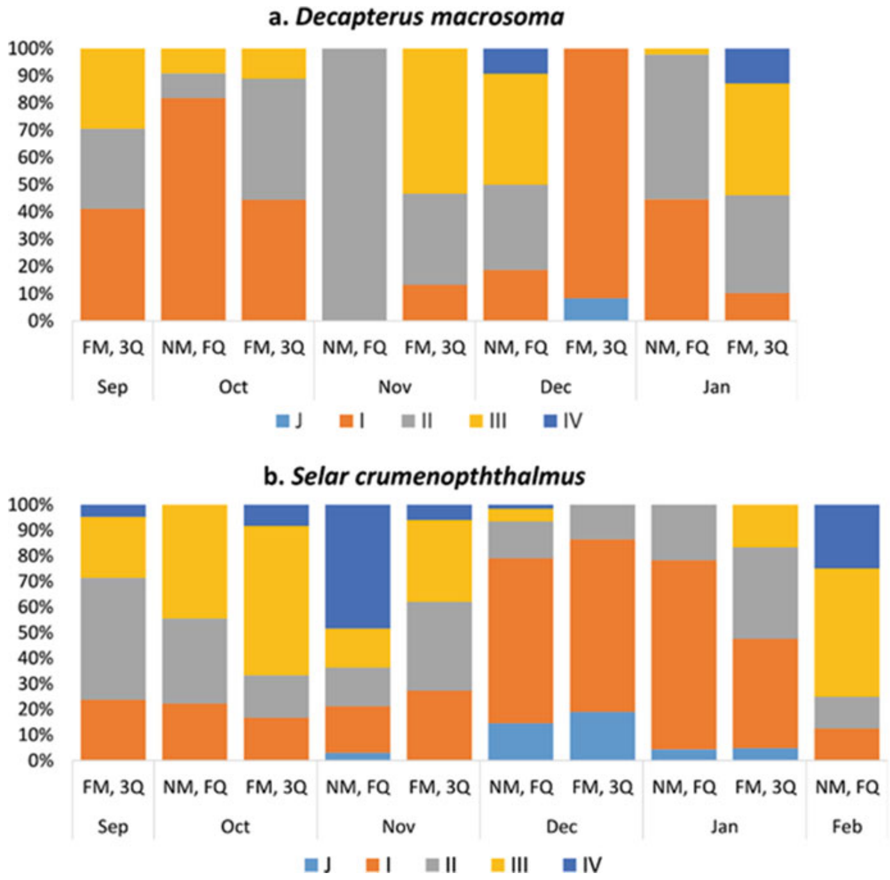


Fig. 7.2 Percentage frequency occurrence of gonad stages I-IV of (**a**) *Decapterus macrosoma* and (**b**) *Selar crumenophthalmus* between September 2013 and February 2014

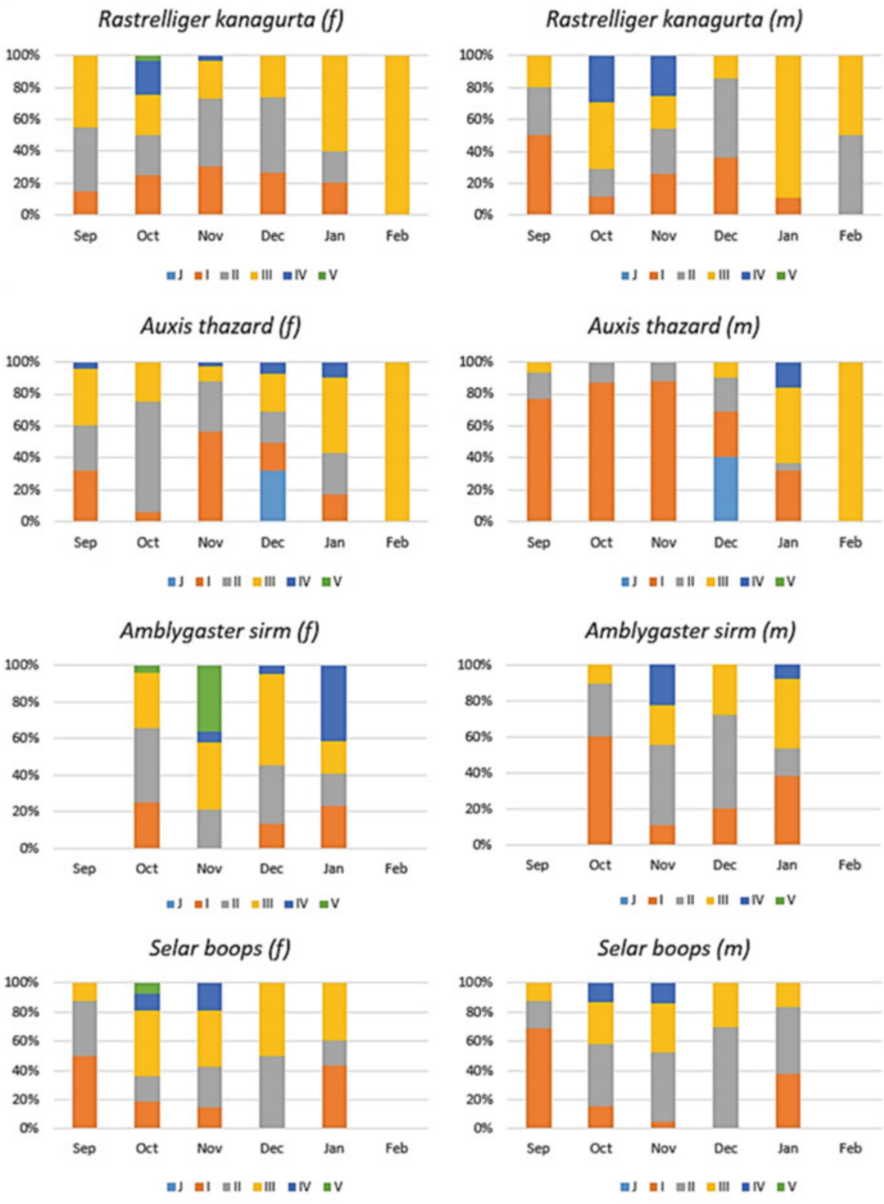
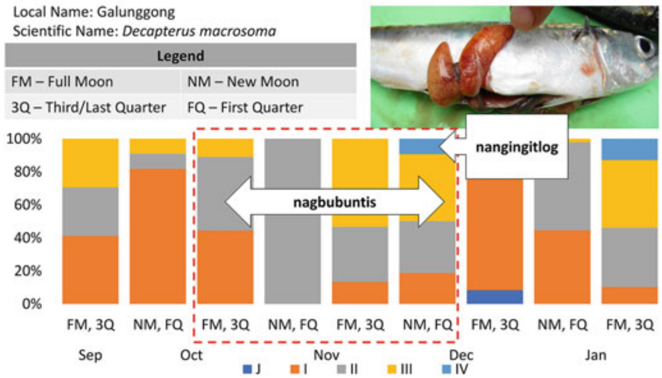


Fig. 7.3 Percentage frequency occurrence of gonad stages I-IV of selected small pelagic species segregated by sex (m, f) between September 2013 and February 2014

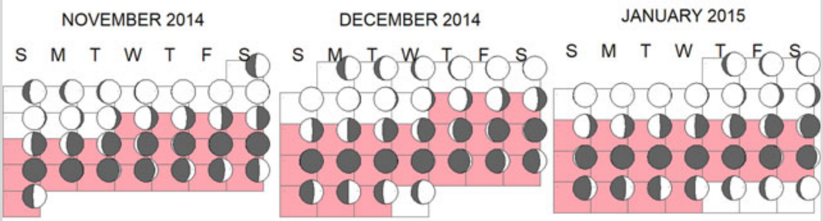
Box 7.1 Communicating the Assessment Results to the Balayan Bay Stakeholders

After the initial assessments, ECOFISH presented the results as well as recommendations to the TWG, which is composed mostly of the Municipal Agriculturists of the 11 LGUs surrounding Balayan Bay and representatives of various sectors including the municipal and commercial fishers, local NGOs and private sector representatives. The TWG members in turn led the presentation of results to the local government official using visual aids and information materials that were designed to convey the results of the scientific studies in a more readily understandable manner. Local terms were also used whenever possible. Some examples are shown below.

Example 1. Graph showing the seasonal appearance by maturity stage of Galunggong (*Decapterus macrosoma*) in the catch of fishing gears in Balayan Bay. "nagbubuntis" or gravid, "nangingitlog" or spawning.



Example 2. Visualized moon phase calendar indicating the recommended closure periods based on the detected seasonal appearance of gravid and spawning small pelagics in Balayan Bay.



- *Ideal closure periods are Last Quarter, New Moon and First Quarter of December with the options to include LQ, NM and FQ of November and January*
- *Affected operations : Ring net (pukutan) and Purse seine (pangulong)*

Thereafter, the TWG members and local government officials led the consultations with the resource users, specifically, the municipal and commercial fishers. This strategy was thought of to empower the TWG and local

(continued)

Box 7.1 (continued)
officials in advocating the use of scientific information to address threats to fisheries livelihoods and to strengthen the institutional arrangements that can facilitate stakeholder involvement in all processes of fisheries management.

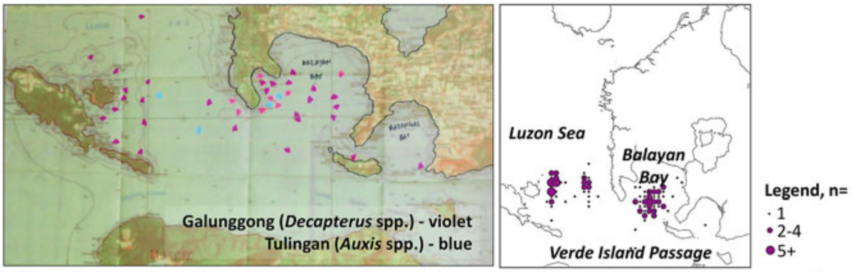
3.2 Communicating the Science

The Provincial Government of Batangas formed a technical working group (TWG) composed of scientists and stakeholder group representatives. It became the platform for discussion and sharing information regarding the proposed closed season. The TWG also functioned as the first-level decision-making body, tasked with developing the policy and regulations to be recommended to the nine Balayan Bay LGUs. Through regular meetings, the TWG developed goodwill and trust among the members, which was crucial for candid discussions on what the scientific studies meant and the implications of proposed regulatory measures. It was in coordination with the TWG that ECOFISH presented the results of the reproductive biology study and the fisheries survey to the different fisheries stakeholder groups in Balayan Bay through a series of consultation meetings in early 2014 (Box 7.1).

During the consultations, it was important to convey the message that the observed declines in fish catches may only worsen if the current level of high fishing effort is maintained, citing real examples of fisheries declines in other Philippine fishing grounds (Stobutzki et al. 2006). It was also crucial to apply various ways of communicating the results to different types and levels of stakeholders, i.e., from the small-scale fishers to the owners of commercial fishing operations, to the policy-makers, local chief executives and the provincial government. We found that information in simplified graphs can be readily conveyed. We also found that the information about the biology of the small pelagics and the results of the studies can be effectively communicated via sequential narration accompanied by pictographs and diagrams, and most importantly by relating them to their very own observations (Fig. 7.4). Equating the complex science and proposed regulations with simple concepts that are culturally relatable proved highly effective. The term "closed season" was, for example, equated to the word "*pagpapahinga*," which refers to the act of resting and rejuvenation. The concept of a closed season for fishing was then more readily appreciated as a period of rest and rejuvenation not necessarily for the fishers alone, but more critically, for the biological resources that are being exploited almost on a daily basis and all throughout the year.

Having on board well-respected fisheries scientists[1] who are seen as credible and effective communicators was also crucial in order to confer legitimacy to the information relayed. However, relying on scientific information alone is not

[1]One such example was Dr. Wilfredo Campos who heads the OceanBio Laboratory at the University of the Philippines in the Visayas, Miag-ao Campus. Their earlier researches provided



(a) Sample output from the participatory mapping workshop with commercial fishers in Batangas City, June 11, 2014. The fishers marked their fishing areas for small pelagics in Balayan Bay and adjacent areas.

(b) Map showing the locations where galunggong (*Decapterus* spp.) at reproductive stages III and IV were caught during the fish catch monitoring and reproductive biology surveys from Sept 2015 to May 2016.

Fig. 7.4 Comparing information from a resource use map produced by the commercial fishers and results of the follow-up fish catch monitoring and reproductive biology study of small pelagics in Balayan Bay and adjacent waters

sufficient for management decision-making. Experience has shown that data from years of scientific studies do not necessarily translate into actionable policies and management regulations. The stakeholders, therefore, also needed to understand and consider the socio-economic impacts of management decisions, so that they could weigh the costs and benefits. For example, if it were up to science alone, the Balayan Bay could have been justifiably closed to fishing for a period of at least three months between September and February to protect more spawning aggregates of the different small pelagic species. Upon consideration of the socio-economic impacts that this might entail, the stakeholders ultimately proposed to limit the scope (i.e., duration, species, and gear types) of the closed season in order to minimize the short-term adverse impact on livelihoods, while still substantially achieving the long-term goal of stock recovery and sustaining fisheries catches.

While the Governor did not personally engage in the details of the process, it is important to note that the popularity and goodwill of the Governor's office is what allowed the provincial government staff to convince the LGUs and the different fisheries stakeholders to engage in open dialogue and to trust the scientific findings. It was also critical to identify and engage with champions from the Provincial Government's Environment and Natural Resources Office (PG-ENRO) who have worked as public servants for decades and were viewed by the stakeholders and LGUs as trusted, dedicated and reliable figures who embody the continued sincerity of the province to support resource management initiatives in Balayan Bay. After the series of consultation meetings, and with the consideration of both the biological and socio-economic implications of a closed season, the stakeholders decided to implement for the first time a closed season in Balayan Bay that prohibits fishing by use of

the scientific basis for the proposed management options in the Verde Island Passage. These subsequently led to more specific studies to narrow down the scope of the proposed closed season.

purse seines, ring nets and bag nets for one month (December 1 to 31, in 2014). This closed season was also dubbed the "*Pagpapahinga ng Look Balayan*."

3.3 Translating the Science into Policy

The key processes leading to the adoption of the closed fishing season in Balayan Bay first involved communicating the research results in a straightforward manner to the different stakeholder groups as described in the preceding section. Second, designing the closed season was done in a consultative and highly participatory manner. The TWG and the different stakeholder group representatives jointly identified the target species, the specific gear types involved, and the duration of the closure, while the fisheries scientists provided the objective bases for the policy. The fisheries surveys and biological assessments likewise provided critical information that supported the evaluation of the feasibility of compliance and enforcement. It helped narrow down the scope of the closure and streamline the planned enforcement activities. With only a targeted group of commercial fishing operations to monitor, resources for enforcement can be optimized. The narrowed scope of the closure also made the regulation easier to draft and have approved, because the rules were easily understood. While each LGU legislated its own closed season ordinance, the rules were uniform, simple, and complementary for the entire Bay. This ensured that the affected fishers will not have an incentive to fish within the waters of a "friendly" LGU that may have more lenient rules and impose lighter penalties than their homeport. Crucially, the policy was informed not only by the biological characteristics of the stock, but also of the socio-economic characteristics of the resource users. The results of an income survey helped design a cash-for-work program that was incorporated into the policy as an incentive to promote voluntary compliance. The survey of 1,530 crew members revealed an average monthly income of Php 3,000, with a low of PHP 500 (8 respondents) and a high of PhP 20,000 (2 respondents). A third of the respondents indicated additional sources of income aside from fishing, such as farming, carpentry, and other types of manual labor. Educational attainment was low: 40% were able to finish elementary education, while another 43% were high school graduates. With these statistics, affected crew members were able to qualify for the cash-for-work program as most of them were receiving incomes below the computed daily regional wage of the Region to which Balayan Bay belonged.

4 Implementing the Closed Season

4.1 Cash-for-Work Program

The Sustainable Livelihood Program (SLP) was the flagship program of the country's Department of Social Welfare and Development (DSWD) from 2010 to 2016. One of its components was the Cash for Building Livelihood Assets (CBLA) Program, which is described as *"a strategy in developing physical and natural assets to increase livelihood gains which is implemented through short-term community mobilization activities that provides an allowance that is equivalent to 75% of the prevailing daily regional wage. Also included is the establishment or rehabilitation of common service facilities within the community to increase production as well as the viability of the program participants' enterprise. CBLA also serves as a skills training activity for the participants which could increase their employability given their work experience*." [2]

The inclusion of CBLA in the Balayan Bay seasonal closure took off from the way the program was originally defined, although in this application the fish stocks were treated as livelihood natural assets, and the seasonal closure was a way of developing and improving the assets to increase livelihood gains, i.e., through improved fisheries. The short-term community mobilization activities consisted of jobs that helped the LGUs implement their coastal resources management (CRM) mandates. The final list of tasks was determined through a series of dialogues with both LGU representatives and fishing crew representatives, for each of the municipalities involved (Table 7.1). Some of the dialogues were conducted on a per LGU basis, while others were organized by the Provincial Government of Batangas. One noticeable feature though was the natural tendency of LGU officials to identify tasks that were related to coastal resources management, even if this was not made a requirement for the program. This may be due to the long history of CRM programs in the area, as noted in the introduction.

As part of the closed season implementation, the CBLA program was launched in all Balayan Bay LGUs. The beneficiaries had to physically register prior to the start of the closure and were organized into work groups to perform tasks that were suited to their skills and/or preferences. The daily time records were then used as verification for making cash payments scheduled in the middle and at the end of the closure. Two payment tranches were made during the closure proper. The first tranche representing the first 11 days was scheduled on December 21 and 22, a few days before Christmas. This meant a lot to the fisherfolk, as they were assured of their Christmas eve meals, a very important event for family gatherings in the Philippines. Payments were handed out individually to each crew member on the list by a representative of the DSWD, with the LGU's Municipal Agricultural Officer and ECOFISH staff witnessing the payment. The second tranche was done a few days after the end of the closed season.

[2]DSWD. June 2014. SLP Concept Note: DSWD-USAID Partnership.

Table 7.1 Tasks Identified for CBLA Program Beneficiaries During the Balayan Bay Seasonal Closure, December 2014

Municipality	Potential Work
Bauan	Coastal cleanup Cleaning of drainage canals in Poblacion Construction of MRF in coastal barangays IEC signages for recycling program Organic fertilizer production
Lemery	Coastal cleanup Cleanup of mangrove areas Removal of dilapidated structures along Maguinan coastline (former fish port) De-clogging of Pansipit River Salt production (if this can be set up by December)
Calaca	Coastal cleanup
Balayan	Coastal cleanup Mangrove tree planting Cleanup of sanctuary MRF construction Planting of bamboos (tie-up with NGP) IEC materials Construction, repair of mangrove boardwalk
Calatagan	MPA guardhouse Cleanup of creek Zoning for seaweed farms Construction needs of LGU Eco-police Participate in new social enterprises, e.g., tomato processing Repair of bridges Raft making for mangrove ecotours

The biggest challenge faced at the onset was the initial lack of trust on many levels. As this was the first ever implementation of a closed season in Balayan Bay, there was the issue of fishing crew members doubting whether actual remuneration would be received once they stopped fishing. There was also the lack of trust on the part of commercial fishing vessel owners, on whether the LGU would indeed take care of the daily sustenance of their crew members. There was some doubt from the part of the DSWD that LGUs can vouch for their constituents' participation in the local CBLA schemes. Finally, some LGUs expressed skepticism on the sincerity of DSWD to provide cash payments to all their constituents affected by the closure. Because of all these doubts, the first round of the closure was only able to get around 50% of fishing crew members to participate in the CBLA component. The identification of displaced fishing crew members proved to be difficult at the onset because of the sheer number (ca. 3 285 crew members), but this was eventually overcome with the full participation of the *barangay* LGUs and the commercial fishing operators themselves. When the barangay captains and vessel owners got on board, the survey was carried out, paving the way to completing the roster of willing participants to the program.

The CBLA program appeared to be the tipping point for some of the mayors, as well as for many of the displaced fishing crew members. Once the provision of alternative jobs was assured, the mayors readily signed the ordinance and provided full support for the various components of the closure scheme. Moreover, the types of jobs provided were in support of coastal resources management, further ensuring the improved state of Balayan Bay's coastal resources.

4.2 Effective Enforcement Through Inter-agency and Inter-local Government Cooperation

An inter-local enforcement operation planning was convened on the auspices of the Provincial Government and the Provincial Police to outline the strategies to uniformly enforce the closed season across Balayan Bay. The authors of the closed season ordinances, municipal agriculturists or fishery technicians of each LGU, the chief of police and chief investigators, the heads of recognized *Bantay Dagat* (fish wardens) groups, and representatives from the local station of the Philippine Coast Guard and the Bureau of Fisheries and Aquatic Resources were all present during the 3-day operation planning. As part of the operation planning, the participants conducted a simplified mapping exercise to identify where commercial fishing vessels operated on a regular basis (see Fig. 7.4). This basic information served as lead information where potential violations of the closed season may occur. In the same exercise, each municipality and enforcement agency identified their enforcement assets (e.g., patrol boats, global positioning systems, search lights, communication system) for inventory and pooling of resources. The enforcers also received an orientation on the scientific grounds for the closed season.

The closed season coincided with the Christmas season. This would have made voluntary compliance by the fishers extremely difficult without the cash-for-work program. The challenge also holds true for the enforcers. Each municipality established a local response team who were tasked to enforce the closed season at the LGU-level. The response team members were largely male and heads of family. Some of the Chiefs of Police (COPs) who come from municipalities outside of the Balayan were expectedly on home break for the Christmas holiday and therefore, in-resident non-commissioned police officers took the helm at varying times during the closed season. While on a "holiday mood," people are traditionally more tolerant and forgiving, including the enforcers who allegedly let minor violations pass during this time.

Incredibly, all official reports of the Philippine National Police during the closed season produced good compliance to the closed season. Except for some attempts by commercial operators from nearby provinces who were forewarned via radio, there were no known violations. One month after the closed season, the PGENRO and the Batangas Provincial Police Office conducted a post-operation conference where all Chiefs of Police were made to report. All COPs reported full compliance. This was corroborated by their counterpart from the local government units and civil society organizations.

During the closed season, BFAR deployed its Monitoring, Control and Surveillance (MCS) boat, a 30-meter long patrol vessel to support the enforcement activities. The MCS boat was anchored in the vicinity of Lemery, Batangas—the municipality with the highest number of home-ported commercial fishing boats. The mere physical presence of the MCS boat proved to be an effective deterrent for potential violators. The local response teams were also required to take part in an intensive information drive prior to the launch of the closure. They talked with village chiefs to explain the ordinance, the enforcement operation, and how the community can participate by reporting the violations. Altogether, the combination of voluntary compliance promoted by economic incentives, participatory governance across all levels, and social capital build-up led to the highly successful implementation of the closed season in Balayan Bay.

5 Monitoring of (Implementation and) Impacts and Feedbacking

In the months immediately following the inaugural closed season in Balayan Bay, the Provincial Government of Batangas along with the members of the TWG gathered the representatives of the coastal LGUs, enforcement agencies, commercial fishers, local enforcers, fisherfolk communities and partner NGOs in a feedbacking session. The most common observation shared by the participants was an increased abundance of small pelagic fishes in the catch and their availability in the market after the closed season. Further, some participants also reported increased catches of intermediate pelagics (e.g., Spanish mackerel, skipjacks tunas). They added, however, that the small pelagics that were caught were still small in size. They further expressed concern that these may be the young recruits from the spawning event in the months prior. This prompted several participants to suggest a longer closed season in order to also protect the juvenile fish from fisheries exploitation. They, likewise, called for continued monitoring of catches and additional assessments, particularly on the catches of "*dulong*," which is a local name generically applied to small goby-like fishes that are typically caught with fine mesh netting in the nearshore; however, they may also include the juveniles of many other fish species including the small pelagics.

Thus, another reproductive biology study and fisheries surveys were conducted to document any potential changes in the stocks and fish catches that may be attributed to the implementation of the closed season. This time the surveys were conducted from September 2015 to May 2016 in an attempt to also document the reported minor spawning events outside of the identified peak spawning months. The same standard data collection and assessment methods were applied with some changes and/or additions in monitoring stations, as informed by the previous survey results.

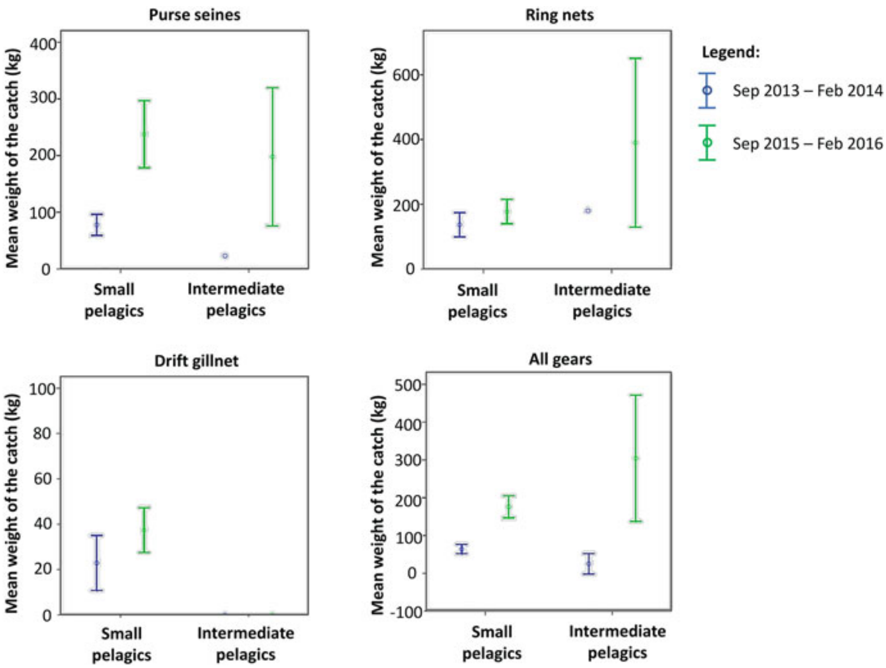


Fig. 7.5 Mean weights of small and intermediate pelagics in the landings of major gear types targeting small pelagics in Balayan Bay between 2 survey periods

For consistency, however, only information that was collected between the months of September and February of each survey year were used for the statistical comparisons[3]. While relative increases were observed in the average catch rates of the major gear types targeting small pelagics, only the increment by the purse seine CPUEs was statistically significant. However, the mean weights of both small and intermediate pelagics in the total landings increased significantly (Fig. 7.5), thereby corroborating the fishers' observations. Disaggregated by fishing gear type, the increments of small pelagic catches by purse seines and drift gillnets were also statistically significant. The reproductive biology survey results for *Decapterus macrosoma* also showed an increase in the frequency of occurrence of mature (Stage III) and gravid (Stage IV) individuals between the 2 survey periods. Some individuals with spent gonads (Stage V) were also observed in March and April 2016, thereby confirming the reported minor spawning events at this time of the year.

These findings were presented to the members of the TWG and other stakeholder representatives in October of 2016. There was then a general acknowledgment of the success of the closed season and an expressed willingness to institutionalize it as an

[3]Non-parametric comparison of means, Mann-Whitney U Test (Sig = 0.000).

annual fisheries management initiative in Balayan Bay. Moreover, news of increased catches in Balayan Bay quickly spread and encouraged even the neighboring province of Oriental Mindoro to replicate the Batangas closed season (Malampaya Foundation 2017).

6 Succeeding Implementation of the Closed Season

Buoyed by the success of the inaugural closed season in Balayan Bay, the province of Batangas along with several coastal LGUs championed its implementation for a second year. Unfortunately, there was no more financial support from the national government to fund the CBLA or cash-for-work program. While this discouraged a couple of LGUs from participating, two additional Batangas LGUs nonetheless participated. With no DSWD funds involved, the participating LGUs committed to fund the economic incentives themselves. Promisingly, these and other details pertaining to the continued coordination between agencies were incorporated in the LGUs' modified ordinances. Even more remarkable was the explicit inclusion of the scientific findings in the Provincial Resolution[4] to support the extension of the annual implementation of the closed season for a period of 6 years (2015–2020). In addition to the purse seines, ring nets and bag nets, other fine mesh nets were included in the list of regulated gears. The harvesting of "*dulong*" has likewise been banned. The Bureau of Fisheries and Aquatic Resources (DA-BFAR) now plays a central role in the fisheries monitoring and assessments not only in Balayan Bay, but also in adjacent bays. Supported by the recent BFAR findings[5], the spatial coverage of the closed season eventually included these adjacent bays. While the full compliance reported in the first year of implementation has not been replicated, the Province of Batangas and the fisheries stakeholders continue to practice and reap consistent gains from multi-sectoral participation and science-informed decision-making in managing their fisheries resources.

---

[4]Provincial Resolution No. 377, 2015 Resolution Supporting the Six-Year (2015–2020) Extension of Pagpapahinga ng mga Look ng Balayan, Talim at Nasugbu, Implementing a Closed Season for Purse Seine (pangulong, paipot), Ring Net (pukutan, pukot), and Bag Net (basing) Operations in Balayan, Talim, and Nasugbu Bays.

[5]'*Preliminary result of the stock assessment in Calatagan, Balayan and Nasugbu Bays*' a presentation by the DA-BFAR Region IV-A during the consultation meetings and feedbacking sessions (unpublished).

7 Summary

This case study highlighted the following main innovations in implementing the inaugural closed season of the Balayan Bay and the succeeding closed seasons in the Province of Batangas:

Fully participatory data gathering to inform decision-making. The local knowledge of resource users filled in the initial data gaps and informed the design of the baseline data collection. Local members of the community were also trained and employed in the baseline data gathering and in subsequent monitoring activities. The biological and socio-economic survey results both informed the decision-making by the TWG, which is composed of various stakeholder group representatives.

Non-traditional application of a CBLA program wherein fish stocks were treated as livelihood natural assets and the seasonal closure was a way of developing and improving the assets to increase livelihood gains. As a clear demonstration of their acknowledgment of the value of these assets, the participating LGUs are now appropriating local funds to support the economic incentives themselves. Further, the closed season likewise demonstrated that fishers can perform other jobs, albeit for a short period of time.

Uniform ordinances enabled a bay-wide enforcement of the close season and eliminated the possibility for potential violators to take advantage of "friendly" waters that may have more lenient rules and lighter penalties.

Broad participation in rule-making led to increased voluntary compliance and local vigilance. The commercial fishers complied with the rules that they themselves helped define and the municipal fishers with their local fish wardens were alert in monitoring their municipal waters for potential violators. This similarly reflects a key lesson of several other CRM cases in the Philippines and elsewhere that highlight stakeholder participation as one of the crucial factors in successful coastal and fisheries management (Anda and Dalabajan 2009; Beger et al. 2004; Christie et al. 2005; Karr et al. 2017; Pomeroy 1995; Quimby and Levine 2018; White et al. 2005; White and Courtney 2004).

This case study also described how the different actors each provided a piece of the management puzzle that led to the successful implementation of the closed season. The NGOs, fisheries scientists and the local community worked together to establish and communicate relatable science that became the basis for the closed season policy and regulations. The LGUs and the Provincial Government of Batangas acted as champions in good governance. Regular consultations with the stakeholder groups and feedbacking of the assessments and survey results conveyed the government's sincerity and transparency, thereby earning them the trust of their constituents and subsequently, their compliance to the closed season. The DSWD representing the national government provided the pivotal economic incentive that gained the full support of all Balayan Bay mayors and the owners of the commercial fishing operations during the inaugural closed season. The inter-agency and multi-sectoral nature of the enforcement teams allowed for the efficient use of resources and manpower to conduct a comprehensive enforcement of the closed season across the entire bay.

The assessments likewise showed potential evidence of the closed season's success in improving the small pelagic stocks, specifically *Decapterus macrosoma*. Increases in the average catch rates of the major fishing operations targeting small pelagics and the recorded significant increases in the average weight of small pelagics in the catch are also indicative of stock improvements within a short period of time. In a fishing ground where majority of the users are small-scale and subsistence-level fishers, it is crucial to be able to demonstrate positive results within the short term to ensure continued support of the management initiative for the long term.

The recorded increase of intermediate pelagic species in the catch may further be an indicator of improved ecological productivity (i.e., increased food availability for larger consumers) in Balayan Bay. It is thus important to further quantify these potential biological and ecological impacts through regular and more comprehensive fisheries monitoring and assessments. Furthermore, the potential economic impacts of the closed season should likewise be quantified *sensu* (Rola et al. 2018) and traced through the value chain in order to identify its full impacts (+/-) across a broader range of resource users and ultimately, the consumers. Apart from the cash-for-work program, it would also be important to identify the other factors that promoted voluntary compliance in order to help fine-tune the subsequent implementation of the closed season in Balayan Bay, should the Province of Batangas resolve to extend its implementation anew after the original extension of six years has passed.

References

ADB (2011) Comprehensive action plans of the Sulu-Sulawesi marine ecoregion: A priority seascape of the coral triangle initiative. Asian Development Bank. https://books.google.de/books?id=3PrwCwAAQBAJ

Amante C, Eakins BW (2009) ETOPO1 arc-minute global relief model: Procedures, data sources and analysis. NOAA Technical Memorandum NESDIS NGDC-24, Boulder, Colorado, USA. https://www.ngdc.noaa.gov/mgg/global/relief/ETOPO1/docs/ETOPO1.pdf.

Anda RD, Dalabajan DA (2009) Against the tide: Enforcement and governance in the Sulu Sulawesi seas. Environmental Legal Assistance Center (ELAC)

Aripin I, Showers P (2000) Population parameters of small pelagic fishes caught off Tawi-Tawi, Philippines.

Armada NB (2004) Assessment and management of small pelagic fisheries in the Visayan Sea. Unpublished Research Report, UP in the Visayas.

Beger M, Harborne AR, Dacles TP, Solandt J-L, Ledesma GL (2004) A framework of lessons learned from community-based marine reserves and its effectiveness in guiding a new coastal management initiative in the Philippines. Environmental Management 34(6):786–801. https://doi.org/10.1007/s00267-004-0149-z

Bermas N, Chua TE (2018) Roles of the key elements of governance in integrated coastal management practice. In: Chua TE, Chou LM, Jacinto G, Ross SA, Bonga D (eds) Local contributions to global sustainable development Agenda. Case studies in integrated coastal management in the East Asian region. Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) and Coastal Management Center (CMC), Quezon City, Philippines

Bucholtz R, Tomkiewicz J, Dalskov J (2008) Manual to determine gonadal maturity of herring (Clupea harengus L.). DTU Aqua-report 197-08. National Institute of Aquatic Resources, Charlottenlund

Campos WL, Acabado CS, Metillo EB, Naguit MRA, Bagarinao AA, Almaquer CJ, Felix LR, Piloton DR (2015) Estimating early life stage mortality and sources of recruits. Project 3 of development of robust tools for managing sardine fisheries in the Philippines: Zamboanga Upwelling-Bohol Sea System (SarDyn). Terminal report. PCAARRD-DOST. 86 p

Christie P, Lowry K, White AT, Oracion EG, Sievanen L, Pomeroy RS, Pollnac RB, Patlis JM, Eisma R-LV (2005) Key findings from a multidisciplinary examination of integrated coastal management process sustainability. Ocean & Coastal Management 48(3):468–483. https://doi.org/10.1016/j.ocecoaman.2005.04.006

Dalzell P, Corpuz P, Arce F, Ganaden R (1990) Philippine small pelagic fisheries and their management. Aquaculture Research 21(1):77–94

DENR-PAWB (2009) The verde framework. The verde island passage marine corridor management plan framework. Department of Environment and Natural Resources Protected Areas and Wildlife Bureau

ECOFISH (2014a) Baseline assessment report. ECOFISH Document No. 05/2014. ECOFISH

ECOFISH (2014b) Coastal and fisheries profile: Verde Island Passage, Batangas, Philippines. ECOFISH

ECOFISH (2015) Socio-economic monitoring results: Verde Island Passage. ECOFISH

Eng CT (2006) The dynamics of integrated coastal management: Practical applications in the sustainable coastal development in East Asia.

FAO (2003) The ecosystem approach to fisheries. FAO Technical Guidelines for Responsible Fisheries. No. 4, Suppl. 2. FAO Fisheries Department, Rome, Italy

FAO (2005) Putting into practice the ecosystem approach to fisheries. FAO

Garcia SM (2003) The ecosystem approach to fisheries: Issues, terminology, principles, institutional foundations, implementation and outlook. Food and Agriculture Organization of the United Nations

Guanco M, Mesa SV, Belga PB, Nunal DRM (2009) Assessment of the commercial fisheries of Western and Central Visayan Sea. BFAR NFRDI technical paper series 12(1):1–44

Karr KA, Fujita R, Carcamo R, Epstein L, Foley JR, Fraire-Cervantes JA, Gongora M, Gonzalez-Cuellar OT, Granados-Dieseldorff P, Guirjen J, Weaver AH, Licón-González H, Litsinger E, Maaz J, Mancao R, Miller V, Ortiz-Rodriguez R, Plomozo-Lugo T, Rodriguez-Harker LF et al (2017) Integrating science-based co-management, partnerships, participatory processes and stewardship incentives to improve the performance of small-scale fisheries [Perspective]. Frontiers in Marine Science 4:345. https://doi.org/10.3389/fmars.2017.00345

Malampaya Foundation (2017) Oriental Mindoro-MFI partnership poised to establish pioneering 300,000-hectare fisheries management zone with seasonal closure in VIP. https://www.malampayafoundation.org/news142.html

Oglethorpe J (2009) The Global Conservation Program Achievements and lessons learned from 10 years of support for threats-based conservation at a landscape and seascape scale. Sulu Sulawesi Marine Ecoregion. Final Closeout Report. https://rmportal.net/library/content/global-conservation-program/gcp-closeout-reports/sulu-sulawesi-marine-ecoregion-final-closeout-report/at_download/file

PEMSEA (2006) Securing the Future through ICM: The case of the Batangas bay region. http://www.pemsea.org/publications/reports/securing-future-through-icm-case-batangas-bay-region

PEMSEA (2009) Keeping the essentials flowing: Promoting food security and sustainable livelihood through integrated coastal management. PEMSEA. http://www.pemsea.org/publications/case-studies/keeping-essentials-flowing-promoting-food-security-and-sustainable

Pomeroy RS (1995) Community-based and co-management institutions for sustainable coastal fisheries management in Southeast Asia. Ocean & Coastal Management 27(3):143–162. https://doi.org/10.1016/0964-5691(95)00042-9

Province of Batangas (2015) Inter-LGU fisheries management plan: A plan to manage the fisheries of Verde Island Passage/Balayan Bay Marine Key Biodiversity Area (MKBA) Applying the Ecosystems Approach to Fisheries Management (EAFM).

Quimby B, Levine A (2018) Participation, power, and equity: Examining three key social dimensions of fisheries comanagement. Sustainability 10(9):3324. https://www.mdpi.com/2071-1050/10/9/3324

Rola AC, Narvaez TA, Naguit MRA, Elazegui DD, Brillo BBC, Paunlagui MM, Jalotjot HC, Cervantes CP (2018) Impact of the closed fishing season policy for sardines in Zamboanga Peninsula, Philippines. Marine Policy 87:40–50

Stobutzki IC, Silvestre GT, Abu Talib A, Krongprom A, Supongpan M, Khemakorn P, Armada N, Garces LR (2006) Decline of demersal coastal fisheries resources in three developing Asian countries. Fisheries Research 78(2-3):130–142. https://doi.org/10.1016/j.fishres.2006.02.004

Thia-Eng C (2008) Coastal governance: A reflection of Integrated Coastal Management (ICM) initiatives with special reference to the East Asian seas region

Vergara S, Rosales RMP, Quibilan M, Ibuna N, Froyalde H, Villanueva R, Azucena W (2008) Partnerships at work in the seas of Sulu and Sulawesi. Tropical Coasts 15(1):12–21. http://pemsea.org/sites/default/files/tc_v15n1.pdf

Weeks R, Aliño P, Atkinson S, Beldia PI, Binson A, Campos W, Djohani R, Green A, Hamilton R, Horigue V, Jumin R, Kalim K, Kasasiah A, Kereseka J, Klein C, Laroya L, Magupin S, Masike B, Mohan C, White A (2014) Developing marine protected area networks in the coral triangle: Good practices for expanding the coral triangle marine protected area system. Coastal Management 42:183–205. https://doi.org/10.1080/08920753.2014.877768

White AT, Courtney CA (2004) Policy instruments for coral reef management and their effectiveness. In: Ahmed M, Chong CK, Cesar H (eds) Economic valuation and policy priorities for sustainable management of coral reefs. WorldFish Center, pp 128–148

White AT, Christie P, D'Agnes H, Lowry K, Milne N (2005) Designing ICM projects for sustainability: Lessons from the Philippines and Indonesia. Ocean & Coastal Management 48(3):271–296. https://doi.org/10.1016/j.ocecoaman.2005.04.007

White A, Deguit E, Jatulan W, Eisma-Osorio L (2006) Integrated coastal management in philippine local governance: Evolution and benefits. Coastal Management 34:287–302. https://doi.org/10.1080/08920750600686687

WWF-SSME Program (2004) Framework for a network of marine protected areas in the sulu-sulawesi marine ecoregion. WWF Sulu-Sulawesi Marine Ecoregion Conservation Program

Chapter 8
Kenya Case Study Two

Locally Managed Marine Areas: A Double Helix of Challenges and Opportunities: The Case of Kuruwitu LMMA along the Kenyan Coast

Benards Okeyo and Dishon Murage

Abstract Properly managing coastal resources, particularly in developing countries where the majority of people living on the coast largely depend on those resources, can be a difficult situation. Along the Kenyan coast, this challenge has elicited several approaches. There have been different forms of co-management, radiating from loose associations of fishers and fish workers, Beach Management Units (BMUs) enacted by the law, to Locally Managed Marine Areas (LMMAs). This study explores and reviews the successes, challenges and opportunities brought up by the Kuruwitu LMMA in Kenya. It involved visits to the site and several discussion sessions involving Kuruwitu LLMA members, fish workers and an array of community members. The interviews were captured by open semi-structured interview schedules usually at the working sites of those interviewed. It was found that the main reason for its easy acceptance was its close resemblance to the traditional management systems with the additional advantages of being anchored in law, being more elaborate—largely conscious of the several interests of the major stakeholders and having an increased ability to obtain support from external sources. With the LMMA at Kuruwitu, the fishery is now restricted, fishers are trained, and income-generating ventures opened. However, several challenges remain, namely, the initial capital that came with the publicised event has dwindled, less capacity to generate internal funds, the beneficial plans and projects have stalled. Unfulfilled expectations from the community linger and it is easy to detect some dissatisfaction with a number of elements. Nonetheless, the LMMA demarcation and exploitation restrictions remain and the fishers talked of slight increment in catches over the recent years.

B. Okeyo (✉)
Department of Environmental Science, Pwani University, Kilifi, Kenya
e-mail: b.okeyo@pu.ac.ke

D. Murage
Nature Com, Mombasa, Kenya

M. Wolff et al. (eds.), *Challenges in Tropical Coastal Zone Management*,
https://doi.org/10.1007/978-3-031-17879-5_8

Keywords Locally managed marine areas · Kuruwitu Kenya · Opportunities · Challenges · Coastal resources

1 Introduction

1.1 What Are LMMAs?

The term LMMA has evolved as a global generic term for community or locally managed areas in the marine environment, which have some form of protection or regulation built through consensus by the surrounding community and stakeholders. In Kenya, several names have come up to refer to these areas, including community conservation areas (CCAs), *tengefu* (Kiswahili for 'set aside', (McClanahan et al. 2016) or community conservancies. The names often relate to the legislation used to declare them or to the various actors who have promoted their existence (Samoilys et al. 2015). Govan et al. (2009) defined an LMMA as 'an area of nearshore waters and coastal resources that is largely or wholly managed at a local level by the coastal communities, land-owning groups, partner organizations, and/or collaborative government representatives who reside or are based in the immediate area'.

LMMAs have perhaps been successful due to their ability to complement government approaches on the management of fisheries besides being culturally sensitive. Even better, they sometimes have emerged from the people that directly depend on the marine and coastal resources and that are compelled to sustainably manage their resources through such arrangements. Because these LMMAs are rooted in the local communities and sometimes even sprouting from their anxieties in regard to local resources not to mention trying to address pertinent issues affecting local coastal and marine resource users, they seem to have an easy birth and less complicated political tussles.

Whereas LMMAs and MPAs (Marine Protected Areas) are often similar in intention, the approach to their formation may be quite different. MPAs are gazetted by government agencies and are usually demarcated for nature conservation (fishing is usually not allowed or restricted to some areas only—mostly within the reserves). LMMAs are largely enacted local agreements and demands. Their activities are largely regulated by consensus. Indeed, within the LMMAs, the amount and duration of resource uptake is determined by agreement amongst local resource users. Nonetheless, it is important to appreciate that there is often still some government control within the LMMAs, like within the Kenyan coast, government agencies are involved in the exploitation and conservation of fishery and wildlife resources through taxation of fishery products, generation of fish capture data thus making them integral stakeholders within the LMMAs.

1.2 History of LMMAs in Kenya

Like in many other tropical coastal areas, the sustainable management of coastal and marine resources remains a challenge to many interested bodies like the government agencies, non-state actors and local residents dependent on the resources. Issues of overexploitation, increasing fishing pressures, degradation of critical habitats, especially spawning and breeding grounds of many fish species are of relevance. Moreover, conflicts may arise from land tenure—most shoreline areas along the Kenyan coast have contested ownership. Besides, there exist divergent interests in regard to the development of the coastal zone adding further complexity to the marine resource management challenges. As a result, coastal communities have struggled over the years with systems that could ameliorate this scenario.

One of the systems widely adopted over the last years has been the adoption of collaborative fisheries management, more often referred to as 'co-management'. In Kenya, co-management is a relatively new concept, estimated to have begun in the 1990s when the Kenyan Government first introduced the Beach Management Units (BMUS). These BMUS were an initial step to incorporate local resource users into the management mechanism of their resources. It was, in fact, an attempt to change from the top-down management systems of the local fishery to a more self-regulated system, where resource users, together with government agencies (Fisheries Ministry), would look for joint management solutions to a sustainable fishery. It took many years to take root. In the initial years, the concept was viewed with disdain and suspicion by the resource users as it was thought to be another management ploy by the Kenyan government to seize full control of the fishery resources. The back and forth arising from the aforementioned delayed the enactment of the relevant legislation till 2016 when the Kenya Fisheries Management and Development Act No. 3.5. This is the very Act that establishes the current Beach Management Units—known for bringing together several stakeholders within a common fishing area and equally usedas vehicles for fisheries co-management. Together with the BMU Regulations of 2007, these guidelines further provided the designation of co-management areas in respect to individual BMUs and even joint co-management areas wherever desirable and ultimately the formation of LMMAs.

1.3 The Evolving Concept of Co-Management

Globally, co-management is taken to mean a **mode of governance** through which resource users' and government share responsibility and authority for the management of fishery resources, with support and assistance as needed from other stakeholders, external agents, academic and research institutions (FAO 2020). In a publication by Linke and Bruckmeier (2015) particularly in regard to fisheries co-management is noted for its multi-functional, multi-faceted nature complete with its need to address different knowledge and resource management problems.

Along the Kenyan coast, fisheries remained an open-access resource for many years—available for any interested party with the requisite skills and who is living near a fishing area. Over time, rules emerged amongst the fishers and fishing communities both (1) in regard to the rights of the human community for exploiting the fishery resources and (2) in regard to the interaction with the biophysical environment supporting the fishery resources and the fishery itself. The former was to create harmony and reduce conflicts amongst the partakers of the fishery resources, whereas the latter was to ensure the sustainability of the resource base.

From the beginning, it is clear that the pillars of the co-management were not entirely new. The traditional arrangements had already exhibited several components of fishery co-management as we know it today. The present definition of fisheries co-management may, therefore, be seen as an attempt to put into writing a practice that had long been accepted amongst the fishery resource users along the Kenyan coast. Hence, in print, fisheries co-management qualifies as a partnership arrangement amongst interested parties to sustainably exploit the fishery resources without causing damage to the ecosystem.

The realisation of the fishery co-management concept in Kenya started with the formation of the BMUs—which consists of fishers, fish traders, boat owners, beach property owners as well as other stakeholders within the beaches supporting sustainable fishery and harmonious co-existence.

BMUs co-manage the fishery in tandem with the relevant government ministry in charge of fisheries using the Fisheries Act and BMU regulations generated through internal administrative rules—usually referred to as by-laws. The by-laws are later registered with the State Agency for Fisheries (Government of Kenya 2007). There exists a possibility for a BMU to get into a joint co-management with another nearby BMUs to be able to cover a larger area and may opt for joint action—say to allow foreign fishers to obtain fishing rights within their areas at an agreed fee. Here, "foreign" fishers need not come from outside the Kenyan borders but may be those whose fishing grounds are away from the landing sites in question. In fact, permission to fish and exploit resources could entail the payment of a fee, acceptance for a joint fishing expedition, exchange for gear, training of youthful unskilled fishers or sharing of catches. Even those who had lineages to the local community through marriages or common ancestry can exploit the relations to gain access.

It thus appears that there is a thin line between the co-management concepts applied by an LMMA and by BMUs. The main difference seems to be the scale—LMMAs usually bring together several BMUs within a framework of an agreed co-management plan or strategy, whereas a BMU is a smaller unit often restricted to a handful of landing sites.

1.4 Formation of LMMAs

As mentioned above, LMMAs are a fishery management practice that has emerged over time. Some workers have traced its roots to the FAO's Ecosystem Approach to

Fisheries Framework (FAO 2011–2019), which is considered as the appropriate and practical way of implementing the Code of Conduct for Responsible Fisheries. The FAO EAF-Net picks outthe main principles, given below, in order to guide the formation and operation of an LMMA or a CCAs (Community Commonly Areas);

(a) Fisheries should be managed in a manner that causes the least impact on the ecosystem to an acceptable level.
(b) Maintains ecological relationships between species.
(c) Management measures are compatible across the entire distribution of the resource.
(d) Precaution in decision-making and action is taken whenever needed knowledge/information on ecosystems is incomplete.
(e) Ensures that governance enhances both human and ecosystem well-being and equity.

These principles applied together with that of the Ecosystem-Based Approach are seen as adequate for the sustainable management of a commonly designated fishery area like that of an LMMA.

1.5 LMMA Formation Phases

From the FAO's Ecosystem Approach to Fisheries, four main phases are identified, namely;

1. Initiation and Planning.
2. Identification of Assets, Issues and their Priority.
3. Management Programming.
4. Implementation Phase.

In a study undertaken along the Kenyan coast by Kawaka et al. (2017), it has been shown that for the Kenyan situation the establishment of LMMAs has taken usually five stages, namely;

1. Conceptualisation.
2. Inception.
3. Implementation.
4. Monitoring and management.
5. On-going adaptive management.

From the discussion with several stakeholders, we found that the conceptualisation phase is usually necessary to allay fears about the concept, particularly in regards to the local fishers' feeling that their resources could be on the verge of being hijacked by the state or by 'outsiders'. Equally, this phase is important to ease fears of the fishing grounds being declared out of bounds for local fisheries. Whereas this phase is instrumental for exploring and communicating the main goals and the underlying need for the establishment of an LMMA, it is also here that awareness of LMMA contributes to its development and the process are elaborated. Both local indigenous knowledge and scientific knowledge are integrated, and potential issues of concern jointly examined. Indeed, ownership issues are explored at this phase in order to remove fears usually harboured by the local communities in regard to alienation of their land. In cases where there have been successful launches of LMMAs—visits are made to those during this phase as well. In fact, the establishment of the Kuruwitu LMMA, one of the most outstanding LMMAs along the Kenyan coast, was preceded by a successful visit to a Tanzanian LMMA—where ideas were exchanged, fears allayed and hopes for a successful and rewarding management strategy were entrenched.

2 The Formation of the First Kenyan LMMA; The Case of Kuruwitu

Kuruwitu was the first LMMA implemented along the Kenyan coast. Initial talks about it started in the year 2003 through a common agreement between local artisanal fishers and several stakeholders straddling from local non-state actors, government agencies to international non-profits. The need for an LMMA in the area was arising from a perceived degradation of the marine and coastal resources within the larger Kuruwitu area. The local communities attributed this degradation to the waning system of management of these common resources in the face of the high demand from the ballooning coastal population, as well as a relaxed and near-absence of government control. The other stakeholders—the businesses and the Non-Governmental Organisations—viewed it as a case of weakened resource exploitation controls occasioned by corruption and apathy towards the implementation of resource-use policies.

The LMMA initiative was then seen as a vehicle that could give the local communities and fishers the right and capacity to locally manage their resources (Rocliffe et al. 2014). It borrowed heavily from the hitherto local traditional system of resource control—where the elder-based system of resource governance was used to determine: (1) the rules and regulations of the resource exploitation (2) the institutions to take charge in the implementation of those rules and regulations as well as (3) the decision-making processes—that are run by the different community members. Thus, whereas the term LMMA was new to many, the concept sounded familiar and was easily anchored onto the known governance structures. Indeed, the initial resistance to such a management option dimmed owing to its bottom-up approach. Prior to this initiative, Kenyan coastal communities had resisted government attempts to give up their rights to manage their coastal resources for the creation of Marine National Parks or Reserves—a resistance that thwarted the initial proposal to establish a marine conservation area in the Diani area, famous for its touristic activities (Benards 2015).

2.1 Why in Kuruwitu?

In Kuruwitu, resource control was vested in the locals and 'outsiders' helped to reinforce local talents and interests in the exploitation of the marine resources. Indeed, the involvement of a local community-based non-state actor, which was later re-named as the Kuruwitu Conservation and Welfare Association, was instrumental for the realisation of the LMMA.

Today, twelve years later, we take up the responsibility to deal with the challenges and opportunities that have since cropped up. We seek to determine if the major intentions have been realised and assess the intervening factors that have since emerged either for the prosperity or disadvantage of the LMMAs. Further, we explore the opportunities that have emerged and describe the local communities' ability to build on the initiative, including the extensive outlay of capital infused during the formative years of the LMMA.

2.2 The Big Challenge at Kuruwitu

The Kuruwitu area, like other places along the Kenyan coast, had faced several challenges like declining fish catches, non-adherence to traditional fishery management rules, and an increasing population of disfranchised local fishers—finding it hard to put enough food on the table for their families. On the other hand, the non-state actors and the government agencies were finding it difficult to build a strong well-united group of people interested in the conservation of marine resources of this region. The Beach Management Units (BMUs)—already initiated by the State Department for Fisheries—needed a stimulus to bring together the stakeholders and inspire them to work towards the same goal.

3 Methods

3.1 The Kuruwitu Area (Fig. 8.1)

3.2 Characterisation of the Kuruwitu LMMA in Kenya

In order to characterise the performance of the Kuruwitu LMMA over time, we employed a modified organisational and capacity development tool (Table 8.1) and administered questionnaires to elicit responses on the organisational and institutional development changes as well as other key aspects of the Kuruwitu LMMA over the last 12 years. The former assisted to assess the sustainability of the initiative and to tease out areas that could be improved if the initiative was to continue to serve its intended purposes. The questionnaires were administered to officials working at the

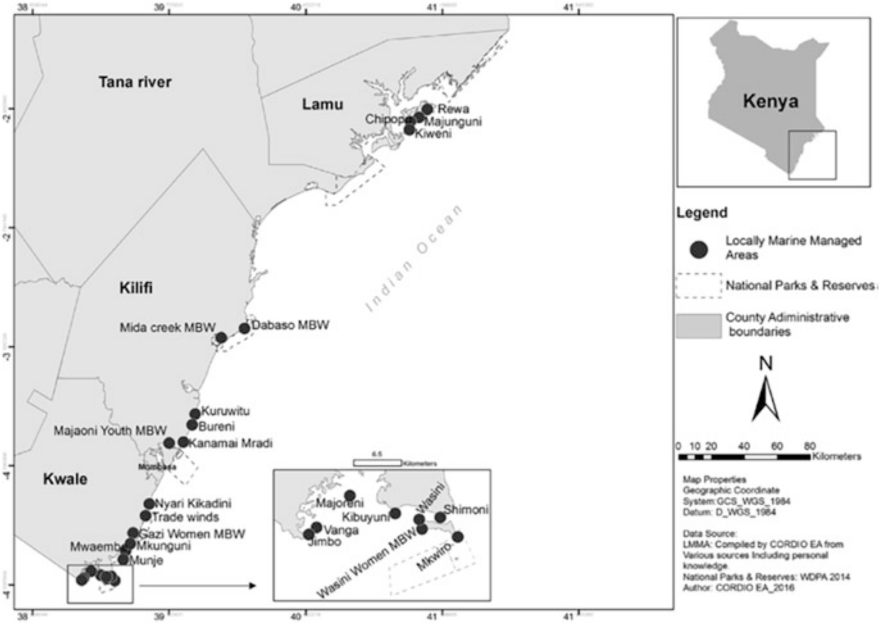


Fig. 8.1 Map of Kenyan coast showing Locally Managed Marine Areas (LMMAs) including the Kuruwitu area as well (Courtesy of Harrison Onganda of Kenya Marine and Fisheries Research Institute—2022)

facilities cum offices of the Kuruwitu LMMA within the nearest village centre of Shariani. The building serving as an office has remained intact and continued to offer several services like; (1) being a meeting area, (2) centre for selling fish to clients, and (3) lately serving as a centre for selling fresh water to the those living in the adjacent areas. We also found a group of enterpreunral local women using one of the rooms for selling tourist artefacts and clothes. Additional, we scouted for former officials and members who for one reason or another had taken inactive roles in the management of the LMMA. We also held several interviews with the fishers, many of them within the landing sites—usually when back from fishing expeditions or when repairing gears and vessels. Summaries from the questionnaires administered provided additional insights.

4 Results

Using the above organisational and institutional development tool, we assessed important parameters of growth and development of the Kuruwitu LMMA since its inception, over 12 years ago (see Table 8.1).

Table 8.1 Organisational and institutional development evaluation tool

	Description of level of organisational capacity				Level Found
Level	1 (Embryonic)	2 (Developing)	3 (Moderately developed)	4 (Fully developed)	
Internal capacity					
Organisational strategy	No plan	Plan exists but does not guide implementation	Plan exists but developed by others with limited stake-holder consultations	Plan exists, developed with extensive stakeholders' con-sultations; describes the orga-nisation's 5 year plan	4
Governance management	Limited to a few individuals; organisation would collapse without them	Governing body exists, roles not clearly defined; sometimes leading to conflicts	Governing body exists; func-tional but not representative of the assembly	Governing body exists; assembly representative is accountable and has the trust of the assembly	3
Conflict resolution	No mechanisms established; conflicts resolved informally	No mechanisms exist, but leaders understand the need to establish conflict resolution mechanisms	Basic conflict resolution mechanisms established yet rarely or never used	Conflict resolution mecha-nisms established and successful	3
Financial planning	None	Exists but rarely/never used. Knowledge limited to a few	Plan exists. Managers trained. No monitoring or reporting to assembly	Accurate records kept. Imple-mentation monitored. Reporting timely and accurate.	3
Financial sustainability	No resources secured for operations and activities over the following year	Some funding secured for activities; no guarantee for additional funding	Some funding secured; prom-ise/prospects of additional funding for remaining activities	Funding secured for all activities	2
External relations					
Networks and links	Most of the work done independently. No shared information with other CSOs	Information shared but pro-cess not formalised. Members of forum/network rarely participate	Information shared at confer-ences and workshops. Regular informal links with members of other CSOs. Network members active	Strong links with other CSOs in similar fields. Key members of the network actively involved. Information shared with international networks	2

(continued)

Table 8.1 (continued)

	Description of level of organisational capacity				Level Found
Level	1 (Embryonic)	2 (Developing)	3 (Moderately developed)	4 (Fully developed)	
External communications	No production of communication materials (i.e. brochures, pamphlets, etc.)	Communication materials produced. Organisation recognises the need to disclose project plans to the audience	Communication materials produced and communication plan developed; good relationship with the media	Communication materials produced and communication plan developed; organisation has high public profile	1
Programme planning and sustainability					
Programme implementation	No implemented projects	Organisation has implemented some projects but faces considerable resource constraints	Organisation has implemented most of the projects. Unclear whether intended outputs have been achieved	Organisation has implemented most of the projects and achieved the intended outputs	3
Programme sustainability	No plan on how activities, projects and programmes can be sustained in the long-term	No formalised plan for sustainability; beneficiaries do not know how plans can be maintained	Beneficiaries know how projects and activities can be sustained. Plan exists	Plan exists, beneficiaries able to maintain project benefits independently	2
Advocacy and engagement					
Engagement with government	Limited contact	Good informal links with local government. Relationship needs to be strengthened	Good formal and informal links; occasionally consulted on relevant matters	Good formal and informal links; regularly consulted on relevant matters	3
Monitoring and evaluation					
Monitoring and evaluation (M&E)	No understanding	Awareness of the importance of monitoring and evaluation. Limited M&E; usually as a response of donor requirements	Importance of M&E recognised, often planned for and conducted by external experts. Limited feedback for decision-making	M&E prioritised and regularly conducted. Outputs and outcomes evaluated. Information feedback for adaptive decision-making	2
Reporting	None	Reports are produced and their importance recognised. Irregular and capacity to generate good reports limited	Some capacity to write reports. Reports done irregularly. Reports provide analysis and demonstrate results achieved	Good internal capacity to write reports. Reports done in a timely manner and of high quality.	3

Organisational Strategy There is a plan in place which was generated by consensus. Over time, there appears to have been no revision of the plan after the five-year lapse. The main reason was that, once the donor funds that assisted the formalisation of the LMMA had dried out, there were not enough funds generated internally to support crucial tasks. This lack of money then became a major challenge. Unfortunately, LMMAs are not usually able to generate internal funds to support their ambitious plans, which affects other organisational aspects like governance and conflict resolution mechanisms. Actually, elaborate governance structures, meetings and decision-making processes are not regularly convened anymore if funds have run out. Under these conditions, qualified staff may even leave the LMMA management context in search for better livelihood support.

External Relations Like any other legal bodies, once in place by law—LMMAs are expected to create liaisons—which then should support their day-to-day operations. We learnt that the contact has dwindled and even internal meetings are fewer when compared to the formative years during which meetings were common and members highly motivated to attend. The production of communication materials like brochures and pamphlets has since stalled, largely due to the limited funds generated as well as the capacity of management to provide such materials.

Programme Planning and Sustainability Most of the intended plans/projects/activities were implemented within the five-year period of active external support. Yet no major additional tasks have been initiated. This lack of new assignments blurs the sustainability of the LMMAs, although the fact that no one of the stakeholders involved underestimates the viability of the enclosure for fishing purposes shows that it may be sustainable in the future.

Advocacy and Engagement This aspect was probably much more needed during the formative stages. Good formal and informal links with both government and non-governmental bodies were built. While currently there is not much interaction mostly due to reduced funds and activity levels, the members appear concerned with engagement and are willing to attend meetings and discussions with other groups.

Monitoring and Evaluation Members concerned with day-to-day running of the LMMA were well briefed on the need for regular monitoring and evaluation. There was, however, no specific plan for internal monitoring and evaluation, except for those controlling activities that were brought about by the presence of a donor. The same also applied to the generation of reports.

Gender Composition Of the people involved in the LMMA, only 26.3% were females, indicating that males were dominating in the organisational development of the LMMA. This is perhaps due to land tenure ownership, which is monopolised by the males within this region. Furthermore, the different gender roles enforced that women mostly remained at home to undertake home-related chores while men took up communal tasks like participating in the formation of communal bodies like LMMAs.

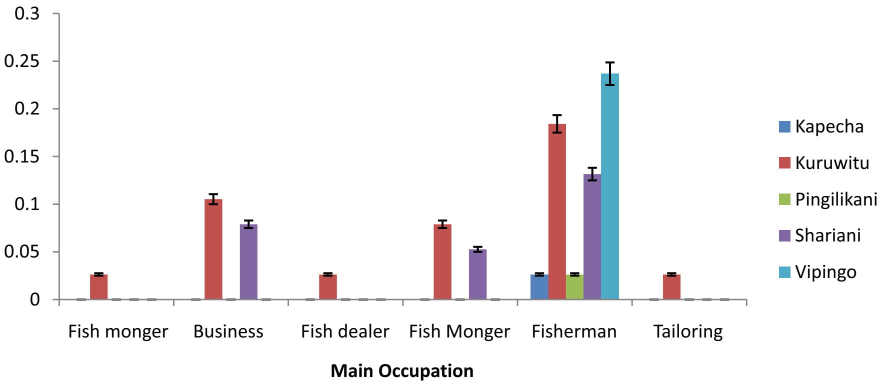


Fig. 8.2 Diagram showing the main occupation of the respondents within the fishery-related tasks

Occupation of Members We undertook two surveys to target non-fishery-related occupations and those involved in fishery operations. This was easy since fishery-related activities were far away from the main road (Mombasa—Malindi Highway) and close to the Kuruwitu LMMA Centre, whereas fishing-related activities were concentrated within approximately 2 km of the shore.

From the first survey (activities far away from the shoreline and close to the Kuruwitu LMMA Centre), it emerged that members of the LMMA had diversified livelihood roles ranging from farmers (45%), casual labourers (30%), land and property owners (10%) with still many other members undertaking beach-related chores, being guards, tour guides, chefs and cobblers.

Concerning the second survey, related to the diversification of roles across fishing and related activities, it emerged that fishing took the largest share (60%) and fish-dealing the lowest (10%), as shown in Fig. 8.2.

In sharing the initial capital outlay that was involved in the formative stages of the LMMA, both fishing-related and non-fishing-related activities had been supported. Thus, it is fair to say that such local initiatives could act as appendages for capital for commercial activities and as a way of supporting socio-economic ventures for the general well-being of those communities.

4.1 *Lack of Funds*

This has been mentioned several times as a fundamental problem. In fact, the formation of the LMMA itself relied on millions of Kenya shillings from a joint funding by the Kenyan government and European Union. Were it not for that decisive funding, perhaps the LMMA could not have come to fruition. Also, within the initial fund, there was a component meant to assist many of the stakeholders, especially the fish dealers. This targeted the improvement of their catches, the taking up of alternative livelihoods and the development of related skills. For example fishing boats, fishing gears, cooler boxes and a relatively well-furnished fish handling facility were provided to the fishermen and fish dealers. Also, markets as far as Nairobi were sorted for the Kuruwitu LMMA as fish catches were lifted to Nairobi—a city of 4.5 million inhabitants roughly 500 km away, by a local airline for free from Kuruwitu to Nairobi.

A major concern is that several years later most of those facilities have either broken down or are currently malfunctioning and are yet to be repaired or replaced. Sad as it may be, this is a common feature for many a community-funded projects. Initially, the Kuruwitu LMMA organisation would collect a given percentage from fees on all catches processed through their facilities. With many of the facilities grounded, this line of revenue is diminished or lost. This is then manifested in other streams of revenue, e.g. reduced registration or membership fees, fish catches storage fees, etc.

4.2 Dependence on Marine and Coastal Resources

When analysing the dependence on marine and coastal resources—it became clear that almost everyone in the vicinity of the Kuruwitu LMMA obtained, to some extent, benefits from the marine area, as shown in Fig. 8.3. These benefits came in the form of fish, corals (both live and dead corals were part of shoreline collections paraded for sale at the Kiriwutu LMMA Centre), seawater—both fresh water and saline water are a rare resource in the villages and communities within the LMMA enclave—the launching of the LMMA came with digging of boreholes to supply not so fresh water as well also connected a few places to the fresh water pipeline. Other benefits were the access to the beach complete with a few facilities like places to sit, to drink and even make some food not to mention the improved ability to move and access far off areas inhabited by sea grasses due to the availability of motorised vessels.

The interviewees were categorical that the benefits they have reaped have been mostly due to the area limiting and having the enclosure. By the successfully observation of resource exploitations practices within the LMMA enclosure, fishers hinted that the fishery, once over-exploited, had shown signs of recovery. In their view, this recovery was possible due to the rejuvenation of related ecosystems like the seagrass meadows and mangroves in the shorelines of the LMMA enclosure.

Kuruwitu makes the best use of all marine resources with 45% benefiting from fish as a resource, fishing and fish vending, whereas 30% of respondents from Shariani also benefit from fish (Fig. 8.3). The other villages benefit from corals, seawater, the beach and seagrass on an average rate of exploitation. Pingilikani has the lowest contribution of less that 5%, while Kapecha exploits fish resources only, at a rate of less than 5%.

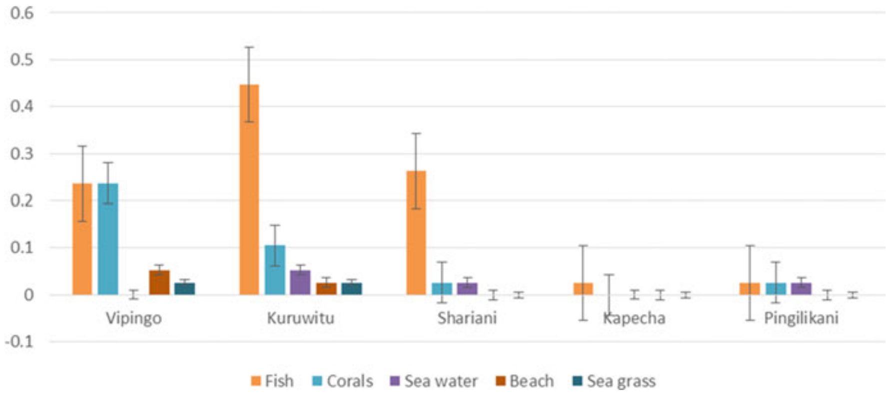


Fig. 8.3 Differences in village sharing of benefits between the various coastal and marine resources

4.3 Stakeholders of the Kuruwitu LMMAs

We identified the stakeholders involved by (1) checking the individual member affiliation to different agencies and (2) looking at the institutional affiliation to the agencies. Concerning individual member affiliations, we realised that 39% of the respondents were affiliated to agencies that support their activities. These agencies included (a) aquarium-based companies that collected live fish for the local and foreign markets, (b) state department of fisheries, (c) the Kenya Marine and Fisheries Research Institute (KMFRI), (d) the Kenya Wildlife Services (KWS) and (e) local fish trading entrepreneurs. In several cases, members were attached to two or more agencies. For example 36% of the respondents were affiliated to both KWS and Fisheries, 7% to KMFRI and Fisheries, while others got attached to single companies. The range of stakeholders was the same both for the individual members as well as for the Kuruwitu LMMA as an institution. We did not attempt to evaluate the strength of relationships between the LMMA and the various stakeholder groups—a research topic that could be undertaken by another study in the future.

4.4 Other Challenges Facing Kuruwitu LMMA

The biggest challenges facing this LMMA as perceived by the interviewees were: changing weather patterns (45.6%), pollution of the sea (12.3%), lack of equipment (12.3%), overfishing (10%) and poaching (8.8%). Bleaching of corals, lack of fish market demand, difficult access to roads, conservation restriction and conflict in land ownership were other challenges mentioned, but only by a few respondents (Table 8.2).

It is difficult to verify the above challenges from scientific literature as there has not been a lot of research done on the Kuruwitu LMMA. However, it is important to

Table 8.2 Summary of the challenges facing the Kuruwitu LMMA

Challenges	Responses
Changing weather patterns	45.6%
Pollution of sea	12.3%
Lack of equipment	12.3%
Overfishing	10.5%
Poaching	8.8%
Bleaching of corals	3.5%
Market of fish	1.8%
Access to road	1.8%
Conservation restriction	1.8%
Land ownership	1.8%
Total	100.0%

note that many of the interviewees ascribe the main challenges to natural factors out of their control, i.e. changing weather patterns and pollution of the sea. From discussions with many fishermen, they hint on the changing fishing seasons and the waters getting too clear. While these could be good indicators of changing weather patterns, it would be better to conduct a much deeper investigation into these challenges to confirm their effect on the local fishery. Again, while this could be true, it could also be a way of obscuring their impacts like overfishing the dwindling fish stocks. Moreover, it is clear that the enactment of the LMMA would have little influence on such natural factors like the changing weather patterns and pollution especially if the sources of pollution happen to be far away from the jurisdiction of the LMMA.

5 Conclusion

The concept of Locally Managed Marine Areas (LMMAs) seems to have taken root within the Kenyan coast. It resembles in many ways the traditional management of common fishing areas where rules of engagement and levels of resource exploitation were built through mutual agreements and consensus. The initial creation of the Beach Management Units (BMUs) seemed to have also taken cue from the traditional management systems, although they were and continue to be, useful only for 'smaller' fishing grounds usually close to landing sites. The LMMA concept is in our view an improved approach, which seems to pick from both, the traditional and BMU ideas of managing these common shared resources. The better component espoused by the LMMAs is that they are anchored strongly in law, their governance systems are more elaborate and hence their ability to seek support from external sources is greater. The Kuruwitu LMMA is a leader at this front. Stakeholders quickly came together to conserve their common fishery resources, to oversee the process of LMMA implementation and to seek financial support from different donors.

Twelve years down the line opportunities have emerged, the LMMA has been formed, the fishery has been closed for non-restricted exploitations, people have been trained, and several income-generating ventures have opened up. Indeed, the relations with the external world soared and, in the process, social capital was built. Many members of the Kuruwitu LMMA have attended conferences outside the country and have learned new ways of resource management and conservation. Not least, sharing their own ways and making their own struggles and successes known. For a small community, shelved within the isolated village of Shariani away from the major touristic cities of Mombasa and Malindi, this is not a small achievement.

There are still some major challenges, namely, the initial capital that came with the highly publicised event has since dwindled, and without much capacity and room to generate internal funds, many of the initial projects have stalled. Expectations from the community regarding the LMMA still remain to be met or considered.

References

Benards O (2015) Fisheries of Kenya's coast: a socio-ecological system in transition. Scholars Press

FAO. (2011–2019). EAF-Net. EAF Projects. FI Institutional Websites. FAO, Rome

FAO (2020) Report of the FAO virtual global expert workshop on the fisheries co-management evaluation guidebook. FAO, Rome

Govan H, Tawake A, Tabunakawai K, Jenkins A, Lasgorceix A, Schwarz AM, Aalbersberg B, Manele B, Vieux C, Notere D, Afzal D (2009) Status and potential of locally managed marine areas in the South Pacific: meeting nature conservation and sustainable livelihood targets through wide-spread implementation of LMMAs: a study report

Government of Kenya (2007) The fisheries Act (cap. 378) The Fisheries (BeachManagement Unit) regulations, 2007. Legal notice No. 402. Kenya Subsidiary Legislature

Kawaka JA, Samoilys MA, Murunga M, Church J, Abunge C, Maina GW (2017) Developing locally managed marine areas: lessons learnt from Kenya. Ocean Coast Manag 135:1–10. https://doi.org/10.1016/j.ocecoaman.2016.10.013

Linke S, Bruckmeier K (2015) Co-management in fisheries–experiences and changing approaches in Europe. Ocean Coast Manag 104:170–181

McClanahan T, Muthiga NA, Abunge CA (2016) Establishment of community managed Fisheries' closures in Kenya: early evolution of the Tengefu movement. Coast Manag 44(1):1–20. https://doi.org/10.1080/08920753.2016.1116667

Rocliffe S, Peabody S, Samoilys M, Hawkins JP (2014) Towards a network of Locally Managed Marine Areas (LMMAs) in the Western Indian Ocean. PLoS One 9(7):e103000. https://doi.org/10.1371/journal.pone.0103000

Samoilys M, Watson R, Omari M, Kamula J, Amiyo N, Odote C (2015) Legislative guidelines for the establishment and operation of locally managed marine areas in Kenya. Coastal Oceans Research and Development Indian Ocean (CORDIO), Kenya

Chapter 9
Tanzania Case Study

Potential and Challenges of Integrated Multi-Trophic Aquaculture (IMTA) System of Seaweed and Sea Cucumber in Tanzania

Godfrey Fabiani, Mary Namukose, Robert Eliakim Katikiro, Yussuf S. Yussuf, Nuri M. Steinmann, and Flower E. Msuya

Abstract Integrated Multi-Trophic Aquaculture (IMTA) is an ecosystem-based method to produce food from different elements of the food web. IMTA processes involve recycling nutrients such as feces, waste feed, or soluble inorganic forms. Production activities under IMTA system in Tanzania face a number of challenges, yet the potential for production is enormously high. This chapter makes use of available published and grey literature on the farming of sea cucumbers and seaweeds from selected endeavors in Tanga (Northern Tanzania) and Zanzibar Island to examine which species of sea cucumbers and algae are farmed and their associated impacts. The potential and challenges of management strategies for IMTA are discussed thoroughly. Special emphasis is placed on the adoption of IMTA as a feasible economic and ecological method for production of sea cucumbers in the country. Economic analysis of IMTA shows that these activities should be viewed as part of a large system that includes more than one species from different trophic levels. IMTA can have a whole range of economic and ecological benefits compared with monocultures yet concerns about its impacts on ecosystems and the general

G. Fabiani (✉)
University of Dar es Salaam, Dar es Salaam, Tanzania

Tanzania Fisheries Research Institute, Dar es Salaam Centre, Dar es Salaam, Tanzania

M. Namukose
National Fisheries Resources Research Institute, Jinja, Uganda

R. E. Katikiro · F. E. Msuya
University of Dar es Salaam, Dar es Salaam, Tanzania

Y. S. Yussuf
University of Dar es Salaam, Dar es Salaam, Tanzania

University of Dodoma, Dodoma, Tanzania

N. M. Steinmann
Leibniz Center for Tropical Marine Ecology, Bremen, Germany

M. Wolff et al. (eds.), *Challenges in Tropical Coastal Zone Management*,
https://doi.org/10.1007/978-3-031-17879-5_9

public remain unexplored. The potential for IMTA of sea cucumbers and seaweed is high, and the market is readily available. However, the IMTA approach requires thorough investigations, skills, and preparations, which are currently at minimal level in Tanzania. Lack of seeds is a major obstacle to IMTA development and is worsened by theft issues, lack of capital, and appropriate skills. This chapter calls for technical support from development partners in managing the IMTA systems at all stages in the production cycle.

Keywords IMTA · Sea cucumber · Seaweed · Potential · Challenges · Tanzania

1 Introduction

Aquaculture is increasingly becoming one of the fastest-growing industries in the world. Global production from farming of aquatic organisms and capture fisheries are almost becoming similar in recent decades (FAO 2016). For example, total global fish production for human consumption stood around 167.2 million tonnes in 2014 and aquaculture contributed around 73.8 million tonnes in this period (FAO 2016). Growth in fish consumption in most countries outstrips supply (Kobayashi et al. 2015), thus production needs to increase through aquaculture. Aquaculture plays an important role in providing animal protein for a growing human population and offers opportunities and benefits to coastal communities, such as employment and income. Therefore, it plays a critical role in the livelihood of the coastal communities (FAO 2014). Despite a huge potential of aquaculture, its share in Africa is still lagging behind other regions of the world (FAO 2018) and Tanzania is no exception. In mainland Tanzania for example, aquaculture started in the early 1950s with experiments on tilapia farming (Lee and Namisi 2016). However, at present, the industry includes more species such as catfish, trout in fresh water, tilapia in fresh and brackish water, milkfish, and prawns in marine waters (MALF 2016). Nonetheless, production is not substantially large amounting to 4000 tonnes per annum (MALF 2016). Women have been active in aquaculture activities in Tanzania, particularly in the farming of seaweeds (Kappaphycus and *Eucheuma*) for carrageenan production, e.g., in Zanzibar (Msuya 2013). There are private mariculture operations with commercial farms for prawns at Bagamoyo and Mafia, where several hundred employment opportunities are being realized. The large-scale prawn farm on Mafia Island produces around 350 metric tonnes of prawn per year.

Despite its importance and expansion worldwide, aquaculture is known to negatively impact the aquatic environment if it is not well designed and implemented (Marinho et al. 2013). Dissolved inorganic and particulate organic matter of the uneaten food remains, as well as dead fish, feces, and excretion products from intensive aquaculture farms cause negative effects to the environment (Marinho et al. 2013). Aquaculture is also associated with the destruction of coastal habitats such as mangrove forests to establish fish farms as well as with the environmental impacts caused by the discharge of polluted waters on adjacent ecosystems (Neto et al. 2015). Concerted efforts including planning, legislating, compliance, and monitoring of the environmental quality of the medium where farming takes place are required to minimize these risks (Neto et al. 2015). Given its massive benefits on food production and economic profits, the scientific community has, over the past two decades, devised strategies to minimize its negative impacts instead of banning this activity.

Different types of farming of aquatic organisms are practiced in various regions of the world. One of the known types particularly in the West Indian Ocean (WIO) region is mariculture of sea cucumbers (Lucas et al. 2019), which are recognized for their important role in maintaining marine ecosystem health and in the generation of foreign income. However, they are still farmed in rudimentary ways (Purcell et al. 2016). To improve the farming, recommendations, and practices of integrating sea cucumbers and other marine organisms have been put forward and practiced. Recent studies have shown the importance of producing sea cucumbers in Integrated Multi-Trophic Aquaculture (IMTA) system (Beltran-Gutierrez et al. 2016; Davis et al. 2011; Fabiani 2013; Namukose et al. 2016). IMTA aims to be an ecologically balanced aquaculture practice that co-cultures species from multiple trophic levels to optimize the recycling of farm waste as a food resource (Ren et al. 2012). Mariculture under an IMTA system utilizes the ecosystem services provided by organisms of low trophic level such as seaweed and sea cucumbers (Barrington et al. 2009). Apart from usage of ecosystem services, this form of aquaculture that produces benthic macro-invertebrates, such as deposit feeding sea cucumbers, is also a means for generating income (Davis et al. 2011). A study by Hayashi et al. (2010) show that in an integrated system, seaweed provides shading for sea cucumbers amidst intensive heat at low tide and were also used as a potential source of food. Several studies (Beltran-Gutierrez et al. 2016; Fabiani 2013; Namukose et al. 2016) highlight the importance of an appropriate stocking density of sea cucumbers for profit optimization under and ecologically sustainable IMTA system.

Until recently, little research in Tanzania has addressed in a participatory, holistic and integrated manner, the feasibility of IMTA for sea cucumbers as a means to increase yield and foster livelihoods in Tanzania. Issues pertinent to the goals of specific projects were addressed, while the whole set of challenges facing the sea cucumber farming community was often overlooked. This chapter presents an overview of the IMTA of sea cucumbers in Tanzania including challenges faced. Its analysis aims to unravel the potential of adopting IMTA for a rapid growth of aquaculture as a market and demand response.

2 Methodology

The chapter uses available published and grey literature on the farming of sea cucumbers particularly from selected endeavors in Tanga (northern Tanzania) and Zanzibar Island, Tanzania, to understand which species of sea cucumbers are currently farmed, patterns, rates and impacts, and management interventions. Gaps and bottlenecks in management are highlighted. Special emphasis is placed on adoption of IMTA as a feasible economic and ecological method for production of sea cucumbers in Tanzania and the WIO region. Recent work and experiences on IMTA from various regions of the world is referred to discern good practices and areas for further investigation.

2.1 Study Area

This review focusses on two areas: Tanga (mainland Tanzania) and Zanzibar Island. In Tanga, a study by Fabiani (2013) focused on the Pangani district, which is among the areas where seaweed is produced in Tanzania. It is located at around 5° 24′S and 38° 59′ E in the northeast of Tanzania, about 50 km south of Tanga town, at the mouth of the Pangani River (Gramly 1981). In the south, there is a national park called Saadani, which extends up to Bagamoyo District (Pangani District 2008). The warmer seasons in the district are from December to February, while May to July are the coolest months. Temperatures seasonally vary from 24 to 33 °C (Pangani District 2008). The Pangani District has good potential for developing polyculture of seaweed and sea cucumbers. In the past, sea cucumbers were naturally abundant within the vicinity (Fabiani personal communication with villagers). The area also has a proven potential for seaweed farming as villagers have been farming seaweed since 1990s. In addition, artisanal fishing has been conducted in the area (Crawford and Shalli 2007).

The second area is in Kiwani Bay, south of Zanzibar, close to the Bweleo and Muungoni villages on the south-western part of Unguja Island, Zanzibar (Fig. 9.1). These sites were selected for studies by Namukose et al. (2016) and Beltran-Gutierrez et al. (2016) Since the Kiwani bay experiences relatively strong currents during high tide, with the substrate comprised of coarse to medium-coarse sandy sediment and seagrass patches, this bay was considered suitable for sea cucumber farming (Namukose et al. 2016).

3 Potential of IMTA of Sea Cucumbers and Seaweed in Tanzania

Tanzania has a potential for aquaculture including the farming of sea cucumbers, offering prospects of better incomes and employment for its people (Lee and Namisi 2016). It has a coastline of approximately 1424 km long and its territorial waters cover an area of 64,000 km^2 (Bugomba 2012). Three large offshore islands (Mafia, Pemba, and Unguja), where much of inshore artisanal fishing is done presently, also have a great potential for IMTA of sea cucumbers.

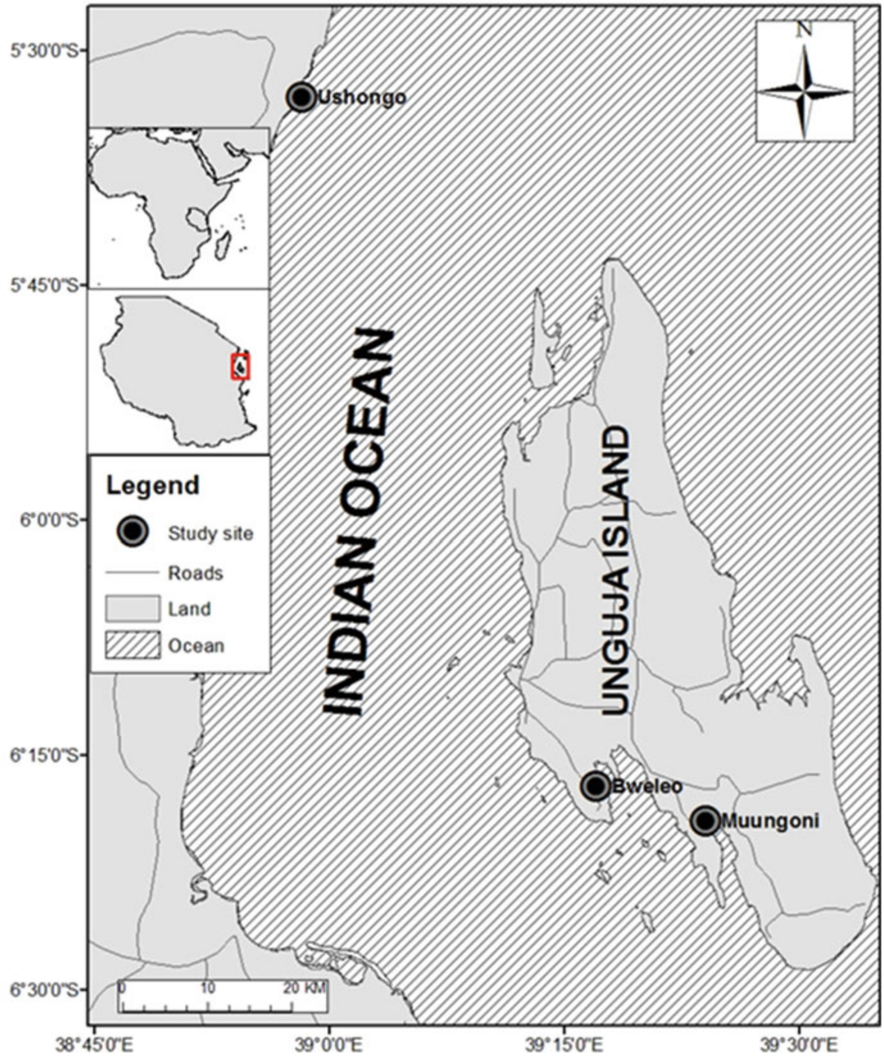


Fig. 9.1 Map of Tanzania showing IMTA experimental sites

3.1 Seaweed Farming

Seaweed farming in Tanzania is among the most important economic activities for coastal residents and is mostly conducted by women (Hedberg et al. 2018). The farming activity supports the socioeconomic livelihood of coastal communities (Radulovich et al. 2015). For instance, in Zanzibar, seaweed farming is one of top-three important economic activities together with clove and tourism in regard to foreign income earnings (Said et al. 2018). The two commercial species

Fig. 9.2 Farm of the seaweed, *Euchema denticulatum*, at Ushongo village in Pangani

commonly produced are *Eucheuma* and *Kappaphycus*. Although the farmed strains were mainly imported from the Philippines, these species are also found naturally in Tanzania (Bryceson 2002). There is extensive experience in seaweed farming in Tanzania dating back to 1989. Currently, around 26,000 seaweed farmers are located in Zanzibar, and 5000 seaweed farmers were counted in 2012 in mainland Tanzania (Msuya and Hurtado 2017). In 2012, the quantity of seaweed exported from Zanzibar (in dry weight) was approximately 14,400 MT for a total value of about US $3.6 million (Breuil and Grima 2014). Seaweeds have been used in the manufacturing industry for products of hydrocolloid components, such as alginate, agar, and carrageenan (Radulovich et al. 2015). These hydrocolloids are used by the biotechnology industries for cosmetics, food, pharmaceutical products, paper, and textiles, as stabilizers, thickeners, emulsifiers, and fillers (Khalil et al. 2018). The species farmed in Tanzania produce carrageenan (Fig. 9.2).

In Tanzania, there are several possibilities of adding value to the culture of seaweed including modifying methods of culture, processing, and marketing. In recent years, the Zanzibar Seaweed Cluster Initiative (ZaSCI) has been adding value through the production of seaweed soaps, seaweed powder, massage oil, body cream, cakes, cookies, jam, puddings, and salads. Body creams, soaps, and powder are marketed commercially in and outside Zanzibar (Msuya 2013; Msuya and Hurtado 2017; Seif 2013) and ZaSCI-various reports.

3.2 Sea Cucumbers Resources

Sea cucumbers are echinoderms from the class Holothuroidea and are listed among the most valuable species on the Chinese seafood market, with the dried body wall sold as *beche de mer or trepan* (Purcell et al. 2013; Uthicke et al. 2004). They are found in seas and oceans from the intertidal zone to the deep sea all over the world (Xu et al. 2015). As benthic detritus feeders, they are able to ingest muddy, sandy sediments and assimilate the organic matter in it (Altamirano et al. 2017). Through their feeding, they recycle nutrients in the water column and hence increase primary production, for example, in coral reefs and seagrass ecosystems (Namukose et al. 2016). In addition, they also facilitate bacterial activities in sediments, by decomposing organic matter (Altamirano et al. 2017). A study by Purcell et al. (2012) indicated that there are 1200 species of sea cucumbers, of which 70 are of commercial importance including tropical and temperate species. The main driving force beyond the sea cucumber fishery and aquaculture is the growing consumer market, especially in China (Xu et al. 2015). In Tanzania, like other parts of the world, sea cucumbers are also regarded as playing a vital role in the maintenance of marine ecosystem health and in the generation of foreign exchange income (Table 9.1) (Eriksson et al. 2010; Jiddawi and Ohman 2002). Overfishing of sea cucumbers in recent decades has posed a serious threat to the marine ecosystem

Table 9.1 Commercial sea cucumber species harvested in Tanzania. Source: modified from Mgaya and Mmbaga (2007) and Purcell et al. (2012)

Scientific Name	Common Name	Local Name
Actinopyga echinites	Deep water redfish	Unknown
A. mauritiana	Surf redfish	Mbura-khaki
A. miliaris	Blackfish	Kijino
Bohadschia argus	Leopard Tigerfish	Barango
B. marmorata	Brown-spotted sandfish	Unknown
Holothuria atra	Lollyfish/blackfish	Pesa
H. cinerascens	Zanga fleur	Unknown
H. edulis	Pinkfish	Unknown
H. Fuscogilva	White Teatfish	Pauni nyeupe
H. fuscopunctata	Elephant trunkfish	Unknown
H. Leucospilota	Snakefish	Sumu /Kichupa
H. nobilis	Black Teatfish	Pauni - nyeusi/Chui
H. parva	Unknown	Unknown
H. scabra	Sandfish	Jongoo mchanga
H. spinifera	Brownfish	Nanasi
Pearsonothuria graeffei	Blackspotted	Unknown
Stichopus chloronotus	Greenfish	Unknown
St. herrmanni	Curryfish	Unknown
Thelenota ananas	Prickly redfish	Spinyo mama
Thelenota anax	Amber fish	Unknown

(Jiddawi and Ohman 2002) and to the livelihoods of coastal communities (Eriksson et al. 2010). Despite their importance for the country, the abundance of sea cucumbers has declined as a result of overfishing, climate change, and changes in market structure (Eriksson et al. 2010; Yunwei et al. 2007). While Tanzania produced as much as 1644 metric tonnes in 1996, the production has sharply declined to only 10 metric tonnes in 2004 (Mgaya and Mmbaga 2007).

In Zanzibar, catch declines were reported by Jiddawi (1997), in Mtwara by Guard (1998), and Kithakeni and Ndaro (2002) made similar observations for Dar es Salaam. Furthermore, 13 out of 30 sea cucumber species found in Zanzibar are exploited commercially and are mostly caught below the minimum legal landing size (Eriksson et al. 2010). Consequently, the authorities in Tanzania decided to impose a moratorium on the fishery in 2006 to minimize the further degradation of the resources. However, as of yet no significant recovery has been noted (Eriksson et al. 2010). The focus at the moment should be the promotion of mariculture of sea cucumbers which is an alternative approach for increasing production in Tanzania (Eriksson et al. 2012; Kunzmann et al. 2018).

4 Genetic Population Structure of Sea Cucumbers

Studies on population genetic structures in an aquaculture context are becoming more important and have recently been used in management decisions for invertebrate organisms including holothurians (Soliman et al. 2016). The increasing demand for sea cucumbers and their ecological importance have triggered more studies on the sea cucumbers genetic population structure (Purcell et al. 2018). The understanding of the mechanisms by which demographic exchange can maintain gene flow and overcome local extinction and of the translocation effects of specimens is essential in this context. The degree of inter-population connectivity and the location of genetic breaks shared among species in the community define the spatial scale at which management is most effective in ensuring population persistence (Soliman et al. 2016).

Likewise, a large number of artificially produced sea cucumber released from aquaculture facilities might alter the genetic composition of wild populations by either displacing them or through interbreeding (An et al. 2013; Han et al. 2016). Furthermore, there is growing interest in the optimization of the genetic characteristics of the cultured species to avoid low seed performance (Kim et al. 2008). It has become clear from former studies that for successful breeding to take place, the base population must have sufficient genetic variation and that good estimates of genetic diversity can help to conserve the genetic resources (Munguía-Vega et al. 2015). Therefore, a genetic monitoring system is necessary to avoid the loss of genetic variation in sea cucumber aquaculture activities. The use of different molecular methods and DNA markers, including allozymes, amplified fragment length polymorphism (AFLP), expressed sequence tags (EST), microsatellite, mitochondrial DNA, restriction fragment length polymorphism (RFLP), random amplification of polymorphic DNA (RAPD) and single nucleotide polymorphism (SNP) markers have allowed rapid progress in a variety of aquaculture studies (Yang et al. 2015). For example, microsatellite markers have been used for various analyses of sea cucumber populations to examine the reproductive contribution of released sea cucumber specimens into natural populations (Kim et al. 2008). Furthermore, the population genetic structure of *H. scabra* in Zanzibar, Tanzania has been recently studied to provide genetic baseline data for this region. Microsatellite genotyping indicates low but significant differences between populations within the Zanzibar archipelago, with an overall low genetic diversity (Steinmann et al. 2019).

5 Potential and Challenges of Integrated Multi-Trophic Aquaculture

5.1 Potential of Integrated Multi-Trophic Aquaculture

5.1.1 Sea Cucumber Seeds

One of the major limiting factors to the IMTA of sea cucumber farming in Tanzania is the lack of hatchery systems for producing seeds. People planning to venture on IMTA of sea cucumbers depend on wild sources, which are not always available. Insufficient supply of sea cucumber seeds coupled with an absence of a regulatory framework that could provide incentives to IMTA adopters have shown to be drawbacks for IMTA establishment in Tanzania. However, in 2018 the FAO in collaboration with the Korea International Cooperation Agency (KOICA) and the Government of Zanzibar, established a Multi-Species Mariculture Project that includes one commercial hatchery for the production of juveniles of mud crabs, milkfish, and sea cucumbers. This hatchery is expected to produce one million sea cucumber juveniles by 2020 (Menezes 2018). Should this hatchery be effectively managed, it will increase the availability of sea cucumber seed in Tanzania.

5.1.2 Sea Cucumbers and Seaweed under an IMTA System

Integrated Multi-Trophic Aquaculture (IMTA) is an ecosystem-based method to produce food from different elements of the food web. It is done through recycling nutrients such as feces and waste feed or soluble inorganic forms (Lamprianidou et al. 2015). The organisms from different trophic levels effectively convert nutrients from an organic to an inorganic form (DFO 2013). The process involves recuperating some of the nutrients in collected biomass. The main target is to achieve environmental sustainability through bio-mitigation, economic stability through product diversification and risk reduction, and social acceptability (Chopin et al. 2010). IMTA goes beyond environmental sustainability; it provides economic diversification and reduces economic risk when suitable species are chosen.

Nowadays, IMTA advanced systems have several other components such as crustaceans in mid-water reefs; deposit feeders such as sea cucumbers, sea urchins and polychaetes in bottom cages or in suspended trays and bottom-dwelling fish in bottom cages for either different or similar functions but for different size brackets of particles (Lamprianidou et al. 2015).

5.1.3 Economic Viability of IMTA

One of the significant roles of economic viability analysis is to understand tradeoffs among IMTA activities and options for development. According to Kunzmann et al. (2018) generally, performance in terms of returns varies substantially between IMTA and traditional monoculture system. However, a higher economic yield is normally achieved in IMTA when compared to a monoculture system. So far, a great deal of effort has been put into promoting traditional monoculture and polyculture as alternative livelihood activities in Tanzania. Hitherto, in the long-term, even with the best outcomes in terms of profit, these efforts are not likely, on their own, to substantially reduce environmental pollution (Kinney 2017). Economic analysis of IMTA shows that these activities should be viewed as part of a large system that includes more than one species from different trophic levels (Alexander et al. 2015). IMTA can have a whole range of economic and ecological benefits compared with monocultures, including greater overall production, more product diversity and positive ecosystem services (Ferreira et al. 2012). It is argued that the cost of setting up IMTA does not need to be a great challenge if it builds on a monoculture setup which is already well established like in the seaweed farms. The infrastructure of seaweed farming is well developed in Tanzania and the cost of expanding to IMTA is minimal due to the structures already in place. It is thus much more cost-effective to convert existing fish farms to IMTA than to build a brand new IMTA facility from scratch. The improved efficiency and the extra benefit of broader commercial and valuable products (e.g. seaweed and sea cucumbers instead of one product (mostly farmed seaweed) could offset the start-up costs.

The IMTA concept is highly flexible and can be developed in open or closed systems (Barrington et al. 2009). However, local participation in IMTA is currently non-existent in Tanzania, though it is an area with the potential to employ large numbers of people and generate large amounts of revenue. Some pilot studies on economic analysis of combined seaweed and sea cucumber farms show how the appropriate IMTA can be achieved.

5.1.4 Community Perception of IMTA

The community perceptions provide important information about the way communities and other stakeholders value IMTA (Kinney 2017). However, there are also concerns about the activity's impacts, and parts of the public remain largely unaware of IMTA of seaweed and sea cucumber. In order to improve public understanding and support for seaweed and sea cucumber culture, a mix of long and short-term approaches are required. This is particularly important to ensure that decisions about IMTA use the most recent and relevant information with regards to the activity's social impacts and that it creates meaningful dialogues within communities. There are opportunities for the government and the communities to build on this activity and increase awareness of the IMTA of seaweed and sea cucumbers specifically on socioeconomic and environmental benefits. In addition, regular monitoring of public opinion is important as communities' perceptions tend to change quickly and normally vary across different aquaculture production systems (Mazur and Curtis 2008).

5.1.5 Promising Market

Sea cucumbers have been cultivated in Chinese IMTA systems for many generations together with organisms like seaweed and fin fishes (Perez and Brown 2012). Thus, the combination of sea cucumbers with the high market value of seaweed may give good grounds to farm sea cucumbers in IMTA systems in Tanzania similarly to how it is done in countries like Madagascar and China. There is high demand and thus a high market value for these organisms across Asia, although not yet in Tanzania. For example, in China it is common to eat sea cucumbers together with other seafood. On the Chinese market for sea cucumbers the average price for *H. scabra* of less than 10 cm product length was (in 2016) around US$213 per kg and US$5.5 per individual. Equally, for *H. scabra* larger than 10 cm length the average price per kg was US$570 per kg and US$54 per individual in Hong Kong stores (Purcell et al. 2018). In Tanzania there has been a large market of selling sea cucumbers to Chinese traders. This provides an opportunity to continue selling should the production of sea cucumbers (including in IMTA) can be strengthened (Fig. 9.3).

5.2 Challenges of IMTA of Sea Cucumbers

The major challenges facing Tanzania's IMTA include lack of sea cucumbers seed, lack of capital investment, poaching, low skills, and conflict of interest with other users of the coastal zone i.e. fishers. Some researchers (Beltran-Gutierrez et al. 2016; Davis et al. 2011; Fabiani 2013; Namukose et al. 2016) have noted the challenges related with the dependence on wild sea cucumber seed collection that not only could affect the stock in the ecosystem but could also affect the stocking plan for the farmers. More importantly, the inadequate supply of sea cucumber seed will be a hurdle to the growth of IMTA. Farmers are likely to give up farming because they run into shortage of seeds. However, if the currently opened marine hatchery in Zanzibar operates successfully, farmers are likely to get sufficient sea cucumber seed. But if the hatchery operates haphazardly producing seeds just occasionally, the seed supply will remain an obstacle to IMTA development. Other factors that are

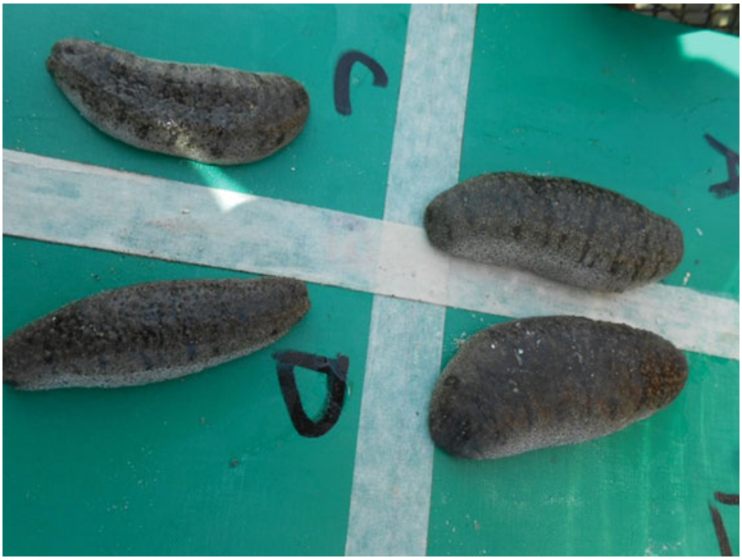


Fig. 9.3 Sandfish, *Holothuria scabra*, during experiment at Ushongo in Pangani

affecting the growth of IMTA include lack of a comprehensive aquaculture policy (Fabiani 2013). Indeed, improvements in IMTA systems, such as increasing productivity, and developing a sustainable mechanism for production and distribution of inputs, are challenges that still remain to be addressed.

6 Recommendations

- Sea cucumber and seaweed grow better when appropriately combined in an IMTA system.
- Enhancement of an IMTA of sea cucumber and sea seaweed can generate additional income for coastal communities.
- High investment costs, especially from construction materials to prevent sea cucumbers from escaping, require more attention.
- Technical expertise especially on the use of suitable infrastructures for IMTA is still lacking and more training of culturists is needed.
- Sea cucumber hatchery operations should be strengthened to overcome the problem of seed shortages.
- Efforts to improve IMTA should go hand-in-hand with strategies for adoption of new techniques.
- While IMTA could enhance mariculture in the country, activities need constant monitoring to preserving the marine ecosystem.

References

Alexander KA, Potts TP, Freeman S, Israel D, Johansen J, Kletou D, Meland M, Pecorino D, Rebours C, Shorten M, Angel DL (2015) The implications of aquaculture policy and regulation for the development of integrated multi-trophic aquaculture in Europe. Aquaculture 443:16–23. https://doi.org/10.1016/j.aquaculture.2015.03.005

Altamirano JP, Recente CP, Rodriguez JC (2017) Substrate preference for burying and feeding of sandfish *Holothuria scabra* juveniles. Fish Res 186:514–523. https://doi.org/10.1016/j.fishres.2016.08.011

An HS, Lee JW, Hong SW, Hong HN, Park JY, Myeong JI, An CM (2013) Genetic differences between wild and hatchery populations of red sea cucumber (*Stichopus japonicus*) inferred from microsatellite markers: implications for production and stocking programs design. Genes Genom 35(6):709–717

Barrington K, Chopin T, Robinson S (2009) Integrated multi-trophic aquaculture (IMTA) in marine temperate waters. Integrated mariculture: a global review. FAO Fisheries and Aquaculture Technical Paper, 529, pp 7–46

Beltran-Gutierrez M, Ferse SCA, Kunzmann A, Stead SM, Msuya FE, Hoffmeister TS, Slater MJ (2016) Co-culture of sea cucumber Holothuria scabra and red seaweed *Kappaphycus striatum*. Aquac Res 47(5):1549–1559. https://doi.org/10.1111/are.12615

Breuil C, Grima D (2014) Baseline Report Tanzania. SmartFish Programme of the Indian Ocean Commission, Fisheries Management FAO component, Ebene, Mauritius

Bryceson I (2002) Coastal aquaculture developments in Tanzania: sustainable and non-sustainable experiences. AMBIO: A J Human Environ 31(7):537–542

Bugomba K (2012) The impact of coastal community action fund on the livelihoods of artisanal fishers in coastal areas of Tanzania. United Nations University, Fisheries Training Program, Final project

Chopin T, Troell M, Reid G, Knowler D, Robinson S, Neori A, Buschmann A, Pang S, Fang J (2010) Integrated multi-trophic aquaculture (IMTA)—A responsible practice providing diversified seafood products while rendering biomitigating services through its extractive components. Abstracts. Aquaculture Europe

Crawford B, Shalli MS (2007) A comparative analysis of the socio-economics of seaweed farming in two villages along the mainland coast of Tanzania, p 9

Davis B, Stead S, Jiddawi NMA, Slater M (2011) A novel polyculture system for sea cucumber Holothuria scabra and seaweeds (*Euchemadenticul atum* and *Kappaphycus alvarezii*) in Tanzanian lagoons

DFO (2013) Review of the organic extractive component of Integrated Multi-trophic Aquaculture (IMTA) in Southwest New Brunswick with Emphasis on the Blue Mussel. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/056

Eriksson BH, de la Torre-Castro M, Eklof J, Jiddawi N (2010) Resource degradation of the sea cucumber fishery in Zanzibar, Tanzania: a need for management reform. Aquat Living Resour 23(4):387–398. https://doi.org/10.1051/alr/2011002

Eriksson H, de la Torre-Castro M, Olsson P (2012) Mobility, expansion and Management of a Multi-Species Scuba Diving Fishery in East Africa. PLoS One 7(4):e35504. https://doi.org/10.1371/journal.pone.0035504

Fabiani G (2013) Community-led integrated polyculture of sea cucumber Holothuria scabra and seaweed *Kappaphycus alvarezii* at Ushongo, Pangani in Tanzania. MSc thesis International Studies in Aquatic Tropical Ecology (ISATEC), Bremen University,

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

FAO (2016) The state of world fisheries and aquaculture. Contributing to food security and nutrition for all. FAO, Rome

FAO (2018) Fishery and aquaculture statistics global production by production source 1950–2016 (FishstatJ). In: FAO Fisheries and Aquaculture Department. FAO, Rome

Ferreira J, Pardini R, Metzger JP, Fonseca CR, Pompeu PS, Sparovek G, Louzada J (2012) Towards environmentally sustainable agriculture in Brazil: challenges and opportunities for applied ecological research. J Appl Ecol 49(3):535–541. https://doi.org/10.1111/j.1365-2664.2012.02145.x

Gramly RM (1981) Archaeological reconnaissance at Pangani Bay. Tanzania Notes Rec 86(87):17–28

Guard M (1998) Marine biological and marine resource use surveys in the Mtwara District, Tanzania. Report no.4 local resource use within and adjacent to Mnazi Bay. Frontier-Tanzania marine research Programme. The Society for Environmental Exploration and the University of Dar es Salaam, p 30

Han QX, Keesing JK, Liu DY (2016) A review of sea cucumber aquaculture, ranching, and stock enhancement in China. Rev Fish Sci Aquac 24(4):326–341. https://doi.org/10.1080/23308249.2016.1193472

Hayashi L, Hurtado AQ, Msuya FE, Bleicher-Lhonneur G, Critchley AT (2010) A review of Kappaphycus farming: prospects and constraints. In: Seaweeds and their role in globally changing environments, vol 15. Springer Nature, pp 251–283. https://doi.org/10.1007/978-90-481-8569-6_15

Hedberg N, von Schreeb K, Charisiadou S, Jiddawi NS, Tedengren M, Nordlund LM (2018) Habitat preference for seaweed farming - a case study from Zanzibar, Tanzania. Ocean Coast Manag 154:186–195. https://doi.org/10.1016/j.ocecoaman.2018.01.016

Jiddawi N (1997) The reef dependent fisheries of Zanzibar. Proceedings of the national conference on coral reefs. Coral reefs: values, threats and solutions. Zanzibar, Tanzania

Jiddawi NS, Ohman MC (2002) Marine fisheries in Tanzania. Ambio 31(7–8):518–527. https://doi.org/10.1639/0044-7447(2002)031[0518:Mfit]2.0.Co;2

Khalil HPSA, Lai TK, Tye YY, Rizal S, Chong EWN, Yap SW, Hamzah AA, Fazita MRN, Paridah MT (2018) A review of extractions of seaweed hydrocolloids: properties and applications. Express Polym Lett 12(4):296–317. https://doi.org/10.3144/expresspolymlett.2018.27

Kim MJ, Choi TJ, An HS (2008) Population genetic structure of sea cucumber, *Stichopus japonicus* in Korea using microsatellite markers. Aquac Res 39(10):1038–1045. https://doi.org/10.1111/j.1365-2109.2008.01962.x

Kinney H (2017) Aquaculturists' perceptions of Integrated Multi-Trophic Aquaculture (IMTA)

Kithakeni T, Ndaro SG (2002) Some aspects of sea cucumber, *Holothuria scabra* (jaeger, 1935), along the coast of Dar Es Salaam

Kobayashi M, Msangi S, Batka M, Vannuccini S, Dey MM, Anderson JL (2015) Fish to 2030: the role and opportunity for aquaculture. Aquac Econ Manag 19(3):282–300. https://doi.org/10.1080/13657305.2015.994240

Kunzmann A, Beltran-Gutierrez M, Fabiani G, Namukose M, Msuya FE (2018) Integrated seaweed–sea cucumber farming in Tanzania. West Indian Ocean J Mar Sci 17(2):35–50

Lamprianidou F, Telfer T, Ross LG (2015) A model for optimization of the productivity and bioremediation efficiency of marine integrated multitrophic aquaculture. Estuar Coast Shelf Sci 164:253–264. https://doi.org/10.1016/j.ecss.2015.07.045

Lee R, Namisi P (2016) Baseline study on Tanzania fisheries. Draft final report. Danish Ministry of Foreign Affairs

Lucas JS, Southgate PC, Tucker CS (2019) Aquaculture: farming aquatic animals and plants. John Wiley & Sons, West Sussex

Ministry of Agriculture, Livestock and Fisheries Development (MALF) (2016) Tanzania fisheries sector: challenges and opportunities

Marinho G, Nunes C, Sousa-Pinto I, Pereira R, Rema P, Valente LMP (2013) The IMTA-cultivated *Chlorophyta ulva* spp. as a sustainable ingredient in Nile tilapia (Oreochromis niloticus) diets. J Appl Phycol 25(5):1359–1367. https://doi.org/10.1007/s10811-012-9965-3

Mazur NA, Curtis AL (2008) Understanding community perceptions of aquaculture: lessons from Australia. Aquac Int 16(6):601–621. https://doi.org/10.1007/s10499-008-9171-0

Menezes A (2018) Development of Mariculture in Zanzibar, Tanzania. FAO Aquaculture Newsletter 59:41–42

Mgaya Y, Mmbaga T (2007) Sea cucumbers in Tanzania. Commercial Sea cucumbers: a review for the Western Indian ocean. WIOMSA Book Series No. 5, pp. 51–56

Msuya FE (2013) Social and economic dimensions of carrageenan seaweed farming in the United Republic of Tanzania. In: Valderrama D, Cai J, Hishamunda N, Ridler N (eds) Social and economic dimensions of carrageenan seaweed farming, Fisheries and aquaculture technical paper no. 580. FAO, Rome, pp 115–146

Msuya FE, Hurtado AQ (2017) The role of women in seaweed aquaculture in the Western Indian Ocean and South-East Asia. Eur J Phycol 52(4):482–494. https://doi.org/10.1080/09670262.2017.1357084

Munguía-Vega A, Sáenz-Arroyo A, Greenley AP, Espinoza-Montes JA, Palumbi SR, Rossetto M, Micheli F (2015) Marine reserves help preserve genetic diversity after impacts derived from climate variability: lessons from the pink abalone in Baja California. Glob Ecol Conserv 4:264–276

Namukose M, Msuya FE, Ferse SCA, Slater MJ, Kunzmann A (2016) Growth performance of the sea cucumber Holothuria scabra and the seaweed *Eucheuma denticulatum*: integrated mariculture and effects on sediment organic characteristics. Aquac Environ Interact 8:179–189. https://doi.org/10.3354/aei00172

Neto RM, Nocko HR, Ostrensky A (2015) Environmental characterization and impacts of fish farming in the cascade reservoirs of the Paranapanema River, Brazil. Aquac Environ Interact 6(3):255–272. https://doi.org/10.3354/aei00130

Pangani District (2008) Pangani District investment profile. Pangani, Tanga Region in Tanzania

Perez ML, Brown EO (2012) Market potential and challenges for expanding the production of sea cucumber in South-East Asia

Purcell SW, Samyn Y, Conand C (2012) Commercially important sea cucumbers of the world. Southern Cross University, Coffs Harbour

Purcell SW, Mercier A, Conand C, Hamel JF, Toral-Granda MV, Lovatelli A, Uthicke S (2013) Sea cucumber fisheries: global analysis of stocks, management measures and drivers of overfishing. Fish Fish 14(1):34–59. https://doi.org/10.1111/j.1467-2979.2011.00443.x

Purcell SW, Conand C, Uthicke S, Byrne M (2016) Ecological roles of Exploited Sea cucumbers. Oceanogr Mar Biol Annu Rev 54(54):367–386. https://doi.org/10.1201/9781315368597

Purcell SW, Williamson DH, Ngaluafe P (2018) Chinese market prices of beche-de-mer: implications for fisheries and aquaculture. Mar Policy 91:58–65. https://doi.org/10.1016/j.marpol.2018.02.005

Radulovich R, Neori A, Valderrama D, Reddy C, Cronin H, Forster J (2015) Farming of seaweeds. In: *Seaweed sustainability*. Elsevier, Amsterdam, pp 27–59

Ren JS, Stenton-Dozey J, Plew DR, Fang JG, Gall M (2012) An ecosystem model for optimising production in integrated multitrophic aquaculture systems. Ecol Model 246:34–46. https://doi.org/10.1016/j.ecolmodel.2012.07.020

Said AH, Kyewalyanga MS, Msuya FE, Mmochi AJ, Mwihia EW, Skjerve E, Ngowi H, Lyche JL (2018) Health problems related to algal bloom among seaweed farmers in coastal areas of Tanzania. J Public Health Epidemiol 10(8):303–312

Seif RS (2013) The influence of price on seaweed farming growth: A case of east coast region of Zanzibar

Soliman T, Fernandez-Silva I, Reimer JD (2016) Genetic population structure and low genetic diversity in the over-exploited sea cucumber *Holothuria edulis* lesson, 1830 (Echinodermata: Holothuroidea) in Okinawa Island. Conserv Genet 17(4):811–821. https://doi.org/10.1007/s10592-016-0823-8

Steinmann MN, Yussuf YS, Kühnhold H, Mirimin L, Kunzmann A (2019) High gene flow in sandfish (Holothuria scabra) in Zanzibar, Tanzania (Unpublished)

Uthicke S, Welch D, Benzie JAH (2004) Slow growth and lack of recovery in overfished holothurians on the great barrier reef: evidence from DNA fingerprints and repeated large scale surveys. Conserv Biol 18(5):1395–1404. https://doi.org/10.1111/j.1523-1739.2004.00309.x

Xu D, Su L, Zhao P (2015) Apostichopus japonicus in the worldwide production and trade of sea cucumbers. In: *Developments in aquaculture and fisheries science*, vol 39. Elsevier, Amsterdam, pp 383–398

Yang H-B, Kang W-H, Nahm S-H, Kang B-C (2015) Methods for developing molecular markers. In: Current technologies in plant molecular breeding. Springer, pp 15–50

Yunwei D, Tingting J, Shuanglin D (2007) Stress responses to rapid temperature changes of the juvenile sea cucumber (*Apostichopus japonicus* Selenka). J Ocean Univ China 6(3):275–280

Chapter 10
Indonesia Case Study

Let Us Get Political: Challenges and Inconsistencies in Legislation Related to Community Participation in the Implementation of Marine Protected Areas (MPAs) in Indonesia

Wasistini B. Barnhart and Sebastian C. A. Ferse

Abstract The process of Marine Protected Area (MPA) establishment in Indonesia entered a new stage with the shift of the political regime in the late 1990s that marked the transition from a centralized, authoritarian regime to a more democratic, decentralized one. New legislation on MPAs has become more representative and democratic and includes provisions for the involvement of communities in the establishment of MPAs, something that did not exist in the previous legislation. This chapter examines the body of legislation that covers community involvement in the MPA establishment process in Indonesia. The examination draws on an analysis of texts and documents, and includes the history of legislation on marine area management, its development, and the more recent state of MPAs in Reform Era legislation. MPAs in Indonesia have many names, falling into several categories and sub-categories defined in different pieces of legislation. These pieces are scattered in the legislation and are not easy to find. Furthermore, due to Indonesian MPAs being administered by multiple ministries and governed by multiple legislations, there are gaps and inconsistencies particularly in the differences between categories. Lastly, MPA legislation provides opportunities for communities to be informed and consulted in the MPA establishment process. However, this falls short of the active participation of communities that is required in order for MPAs to be successful. For

An extended version of this chapter has previously been published as part of a doctoral dissertation at the University of Bremen (Baitoningsih, 2015). The present text has been shortened, amended in parts, and updated to account for changes in legislation since the thesis was published.

W. B. Barnhart (✉)
Freelance Consultant, Böblingen, Germany

S. C. A. Ferse
Marine Ecology Department, Faculty of Chemistry and Biology, University of Bremen, Bremen, Germany

Leibniz Centre for Tropical Marine Research (ZMT), Bremen GmbH, Bremen, Germany

M. Wolff et al. (eds.), *Challenges in Tropical Coastal Zone Management*,
https://doi.org/10.1007/978-3-031-17879-5_10

future administrations, it is important to understand the need to involve coastal communities in every step of the MPA establishment process, beyond being informed and consulted. To support this, trainings and workshops on how to achieve higher levels of community participation for national and provincial governments, as well as a continuous evaluation process, are suggested.

Keywords MPA · Community · Participation · Establishment · Legislation · Indonesia

1 Introduction

As the largest archipelagic country in the world, marine resource management has been practiced since time immemorial in Indonesia (Noel and Weigel 2007). These practices were conducted locally, mainly based on shared tribes, kingdoms, and/or religions (Cinner 2005; Polunin 1984) Since Indonesia became a sovereign country in 1945, marine resource management is arranged as legislations that apply to Indonesian citizens instead of local practices (Cinner 2005; Ruddle and Satria 2010). This chapter draws on an analysis of texts and documents to describe the evolution of the legislation, which is mainly tied to political circumstance, and discusses the challenges this embedding entails. The establishment of Marine Protected Areas (MPAs) is chosen as a focal aspect of marine resource management in order to provide a comprehensive picture, from locally practiced to the nation-wide framework. Most of the analysis was developed in the frame of a dissertation regarding the role of local communities in MPA establishment completed in 2015 (Baitoningsih 2015). Subsequent legislation is listed to provide an up-to-date overview of relevant legislation at the time of writing, but is not analyzed in detail. Reflecting the high importance of marine resources for coastal communities in Indonesia, MPAs in the country are managed as multi-use areas with a zoning system that allows some (restricted) marine resource use (Lazuardi et al. 2020). This aspect is also reflected in the fact that MPAs are established mostly in nearshore (i.e., up to 12 nm from shore) areas, and underlines the importance of community participation in the implementation of MPAs in Indonesia (Ferse et al. 2010; Fidler et al. 2022).

2 A Brief History of Marine Resource Management in Indonesia

The history of marine resource management in Indonesia can be divided into five significant eras (Fig. 10.1), as outlined below.

Fig. 10.1 Five eras of marine resource management in Indonesia

2.1 Pre-Colonial Era (≤ Seventeenth Century)

Traditional management in the form of customary law (Indonesian: *hukum adat*) and community territorial rights (Indonesian: *hak ulayat*) is known and practiced within coastal communities since pre-colonial times. These practices involve regulation of harvesting times of particular species or of marine resources in general in order to ensure the yields (i.e., catches) are distributed equally among members of the community (Govan et al. 2008; Novaczek et al. 2011; Polunin 1984). Violation of customary laws and regulations generally resulted in customary sanctions that were either social, economic, or supernatural, or physical punishment (Ruddle and Satria 2010). Examples for such customary practices are *Sasi* in Maluku (Evans et al. 1997; Harkes and Novaczek 2000; Novaczek et al. 2011) and in West Papua (McLeod et al. 2009), and *Lilifuk* on the island of Timor, in Nusa Tenggara Timur (Anakotta et al. 2009; Baitoningsih 2015).

Sometimes harvesting times are defined by a religious practice that follows no particular pattern. A higher animist priest decides the closure time of fishing in a certain marine area after a revelation, and normal harvesting is resumed after the ban is lifted. However, the harvesting time is not celebrated as in the *Sasi* practices. Violation of these kinds of rules would usually result in supernatural sanctions, i.e., some form of spiritual repercussion. An example of such religious practice is the *Panadahi* from Raijua Island in Savu Sea, East Nusa Tenggara (Baitoningsih 2015).

Other practices apply no closure time but regulate fishing permits in order to prevent conflicts among fishermen over access to the fishing ground. The permits are issued by local rulers. Examples of these practices are *Panglima Laot* in Aceh (Wilson and Linkie 2012), *seke* in North Sulawesi, *awig-awig* in Lombok, and *petuanan laut* in Maluku (Ruddle and Satria 2010).

All of these traditional practices are underpinned by shared ethnicities, kinship (i.e., clans), and/or beliefs (Cinner 2005; Polunin 1984). As a result of Indonesia's political development during the process of becoming one country, many of these practices are no longer operative, are less wide-spread, or have been considerably modified reflecting socioeconomic and political developments (Ruddle and Satria 2010). Internal migrations of people from different ethnicities and beliefs, and different governments from the colonial era to present, contributed to the abandonment of traditional marine resource management practices (Cinner 2005; Ruddle and Satria 2010).

2.2 Dutch Colonial Era (Seventeenth Century – 1945)

During the Dutch Colonial Era (seventeenth century – 1945), the government began to establish protected areas in the early twentieth century following an international movement towards the protection of game species and/or scenic landscapes (Boomgaard 1999; Cribb 1988; Jepson and Whittaker 2002). The protected areas were managed by the Forestry Service of the Dutch Colonial Government's Department of Economic Affairs (Cribb 1988).

Sixty-six protected areas were established during this era, including three sites that contain marine areas, i.e., Sukawayana Nature Reserve in West Java, Napabalano Nature Reserve in Southeast Sulawesi, and Banyuwangi Selatan Reserve in East Java (Jepson and Whittaker 2002). However, the marine part in these three protected areas were merely an extension of terrestrial areas (Wood 2007).

2.3 Post-Independence Era (1945–1966)

In this era, no new protected area was established (Wood 2007). During this time, Indonesia was still struggling to gain international recognition as a new country, combating insurgencies, and deciding on the direction of its national development (Booth 2010; Suryo 2000).

2.4 New Order Era (1966–1998)

During this time, protected areas were managed by the Ministry of Forestry, continuing the arrangement of the colonial era (Cribb 1988) and reflecting the land-based development paradigm that was predominant in Indonesia at the time (Idrus 2009; Satria and Matsuda 2004; Siry 2011; Syarif 2009; Wiadnya et al. 2011).

Scattered references to marine affairs and fisheries in the legislation divided responsibility for their administration among the ministries of Forestry, Agriculture, and the Environment (Kusuma-Atmadja and Purwaka 1996; Satria and Matsuda 2004; Siry 2011; Syarif 2009).

Legislation pertaining to the establishment of protected areas was enacted in 1990, known as the Biodiversity Conservation Law (Kusuma-Atmadja and Purwaka 1996; Syarif 2009). Although this law mainly targeted land or forest protection, seven "Marine" National Parks were established at Seribu Islands, Cendrawasih Bay, Bunaken, Taka Bonerate, Wakatobi, Togean, and Karimunjawa (Patlis 2005; Wiadnya et al. 2011).

Following the top-down approach in every sector of the government, laws and regulations on marine management were centralized at the national level. This meant eliminating the recognition of traditional marine management systems (Boomgaard 1999). Furthermore, the top-down approach also disregarded the needs and desires of local governments in managing their resources and environment (Seymour and Turner 2002; Siry 2011; Suryo 2000). Several conflicts erupted from this different perspective on marine management between central government and local governments and communities (Erb 2012; Gustave and Borchers 2008).

Corruption played an important role during this era (Fritzen 2007; Suryo 2000), and affected the management of marine areas. Controls over fishing, such as quotas, only existed on paper, destructive fishing practices were supported by law enforcement individuals, and mangrove conversion into shrimp ponds that did not follow spatial and/or environmental management plans were some of the examples of practices involving corruption (Baitoningsih 2009; Fritzen 2007; Seymour and Turner 2002; Siry 2011; Suryo 2000). This mismanagement, along with the change in the climate pattern, led to the decline of marine resources in Indonesia (Glaser et al. 2010; Kusumanti 2013).

2.5 Reform Era (1998 – Present)

Following the economic crisis in 1997, there were growing demands for a government reform. With the new government regime, Indonesia became a more decentralized system, in which greater power and autonomy was given to provinces and districts (Fritzen 2007; Idrus 2009; Seymour and Turner 2002; Siry 2011; Syarif 2009).

Another key transformation of the Reform era was that the marine sector was granted the same priority as the agriculture and forestry sectors (Siry 2011). Accordingly, in 1999, a new ministry to deal with marine issues was established, which later became the Ministry of Marine Affairs and Fisheries (MMAF). MMAF took steps to improve marine management in order to prevent improprieties and avoid the repetition of conflicts that had taken place under the previous Soeharto administration (Gustave and Borchers 2008). Decentralization (Satria and Matsuda 2004; Siry 2011), bottom-up processes (Satria and Matsuda 2004; Syarif 2009), and stakeholder involvement (Siry 2011) were incorporated into the laws and regulations on marine management, particularly with regards to MPA establishment processes.

Following the spirit of the Reform era, in the first law setting out the authority of local government (Law 22/1999), district governments were given the permission to manage marine areas up to four nautical miles from the coastline (Article 10 Clause 3), while provinces were given the authority over marine areas between four and twelve nautical miles from the coast (Article 3). Subsequently, this law was revised by Law 23/2014, which transferred all districts' authority to manage the inshore marine areas to the provincial level. This affected numerous MPAs that had been established under districts at the village level, e.g., in the frame of the Coral Reef Rehabilitation and Management Program (COREMAP), as not all provincial governments were ready and able to provide the dedicated resources for MPA governance at the provincial level (Lazuardi et al. 2020).

3 Current Legislation on MPAs

While the newly established MMAF established several new marine-focused MPAs, several dozen MPAs in Indonesia remain under the responsibility of the Ministry of the Environment and Forestry (MoEF) as a legacy of the situation during the New Order Era. These MPAs fall under a different set of regulations and frameworks and have different targets than those established by the MMAF, which aim primarily at sustainable fisheries (MMAF 2020). As management of all MPAs is slated to eventually transition to MMAF, the remainder of the chapter focuses on those types of MPAs under the responsibility of the MMAF. MMAF distinguishes three categories of MPAs (described below), while MoEF classifies its protected areas, aimed primarily at nature conservation, into two main categories: Nature Reserve Areas and Nature Conservation Areas. To implement marine conservation, MMAF has issued a number of legislations. However, specific regulations on marine conservation framework and implementation are scattered amongst different pieces of more general legislation and are not easy to find. Two laws constitute the main point of departure for marine conservation; they are Law 31/2004 on Fisheries (subsequently revised in Law 45/2009) and Law 27/2007 on the Management of Coastal Zones and Small Islands (subsequently revised in Law 1/2014).

3.1 Law on Fisheries

Law 31/2004 was the first law under the administration of MMAF that recognized the need to conserve fishery resources. As the title of the law suggests, the principal aim of conservation of Indonesian marine areas is the sustainable management of fishery resources, rather than biodiversity conservation as suggested by IUCN (Dudley 2008). Supplementary regulations provided further explanation of how the conservation of fishery resources is to be operationalized, including identification of categories of protected areas and details of the corresponding establishment processes (Government Regulation No. 60/2007, MMAF Regulations No. 2/2009 and 30/2010; the latter two have recently been replaced by MMAF Regulation 31/2020). An overview of the laws and MMAF regulations related to marine conservation areas is given in Table 10.1.

Government Regulation 60/2007 on Fishery Resource Conservation first refers to the term Marine Conservation Area (*Kawasan Konservasi Perairan – KKP*; literally this translates to "Aquatic Conservation Areas," but it only applies to marine, not freshwater areas) for MPAs, which are broadly defined as "marine areas that are protected and managed by a zoning system to achieve sustainable management of

Table 10.1 Laws and MMAF regulations related to the management of Marine Conservation Areas

Type	Number	Concerning
Law (UU)	31/2004, revised by 45/2009	Fisheries
	27/2007, revised by 1/2014	Management of Coastal Zones and Small Islands
Government regulation (PP)	60/2007	Conservation of fisheries resources
MMAF ministerial regulation (PerMen KP)	17/2008, replaced by 31/2020	Conservation areas within coastal zones and Small Islands
	2/2009, replaced by 31/2020	Establishment procedures for marine conservation areas
	30/2010, replaced by 31/2020	Marine conservation area management and zonation plans
	13/2014	Marine conservation area networks
	21/2015	Partnerships for the Management of Marine Conservation Areas
	14/2016	Criteria and categories of marine conservation areas for marine nature tourism
	17/2016	General guidelines for the distribution of government assistance in the Ministry of Marine Affairs and Fisheries
	47/2016	Utilization of marine conservation areas
	31/2020	Management of Conservation Areas

fisheries resources and their environment" (Article 1). This category of protected area consists of four sub-categories: national parks, tourism parks, nature sanctuaries, and fish sanctuaries (Article 8). These sub-categories differ in the kinds of activities permitted there. Zones in each sub-category include some or all of the following: strictly protected areas called core zones, fishery-related use areas called sustainable fishery zones, non-fishery use areas called utilization zones, and areas used for other purposes called other zones (Article 17 Clause 4).

3.1.1 Establishment Process of Marine Conservation Areas

According to the MMAF Regulation on Establishment Procedures for Marine Conservation Areas (No. 2/2009; the process is streamlined for different conservation areas but remains largely similar in the new Regulation 31/2020 on the Management of Conservation Areas), five steps are required to establish an MPA (Fig. 10.2). A proposal for establishing a Marine Conservation Area may come

Fig. 10.2 Steps of the Aquatic Conservation Area establishment process

from different stakeholders, including individuals, community groups, research institutes, education institutes, government agencies, and NGOs (Article 9 Clause 1). The proposals need to contain ecological and/or biological data on the proposed areas and the management plans for around 25–30 years. By giving different stakeholders the opportunity to propose Marine Conservation Areas, the intention was to improve on the former centralized process administered by the Ministry of Forestry.

3.1.2 Role of Coastal Communities in the Marine Conservation Area Establishment Process

As mentioned above, community groups may propose a Marine Conservation Area. However, if the proposal comes from a different stakeholder, the role of coastal communities is limited to being informed and consulted about the proposal. First, they are informed (in Step 2) about the proposed Marine Conservation Area through "socializations." Second, they are consulted (also in Step 2) in order to provide input on the category of the proposed area that include its location and total area. The procedure for conducting socializations and public consultations is not mentioned; these could involve entire communities or only their representatives.

However, in the subsequent MMAF Regulation on Management and Zonation Plans of Marine Conservation Areas, the role of communities was enhanced. They are to be publicly consulted on the zoning and management plans of the proposed areas in two rounds of consultations (Article 30), and representatives of community groups and traditional communities are to be involved in a working group developing recommendations for the spatial plan of the Marine Conservation Area, which also requires public consultation (Article 31). Again, the procedure for conducting these public consultations or for involving community representatives is not elaborated. Thus, even though this regulation requires communities to be involved in more than one step of the MPA establishment process, their role is still limited. The entire process is mandated to government and the role of communities is largely restricted to being informed and consulted, with formal decisions being made at higher levels of government.

Furthermore, the Fisheries Law and its supplementary regulations do not contain any provision for objections or opposition from communities. It seems that the whole Marine Conservation Area establishment process is designed to gain support and approval from local communities. Since there is no provision for arbitration, the process can only be successfully concluded by avoiding disputes altogether. The process as set out in the more recent regulations thus still seems poorly adapted to social and political conditions in the more democratic Reform Era.

3.2 Law on the Management of Coastal Zones and Small Islands

This law is an elaboration of the Law on Local Government (No. 22/1999) which mentions the authority of provincial and district governments on marine waters. This law governs the spatial planning of coastal areas up to 12 nautical miles from the coastline (and is also known as the coastal spatial planning law). This law establishes four categories of use in coastal and marine areas: general use area, conservation area, area of strategic national importance, and sea lane. Each district and province that has coastal areas should allocate their areas accordingly. Further details of the procedure for developing coastal spatial plans are set out in the MMAF Regulation on Management Planning of Coastal Zones and Small Islands (No. 16/2008, later revised in No. 34/2014 and No. 23/2016). Specific procedures for conservation areas are set out in the MMAF Regulation on Conservation Areas within Coastal Zones and Small Islands (No. 17/2008, later replaced by MMAF Regulation 31/2020). An overview of laws and regulations related to the management of coastal zones and small islands is given in Table 10.2 and small islands are given in Table 10.2.

Law 27/2007 mandates the establishment of conservation areas in coastal and marine areas. Furthermore, the MMAF Regulation on Management Planning of Coastal Zones and Small Islands (No. 16/2008 and revisions) defines four categories of conservation areas: Marine Conservation Area, Coastal and Small Islands Conservation Area, Maritime Conservation Area, and Protected Coastlines (Article 15 Clause 4). The procedures for establishing different categories of conservation areas are set out in the MMAF Regulation on Conservation Areas within Coastal Zones and Small Islands (No. 17/2008) and the successor, Regulation 31/2020. While Marine Conservation Areas were governed by Regulation 2/2009, Regulation 17/2008 governed two categories of conservation areas, i.e., Coastal and Small Islands Conservation Areas and Maritime Conservation Areas. Their subsequent replacement, Regulation 31/2020, applies to all types of conservation areas in coastal, small island and marine areas.

According to Regulation 17/2008, the category Coastal and Small Islands Conservation Area (*Kawasan Konservasi Pesisir dan Pulau-pulau Kecil – KKP3K*) consisted of four sub-categories, i.e., coastal park, small islands park, coastal sanctuary, and small islands sanctuary (Article 5). The Maritime Conservation Area (*Kawasan Konservasi Maritim – KKM*) category consists of two sub-categories, i.e., Maritime Customary Protected Area and Maritime Cultural Protected Area (Article 7). The new Regulation 31/2020 on Conservation Areas distinguishes the three categories parks (with sub-categories coastal park, small islands park, marine national park, and marine tourism park), sanctuaries (with

Table 10.2 Laws and regulations related to the management of coastal zones and small islands

Type	Number	Concerning
Law (UU)	5/1983	Exclusive economic zone of Indonesia
	6/1996	Indonesian territorial waters
	27/2007, revised by 1/2014	Management of Coastal Zones and Small Islands
	32/2014	Maritime affairs
Government regulation (PP)	15/2010	Spatial planning
Presidential regulations (PerPres)	121/2012	Rehabilitation of coastal zones and Small Islands
	122/2012	Restoration of coastal zones and Small Islands
	73/2015	National Level Coordination of the Management of Coastal Zones and Small Islands
MMAF ministerial regulation (PerMen KP)	16/2008, revised by 34/2014 and 23/2016	Management planning of coastal zones and Small Islands
	17/2008, replaced by 31/2020 (see Table 10.1)	Conservation areas within coastal zones and Small Islands
	20/2008	Utilization of Small Islands and surrounding waters
	24/2016	Procedures for the rehabilitation of coastal zones and Small Islands

sub-categories coastal sanctuary, small islands sanctuary, marine nature sanctuary, and fisheries sanctuary), and Maritime Conservation Area (same sub-categories as before). This latter category of conservation area deals with submerged ancient relics, hence it will not be discussed further.

Under the revised Regulation 31/2020, the three categories all may contain three types of zones: core zones, which are mandatory for all categories of conservation areas and where access and use of marine resources are highly restricted; limited-use zones, which have to be present in parks and Maritime Conservation Areas and are set aside for specific purposes, and other zones, which are not mandatory and whose specifications depend on the purpose of the type of conservation area (Articles 11–15).

3.2.1 Establishment Process of Coastal and Small Islands Conservation Areas

The steps of the establishment process for Coastal and Small Islands Conservation Areas are similar to those for Marine Conservation Areas (Fig. 10.2) (MMAF Regulation No. 17/2008 Article 9). However, in the initial Regulation 17/2008, there were differences in the details. The proposal to establish a Coastal and Small Islands Conservation Area may come from different stakeholders; however, NGOs are not mentioned (Article 10). Furthermore, in Step 2 of the process, "socializations" are not mentioned (Article 11 Clause 3). Only one round of public consultation is required at this stage; as in other regulations, no details are given on how the consultations should be conducted.

Endorsement of Coastal and Small Islands Conservation Areas requires zoning and management plans. However, in contrast to Marine Conservation Areas, whose zoning and management plans are governed by a separate regulation (No. 30/2010), no such regulation exists for Coastal and Small Islands Conservation Areas.

The new MMAF Regulation No. 31/2020 has removed the previous differences by stipulating one process that applies for all types of conservation areas (Articles 17–30). The initial proposal may come from the national or regional government, so-called customary law communities with acknowledged management areas, or individual persons. Step 2 does not mention socializations, but stipulates public consultation. The following steps, designation and endorsement, are mandated to the gubernatorial and ministerial level, with evaluation by a directorate general. Socialization is then stipulated following endorsement of the conservation area.

3.2.2 Role of Coastal Communities in the Coastal and Small Islands Conservation Areas Establishment Process

The first Reform Era-law on the management of coastal zones and small islands states that the interests of different communities should be accommodated in the design of coastal spatial plans (Law No. 27/2007, Article 61). However, the role of communities in coastal spatial planning is limited to Step 2 of the process. The absence of a regulation on zoning and management plans for Coastal and Small Islands Conservation Areas further limited their involvement (this has been amended to some extent by the new Regulation 31/2020, which established the same procedure for the establishment of all conservation areas). Law 27/2007 contained no provision for community input to these plans. There was a provision for objections to be voiced during the establishment process in the coastal spatial planning law; however, objections could only be raised before the plans are endorsed (Article 60 Clause 1 g), which seems impossible to apply given the very limited provision for communities' involvement prior to this stage. It seems that the principal objective of the establishment process was to obtain support and approval from communities. The revision of the law (Law No. 1/2014) amended some of the previous shortcomings, aiming in particular to better accommodate customary communities.

3.3 Connections and Inconsistencies in MPA Legislation

MPAs in Indonesia have many names, based on the categories and sub-categories defined in different pieces of legislation.

Table 10.3 Summary of inconsistencies in MPA regulations by MMAF and subsequent resolution in Regulation 31/2020, which replaced the two earlier regulations

No.	Topic	Aquatic Conservation Areas (MMAF Regulation No.2/2009)	Coastal and Small Islands Conservation Areas (MMAF Regulation No.17/2008)
1.	Proposers	Mentions NGOs (article 9 clause 1)	Does not mention NGOs (article 10 clause 1)
2.	Survey and potential appraisals	Mentions "socialization" activities (article 13 clause 3b)	Does not mention "socialization" activities (article 11 clause 3)
3.	Scope of areas	Up to 12 nm from the coast (article 8 clause 1 g)	From the inland border of coastal sub-districts (*kecamatan*) up to 12 nm from the coast

To date, the fisheries law and the coastal spatial planning law are broadly compatible. However, additional categories of MPAs may be introduced in the future, particularly outside the coastal areas, e.g. in the zone between the limits of territorial waters and the boundary of the exclusive economic zone (EEZ) (UNCLOS 1982) that have been defined in the more recent Law on Maritime Affairs (No. 32/2014). Currently, all MPAs in Indonesia are designated and management under government authority at the national or regional level. However, there are discussions and developments to also formally acknowledge and accommodate other forms of marine conservation, such as Locally-Managed Marine Areas (LMMAs) or Other Effective area-based Conservation Measures (OECMs; MMAF 2020).

As discussed earlier, inconsistencies are found in the different pieces of recent legislation. Moreover, the difference between Marine Conservation Areas and Coastal and Small Islands Conservation Areas is unclear (Wiadnya et al. 2011). Coastal areas cover marine waters up to 12 nautical miles from the coastline (Law No. 27/2007), and Marine Conservation Areas may also be located within this range (MMAF Regulation 2/2009 Article 8 Clause 1 g). A summary of inconsistencies in the recent MPA regulations is presented in Table 10.3. To some extent, these inconsistencies have been addressed by the recent MMAF Regulation 31/2020, which establishes a uniform approach for the different categories of conservation areas under MMAF jurisdiction. However, the discrepancy in MPAs administered by MMAF and MoEF, and the respective different legislations, remains an issue. While MoEF MPAs are part of conservation areas that contain terrestrial sections, MMAF MPAs focus primarily on marine areas. Coastal ecosystems, e.g., mangroves, coral reefs, saltmarshes, and seagrass beds, as well as their hinterlands, are connected in diverse ways that all are of relevance for the life of marine species; hence protecting only the aquatic (i.e., submerged) part of the ecosystems, without the adjacent terrestrial parts, will not provide the same benefits for conservation. For MMAF MPAs the issue has been settled based on consensus rather than science. If the majority of an MPA consists of water, it belongs to the Marine Conservation

Area category, whereas an MPA that has a bigger portion of land area is considered a coastal and small islands conservation area.

3.4 Role of Coastal Communities According to MPA Legislation

The role of the communities is essentially the same in the different regulations, and consists of being informed and consulted. Guidelines or requirements on how to involve communities are not provided; this aspect is open to interpretation. But it is certainly not envisaged that communities should be equal partners with government (Ferse et al. 2010; Sen and Nielsen 1996) or become decision makers in their own right (Borrini-Feyerabend et al. 2004). The main benefit of the provision for community participation in MPA legislation under the administration of MMAF is that communities are likely to be more aware of the establishment of an MPA in their area than under previous legislation administered by the Ministry of Forestry. Hence, unpleasant “surprises” are less likely than they were before. Still, problems arising from inadequate participation in MPA implementation, such as lack of compliance, are likely to persist. The more recent steps towards better provisions for community involvement and the recognition for other, community-based forms of management by MMAF may offer new opportunities in the coming years (Agung et al. 2022; Jack-Kadioglu et al. 2020).

4 The Way Forward

Decentralization, bottom-up processes, and stakeholder involvement are the key differences in the legislation on marine area management in the more democratic Reform Era compare to the previous eras. However, in practice, district governments interpreted the laws conservatively and did not make use of the full potential for stakeholder involvement provided by the law. Instead the focus was mainly on raising local revenues, e.g., from mining, without considering environmental factors that led into increasing of pollution. In the revision of the Law of Local Government (Law No. 23/2014), the central government shifted the authority over marine areas up to four nautical miles from the coastline from district to provincial governments (Article 27 Clause 3). Provincial governments may delegate marine area management to district governments when it is considered necessary, but in practice, this has meant that the capacity for management of many MPAs established at the district level suddenly faced significant challenges in terms of resources and preparedness use (Lazuardi et al. 2020).

Furthermore, even though bottom-up processes are encouraged, top-down command is still being practiced. Governance is still reliant primarily on leaders than the system (Suryo 2000). It is therefore a sensible strategy for MPA proposers, e.g., NGOs, local communities, or universities, to approach higher government agencies or leaders, but also involve broader stakeholders, particularly coastal communities.

While the recent administration (2014–2019) placed a strong emphasis on combating illegal fishing often carried out by foreigners, as such practice was considered the main cause of low fishery production, MPA establishment remains a main focus of the Indonesian government.

For this to succeed, it is important that the government understands the need to prioritize marine conservation in the form of MPAs, and other effective conservation measures, as an additional tool for fishery management. Cooperation and collaboration in MPA design and management are needed to improve the current state of MPAs in Indonesia. Particularly, MPAs establishment needs to involve coastal communities in every step of the process, beyond being informed and consulted. Recent developments in the legislation on MPAs in Indonesia suggest that there is increasing scope for local communities to be involved, but how this turns out in practice largely depends on the willingness and efforts of the government agencies still ultimately in charge of MPA management. Hence, trainings and workshops on how to achieve higher levels of community participation for national and provincial governments are needed. However, these trainings and workshops should be complemented by systematic follow-up in the form of continuous evaluation that analyzes the level of participation and its relation to marine management effectiveness. It will be a long process, but it is needed as part of more democratic Indonesia.

References

Agung MF, Adhuri DS, Ferse SC, Sualia I, Andradi-Brown DA, Campbell SJ, Iqbal M, Jonas HD, Lazuardi ME, Nanlohy H (2022) Marine conservation beyond MPAs: towards the recognition of other effective area-based conservation measures (OECMs) in Indonesia. Mar Policy 137: 104939

Anakotta A, Bessie D, Anakotta W (2009) Kajian Kelembagaan Daerah Perlindungan Laut Berbasis Masyarakat dengan Kearifan Lokal di Desa Bolok. *Laporan Penelitian Hibah Bersaing*. Universitas Kristen Artha Wacana, Kupang, Indonesia

Baitoningsih W (2009) Community participation in designing MPA in Spermonde archipelago, South Sulawesi, Indonesia. M.Sc. Thesis, University of Bremen, Bremen, Germany, p 90

Baitoningsih W (2015) Let's get political: community participation in the MPA establishment process in Indonesia. Dissertation. University of Bremen, Bremen, Germany, p 147. http://nbn-resolving.de/urn:nbn:de:gbv:46-00105065-15

Boomgaard P (1999) Oriental nature, its friends and its enemies: conservation of nature in late-colonial Indonesia, 1889–1949. Environ History 5(3):257–292

Booth A (2010) Government and welfare in the New Republic Indonesia in the 1950s. Itinerario-Int J History European Expansion Global Interaction 34(1):57–76. https://doi.org/10.1017/S0165115310000057

Borrini-Feyerabend G, Pimbert M, Farvar MT, Kothari A, Renard Y (2004) Sharing power. Learning by doing in co-management of natural resources throughout the world. IIED & IUCN/CEESP/CMWG, Cenesta Tehran: xxxvii + 456p

Cinner J (2005) Socioeconomic factors influencing customary marine tenure in the indo-Pacific. Ecol Soc 10(1):36

Cribb R (1988) The politics of environmental protection in Indonesia, Clayton, Australia, Centre of Southeast Asian Studies, Monash University, p 36

Dudley N (2008) Guidelines for applying protected area management categories. IUCN, Gland, Switzerland, p 86

Erb M (2012) The dissonance of conservation: Environmentalities and the environmentalisms of the poor in eastern Indonesia. Raffles Bull Zool 25:11–23

Evans SM, Gill ME, Retraubun ASW, Abrahamz J, Dangeubun J (1997) Traditional management practices and the conservation of the gastropod (Trochus nilitocus) and fish stocks in the Maluku Province (eastern Indonesia). Fish Res 31(1–2):83–91. https://doi.org/10.1016/S0165-7836(97)00011-8

Ferse SCA, Costa MM, Manez KS, Adhuri DS, Glaser M (2010) Allies, not aliens: increasing the role of local communities in marine protected area implementation. Environ Conserv 37(1): 23–34. https://doi.org/10.1017/S0376892910000172

Fidler RY, Ahmadia GN, Amkieltiela, Awaludinnoer, Cox C, Estradivari, Glew L, Handayani C, Mahajan SL, Mascia MB (2022) Participation, not penalties: community involvement and equitable governance contribute to more effective multiuse protected areas. Sci Adv 8(18): eabl8929

Fritzen SA (2007) Can the design of community-driven development reduce the risk of elite capture? Evidence from Indonesia. World Dev 35(8):1359–1375. https://doi.org/10.1016/j.worlddev.2007.05.001

Glaser M, Baitoningsih W, Ferse SCA, Neil M, Deswandi R (2010) Whose sustainability? Top-down participation and emergent rules in marine protected area management in Indonesia. Mar Policy 34(6):1215–1225. https://doi.org/10.1016/j.marpol.2010.04.006

Govan H, Aalbersberg W, Tawake A, Parks JE (2008) Locally-managed marine areas: a guide for practitioners. Locally-Managed Marine Area Network 3:64

Gustave R, Borchers H (2008) Conservation and conflict in komodo National Park. In: Biodiversity and human livelihoods in protected areas: case studies from the Malay Archipelago. Cambridge University Press, Cambridge, pp 187–202

Harkes I, Novaczek I (2000) Institutional resilience of sasi laut, a fisheries management system in Indonesia. 8th Biennial Conference of the International Association for the Study of Common Property (IACSP), Bloomington, Indiana, USA

Idrus R (2009) Hard Habits to break: investigating coastal resource utilisations and management systems in Sulawesi, Indonesia. Ph.D. Thesis, University of Canterbury, Christchurch, New Zealand, p 254

Jack-Kadioglu T, Pusparini N, Lazuardi M, Estradivari RA, Campbell S, Jakub R, Claborn K, Glew L, Rusandi A, Hakim A (2020) Community involvement in marine protected area governance. Management of marine protected areas in Indonesia: status and challenges. Ministry of Marine Affairs and Fisheries and Yayasan WWF Indonesia, Jakarta, Indonesia, pp 23–55

Jepson P, Whittaker RJ (2002) Histories of protected areas: internationalisation of conservationist values and their adoption in the Netherlands indies (Indonesia). Environ History 8(2):129–172

Kusuma-Atmadja M, Purwaka TH (1996) Legal and institutional aspects of coastal zone management in Indonesia. Mar Policy 20(1):63–86

Kusumanti I (2013) Fisheries dependence and livelihood vulnerability in Jakarta Bay and Seribu Islands: a case study. M.Sc. Thesis, University of Bremen, Bremen, Germany

Lazuardi M, Razak T, Jack-Kadioglu T, Iqbal M, Rusandi A, Hakim A, Sapari A, Andradi-Brown D, Claborn K, Veverka L (2020) Formal marine protected area governance structure. Management of Marine Protected Areas in Indonesia: status and challenges. Kementerian Kelautan and Perikanan and Yayasan WWF Indonesia: Jakarta, Indonesia, 3–20

McLeod E, Salm R, Green A, Almany J (2009) Designing marine protected area networks to address the impacts of climate change. Front Ecol Environ 7(7):362–370. https://doi.org/10.1890/070211

Ministry of Marine Affairs and Fisheries (2020) Management of Marine Protected Areas in Indonesia: status and challenges. Ministry of Marine Affairs and Fisheries and Yayasan WWF Indonesia, Jakarta, Indonesia

Noel J, Weigel J (2007) MPAs: from conservation to sustainable development. Int J Sustain Dev 1(3):223–250

Novaczek I, Harkes IHT, Sopacua J, Tatuhey MDD (2011) An institutional analysis of Sasi Laut in Maluku, Indonesia.: xii + ICLARM-the world fish Centre, p 327

Patlis JM (2005) The role of law and legal institutions in determining the sustainability of integrated coastal management projects in Indonesia. Ocean Coast Manag 48(3–6):450–467. https://doi.org/10.1016/j.ocecoaman.2005.04.005

Polunin NV (1984) Do traditional marine "reserves" conserve? A view of Indonesian and new Guinean evidence. Senri Ethnol Stud 17:267–283

Ruddle K, Satria A (2010) Managing coastal and inland waters: pre-existing aquatic management systems in Southeast Asia. Springer Science & Business Media, Dordrecht, The Netherlands, p 188

Satria A, Matsuda Y (2004) Decentralization of fisheries management in Indonesia. Mar Policy 28(5):437–450. https://doi.org/10.1016/j.marpol.2003.11.001

Sen S, Nielsen JR (1996) Fisheries co-management: a comparative analysis. Mar Policy 20(5): 405–418. https://doi.org/10.1016/0308-597x(96)00028-0

Seymour R, Turner S (2002) Otonomi daerah: Indonesia's decentralisation experiment. N Z J Asian Stud 4:33–51

Siry HY (2011) In search of appropriate approaches to coastal zone management in Indonesia. Ocean Coast Manag 54(6):469–477. https://doi.org/10.1016/j.ocecoaman.2011.03.009

Suryo D (2000) Political transformation in Indonesia. Korean Assoc Southeast Asian Stud 9:165–186

Syarif LM (2009) Promotion and management of marine fisheries in Indonesia. In: Winter G (ed) Towards sustainable fisheries law. A comparative analysis. IUCN, Gland, Switzerland, pp 31–82

UNCLOS (1982) United nations convention on the law of the sea. Montego Bay, Jamaica, p 208

Wiadnya D, Syafaat R, Susilo E, Setyohadi D, Arifin Z, Wiryawan B (2011) Recent development of marine protected areas (MPAs) in Indonesia: policies and governance. J Appl Environ Biol Sci 1(12):608–613

Wilson C, Linkie M (2012) The Panglima Laot of Aceh: a case study in large-scale community-based marine management after the 2004 Indian Ocean tsunami. Oryx 46(4):495–500. https://doi.org/10.1017/S0030605312000191

Wood L (2007) MPA global: a database of the world's marine protected areas. Sea around us project. UNEP-WCMC & WWF, Vancouver

Chapter 11
Panama Case Study

Coastal Zone Management in Panama: Lessons Learned and Outlook for the Future

Janina Seemann, Tania E. Romero, Arturo Dominici-Arosemena, Juan Maté, Anabell J. Cornejo, Jessica M. Savage, Felix Rodriguez, and Arcadio Castillo

Abstract Globally, efforts are being made to sustainably conserve and manage threatened ecosystems and the associated ecosystem services derived. However, evidence suggests that economic interests are increasingly being prioritized over the environment and the livelihoods of local resource-dependent communities. This review consists of four case studies from key coastal regions in Panama, exploring the successes and failures of different approaches to resource management and the impacts of management on the complex socio-ecological interactions between people and their environment. Primarily, we describe how communication and interaction between stakeholders are critical to effective coastal resource conservation. Panama provides an example of a complex sociological web attempting to

---

Janina Seemann, Tania E. Romero, Arturo Dominici-Arosemena and Juan Maté contributed equally with all other contributors.

J. Seemann (✉)
Smithsonian Tropical Research Institute (STRI), Panama, Panama

Zukunft – Umwelt – Gesellschaft (ZUG) gGmbH, International Climate Initiative (IKI), Berlin, Germany

T. E. Romero · A. Dominici-Arosemena
Smithsonian Tropical Research Institute (STRI), Panama, Panama

International Maritime University of Panama, Panama (UMIP), Panama, Panama

J. Maté · A. J. Cornejo · F. Rodriguez
Smithsonian Tropical Research Institute (STRI), Panama, Panama

J. M. Savage
The School for Field Studies (SFS), Bocas del Toro, Panama

School for Cross Faculty Studies, University of Warwick, Warwick, UK

A. Castillo
Smithsonian Tropical Research Institute (STRI), Panama, Panama

School for International Training (SIT), Panama, Panama

M. Wolff et al. (eds.), *Challenges in Tropical Coastal Zone Management*,
https://doi.org/10.1007/978-3-031-17879-5_11

balance a developing economy with the needs of a diverse and often marginalized population. While there is consensus surrounding the need for environmental management efforts, ineffective communication, community engagement, and knowledge exchange have severely impaired success. Overall, we highlight the importance of effective knowledge collection and exchange. For example, effectively utilizing the extensive historical and cultural heritage within the Panamanian indigenous societies would help to encourage stronger cooperation between policymakers and local communities. Fostering trust while simultaneously encouraging transparent and effective natural resource governance.

Keywords Case studies · Panama · Management plans · Governance · Enforcement · Coastal community · Stakeholder · Participation

1 Introduction

Panama's history is characterized by short-term economic interests of individual groups that were often prioritized over the sustainable use of resources, or the maintenance of the livelihoods of local communities, typical of many other places worldwide (COI-UNESCO/CPPS 2016; Harding 2006; Jackson et al. 2001; Little et al. 1987). Attempts to preserve natural areas to support sustainable development in Panama started with the foundation of the Campana National Park in 1966 (Larson and Albertin 1984) and the creation of the first marine national park in Portobelo in 1976 (Strassnig 2010), followed by several similar initiatives. Unfortunately, protection was not coupled with the immediate introduction of management plans or plans were introduced too late. This issue was compounded by both administrative and structural gaps in the legislations and supporting institutions, as well as a lack of political will to enforce them (Spalding et al. 2015). The recent creation of the Ministry of Environment, and the coastal and seas directorate (DICOMAR) (taking over the administration of coastal areas from Authority of Aquatic Resources, ARAP), has caused further delays in the implementation of protection efforts, due to a lack of budget, personnel and equipment. Thus, marine resources have declined along both the Pacific and Caribbean coasts of Panama. Several studies have reported overexploited fisheries, physical destruction of the coastline, sea-level rise, and the occurrence of both temperature stress and hypoxic events (Altieri et al. 2017; Castellanos-Galindo et al. 2017; Marviva 2014; Seemann et al. 2018; Van Oosterzee and Duke 2017). Similarly, evidence suggests that most of the coastal areas are exposed to polluted effluents from industries, agricultural land use and the disposal of untreated wastewater (D'Croz 1988.; INEC 2010; Seemann et al. 2014).

This chapter outlines the most important developments and efforts for coastal protection in four case study regions in Panama (two sites on the Pacific coast and two sites on the Caribbean coast), in order to discuss reasons for successes and

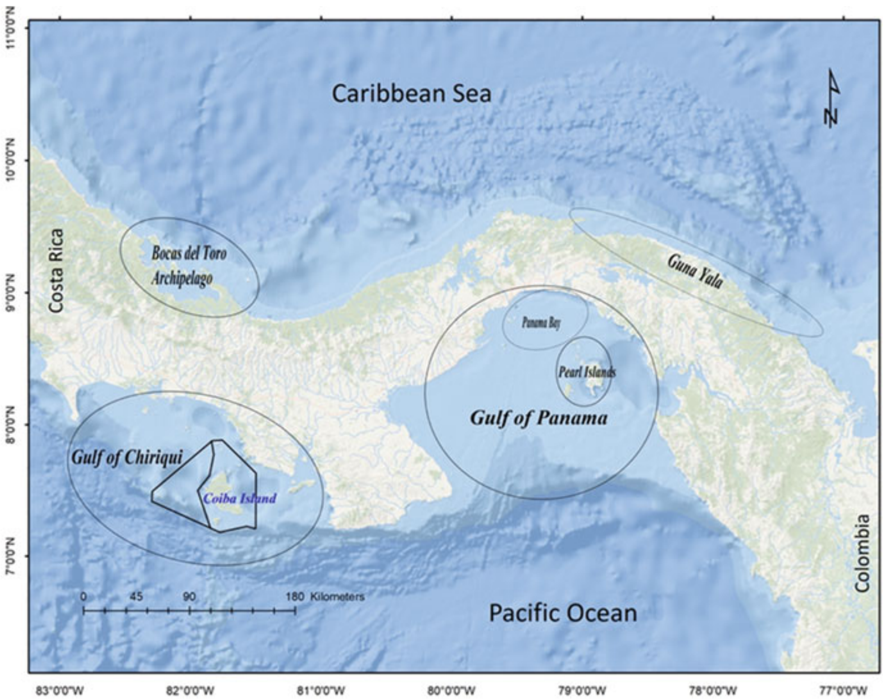


Fig. 11.1 Map of Panama with the four study sites

failures on a national level. The sites on the Pacific coast include the *Gulf of Panama* and the *Gulf of Chiriquí*, and on the Caribbean coast *Bocas del Toro* and *Guna Yala* (Fig. 11.1). Our aim is to help extract positive trajectories and experiences and identify challenges and obstacles to natural resource management and nature protection, in order to improve the application of coastal zone management and conservation efforts in Panama and beyond.

2 Study Sites

2.1 Study Site 1: Gulf of Panama, Pacific

2.1.1 Description of the Study Site

The Gulf of Panama is located on the Pacific coast (COI-UNESCO/CPPS 2016). The most important coastal zones in the Gulf are the Pearl Islands, the Panama Bay wetlands and the Gulf of San Miguel. The coastal topography of the Gulf of Panama is influenced by a coastal seasonal upwelling in the dry season (D'Croz and O'Dea 2007). The Pearl Islands Archipelago is 48 km away from Panama City with an area of 1688 km^2 with 250 islands and islets (Guzman et al. 2008). Around 3200 people live in the archipelago (INEC 2017), where eight local communities are established depending mainly on artisanal fishing (Cooperlas 2010). It has 36 nesting areas for marine turtles (PNUD-MiAmbiente 2017a) and the largest aggregation of coral reefs in the area (Glynn et al. 1991; Guzman et al. 2008). The Panama Bay wetlands cover an area of 856 km^2 (ANAM 2014) and most were declared as a RAMSAR site in 2003 (Centro Regional Ramsar para la Capacitación e Investigación sobre Humedales para el Hemisferio Occidental (Hemisferio Occidental 2009). The entire area is on an alluvial coastal plain of mangroves. The Gulf of San Miguel is located in the south-eastern part of the country in Panama's largest province Darién. It has an area of 16,803 km^2. Around 19,000 people live in the area (INEC 2010). With an extension of 1760 km^2, it supports approximately 17% of the country's mangrove population (Suman 2007). Abundant populations of pelagic fish and sailfish are found in the Gulf during seasonal upwelling.

2.1.2 Historical Development of Coastal Use

The dynamics of marine ecosystems in the Gulf have been impacted by long-term shifts in El Niño variability for at least the past 6000 years (Toth et al. 2012). Secondary impacts result in the collapse of coral reefs in the Pearl Islands (Toth et al. 2012). During the El Niño event in 1982–1983, most of the coral reefs disappeared due to the death of corals from a temperature-induced bleaching and the intense bioerosion (Glynn and Manzello 2015). La Niña events (Conroy et al. 2008) inhibit reef development due to the associated increased precipitation and water turbidity (Kleypas 1997; Lachniet et al. 2004). However, many of these reefs show signs of resilience and recovery (Glynn et al. 2001). Serious levels of overfishing were observed in the Pearl Islands Archipelago (Ramírez-Ortiz et al. 2017). Furthermore, the development of tourism has caused a massive undirected development. For the coastal area, the human settlement is driven by the development of Panama City in 1519 by the Spanish Crown (Mendizábal 2004). Later in the early 1900s, the North American military bases in the Panama Canal zone constrained and expanded the urban footprint towards the east. Predominantly, salt marshes and mangroves were reclaimed and built upon, which has resulted in the loss of important habitats. Today, the communities are impacted by severe floods and the loss of fishery resources (ANAM 2014). Though Panama City has operated a sanitation project since 2001, unregulated construction of houses caused problems with unconnected sewage systems (INEC 2010). Infrastructural issues are combined with the industrial and agricultural runoff, and the whole coastal region is exposed to pollution (Scodelaro et al. 2015).

2.1.3 Management Efforts and Challenges

Coastal management in the Gulf of Panama is characterized by a lack of organization. However, in the Pearl Islands a Marine Special Management Zone has been identified after an extensive participatory process (COI-UNESCO/CPPS 2016) and has resulted in the creation of a framework for participatory governance and laws. Using this framework, limiting factors, such as weak participation from local communities, a limited exchange of knowledge, a lack of governance, and monitoring and enforcement from local authorities, were identified as resulting in the failure of fisheries management efforts. Different NGOs tried to implement coastal management systems (CEASPA 2009). In 2017, ARAP developed a proposal for a Management plan for sustainable fisheries. The plan considers social and economic factors to characterize the well-being of the fishing sector. However, it still needs to be implemented. The region has also been included in the "Sustainable Tourism Master Plan," which focuses on the potential of sustainable tourism and aims to regulate land use. However, economic interests are still prioritized over sustainable development (Almanaque 2010; CEASPA 2009). For the coastal management efforts around Panama City (Panama Bay wetlands), much of the coastal area and adjacent mudflats were initially protected by conservation efforts from the NGO Audubon Society of Panama, prior to being declared a RAMSAR site in 2003. The RAMSAR designation also resulted in the creation of a management action plan. However, this plan did not include any binding tools for decision-making. The NGO still develops programs for bird identification, environmental education and community organization, facilitating the development of sustainable pilot projects with the support of several stakeholders (Kaufmann 2012). The action plan was formalized in 2015 by an official wildlife refuge law (Law No.1 2015). However, a management plan has not yet been prepared. The Panama Bay area has recently become part of the National Waste Management Plan 2017–2027, and the municipality is implementing a pilot program for waste management (Basura Cero) with several educational and inter-institutional challenges. More recently in 2018, the Municipality of Panama has also begun to develop the District Territorial Spatial Plan and has released a resilience strategy, legally adopted by a Municipal Council (Acuerdo Municipal Número 7 2019), which channels urban growth in an orderly and balanced way to reach a sustainable competitive city with the inclusion of actions for protection of urban coastal wetlands in the City. The Gulf of San Miguel is characterized by the implementation of several conservation and multi-use areas, such as the international RAMSAR site called Punta Patiño. This area is privately part-owned by the NGO National Association for Conservation (ANCON). The surrounding communities are restricted to artisanal fishing, and the area was declared as an important area for birds in Panama (Angehr and Rosabel 2009). ANCON supports community programs for biocommerce, sustainable production, surveillance and monitoring of key species, for education and sustainable tourism (ANCON 2017).

2.2 Study Site 2: Gulf of Chiriquí, Pacific

2.2.1 Description of the Study Site

The Gulf of Chiriquí is a large (13,119 km^2), wide, semi-open shelf area on the western Pacific coast of Panama extending for 1527 km (D'Croz and O'Dea 2007; Maté 2006). There are various archipelagos (455 islands and islets, including Coiba Island, the largest island on the Pacific coast of Central America), two large estuaries, fringing mangroves covering 693 km^2, and 12.5 km^2 of coral reefs (Guzmán and Breedy 2008).

2.2.2 Historical Development of Coastal Use

The Gulf of Chiriquí is an important area for fishing in coastal and marine areas of the Panamanian Pacific. While the artisanal/commercial fisheries mostly focus on snappers, lobsters, conch, and sharks (Maté 2006), the industrial fleet mainly target shrimp and small pelagic fish (Maté 2006). Hannibal Bank is the most important area for fishing, including sportfishing for billfish (Maté 2006).

2.2.3 Management Efforts and Challenges

The Gulf of Chiriquí encompasses eight managed areas under five categories of management. All eight areas include mangroves, five protect coral communities and/or coral reefs (Alvarado et al. 2017), and three are either archipelagos or a single island surrounded by rocky outcrops (Alvarado et al. 2017; Maté 2003). While some areas have approved management plans throughout a participatory process with key stakeholders, the implementation of those management measures is minimal. Political and economic interests, insufficiently trained staff, inadequate budgets, or a lack of necessary equipment (e.g., surveillance boats) within the organizations responsible for their implementation are cited as the main reason for the lack of implementation (Alvarado et al. 2017).

The Coiba National Park, as the largest continental MPA in Panama, is a key case study as it is believed to have the best chances for success. Coiba was created in 1991 and legal status upgraded to law in 2004, it is recognized as a UNESCO World Heritage (2005), and has approved management and sustainable fisheries plans. It has three bodies of governance, including a board of directors as the top decision-making entity (a 12-member body, eight from the central and local government, and one each from the business sector, fishing sector, NGOs, and academia). Despite the apparently favorable enabling environment, the park has largely failed to accomplish its management goals. Reasons for this include the lack of consensus between stakeholders, which tend to prioritize their own individual interests rather than the interests of the national park (Alvarado et al. 2017; Maté 2003; Spalding et al. 2015;

Suman 2002). Sustainable fishery plans were approved in 2014 and 2018 for the Coiba National Park and the Special Zone of Marine Protection (ZEPM by its Spanish acronym), respectively. The plans were based on scientific data including the first reports of snapper aggregations for the Pacific coast of Central America (Vega et al. 2016) justifying the first national closed season for snappers in Coiba. The lack of enforcement of the Coiba sustainable fisheries plan meant that the current high exploitation levels of the fishery resources eventually impacted on silky snapper populations (Vega et al. 2016). The ZEPM regulation was based on available data with little local participation and was approved to comply with a deadline set by the UNESCO World Heritage Committee and occurred 14 years after the creation of the MPA. Through the years, these deficiencies in fisheries management have resulted in numerous requests for compliance from the UNESCO World Heritage Committee (Alvarado et al. 2017). The draft decision of the World Heritage Committee was discussed in July 2018 and expresses serious concerns on how the ZEPM regulations will guarantee the long-term preservation of the outstanding values of this ecosystem (https://whc.unesco.org/en/soc/3760). In general, fisheries activities in the Gulf of Chiriquí continue to have a big impact (Carey 2001; Valverde 2013). Sustainable management of marine resources in Panamá is severely hindered by the lack of reliable fisheries statistics (Harper et al. 2014; Maté 2006). Finally, the Gulf of Chiriquí is expected to experience increasing pressure from a variety of local and global factors. El Niño sea warming has previously resulted in coral bleaching and mortality (Glynn 1990; Glynn et al. 2001). However, deeper areas (>11 m) have shown to act as refuges during warming events (Smith et al. 2014; Smith et al. 2017). These areas have also demonstrated resilience to ocean acidification (Manzello 2010; Manzello et al. 2017). Sea level rise associated coastal erosion impact regularly coastal areas in the region. For example, mangrove forests are vulnerable to sea level rise as well as to high-temperature events (Marviva 2014; Van Oosterzee and Duke 2017) threatening the ability to store carbon (328.12 tC/ha according to (PNUD-MiAmbiente 2017b)) and other goods and services valued at approximately $27 million per year (PNUD-MiAmbiente 2017a). Eutrophication or physical destruction has localized impacts, fortunately of little concern. Nutrients are naturally carried into the upper ocean layer through local upwelling of small pockets of cool, deep water (D'Croz and O'Dea 2007). During anomalous rainy years, strong nutrient inputs to the gulf result from freshwater runoff in the ocean waters (Valiela et al. 2012). Due to the limited deforestation, runoff is not yet having a detectable impact on the estuarial runoff regime and has not yet altered the overall levels of nutrient runoff (Viana et al. 2015).

2.3 Study Site 3: Bocas del Toro, Caribbean

2.3.1 Description of the Study Site

The Bocas del Toro Archipelago (on Panama's NW Caribbean coast) encompasses a coastal coral reef-seagrass-mangrove system. It is comprised of six islands surrounded by the mainland and consists of two adjacent semi-enclosed bays. The Almirante Bay in the NW with an approximate surface area of 446 km^2 and the Chiriquí Lagoon in the SW with a surface of 941 km^2 (D'Croz et al. 2005). The northern part is ocean-exposed and the exchange of water between the ocean and the bays occurs though passages between island and sand cays. Furthermore, the Archipelago is exposed to freshwater discharge from several large rivers and creeks, and an oceanic inlet at Boca del Drago that deposits sediment from the rivers Sixaola (Costa Rica) and Changuinola, into Almirante bay. The population (approximately 10,000 people) is largely concentrated in the town of Bocas del Toro on Colón island.

2.3.2 Historical Development of Coastal Use

Since 1905, the Archipelago was strongly influenced by the agricultural development of the banana industry (Chiquita) (Greb et al. 1996.). In the late 1980s, the government promoted commercial fishing, aiming to develop Panama as a major fish exporter (Shepherd 2008; Windevoxhel and ter Heegde 2008). Panama has fishing regulations declaring fundamental restrictions for fishing areas, seasonal closures, size and age classes and type of gear (Asamblea Nacional 1959; Spalding et al. 2015). However, fishing regulations were largely unenforced, and the commercial sector caused a collapse of the fish stocks by the late 1990s, including those in Bocas del Toro. Subsequently, in 1996, the central government prioritized the archipelago as an area for tourism development, encouraging the recreational use of coastal resources (Guzman et al. 2005; Guzmán and Guevara 1998). Encouraging tourism investment was combined with real estate development, which resulted in significant changes in land use and land tenure over time, limiting opportunities for traditional livelihoods or for local communities to maintain ownership (Spalding et al. 2015). Forest cover decreased, and aquatic pollution increased; further complicated by insufficient territorial planning to support tourism, or the growing population and inadequate infrastructure for waste management. Little of the coastline remained in its natural state (Collin et al. 2005; Guzman et al. 2005; Seemann et al. 2014). In addition, frequent high temperatures and hypoxic events in the marine system, caused regular mass mortalities (Altieri et al. 2017; Johnson et al. 2018) resulting in fundamental changes in the ecological state of the bay system in recent decades.

2.3.3 Management Efforts and Challenges

Destructive developments and subsequent impacts on ecosystem function, resulted in various management efforts developed by NGOs, government agencies, and research organizations, but evidence suggests that none of them have really been successful.

In 1988, the 13,000 ha Isla Bastimentos National Marine Park (IBNMP) was declared (see Table 11.1), aiming to protect many habitats, including coral reefs and mangroves. The lack of success of this initiative is attributed to: (1) the design approach. Boundaries were based on opportunities for economic and tourism development, rather that scientific reasoning (Allison et al. 1998; Guzmán and Guevara 2001; Windevoxhel and ter Heegde 2008). (2) inadequate community involvement and consultation. (3) the lack of enforcement of management rules and regulations from authorities such as MiAmbiente attributed to limited resources and enforcement of the sustainable use of resources. In 2008, the Smithsonian Tropical Research Institute (STRI), in collaboration with ARAP established the Matumbal Marine Reserve adjacent to the Research Station (Resuelto ARAP No. 10 2008) aiming to support the repopulation of key marine species. Despite lower rates of mangrove deforestation, infrastructure development did not advance as fast or as extensively as other areas in the archipelago. However, STRI was unable to efficiently keep the area in its natural state and communicate information about the reserve to local people. The third legally protected area is located at the mainland in the north of the shipping harbor Almirante. The wetlands of San Pond Sak were declared a RAMSAR site in 1993. Though this site does not receive any measurable protection, the wetlands are excluded from the land conversion into Banana plantations.

In 1999, a bottom-up, ecosystem-based management program (PROARCA/Costas, see Table 11.1) was developed on a community/municipal level, to complement the IBNMP (Windevoxhel and ter Heegde 2008). Developed with support from numerous national and international organizations, the goal of the PROARCA program was to restore fish stocks to support local livelihoods, while ensuring equitable stakeholder engagement. A community-based program called ADEPESCO (Association for Fishery Development and Conservation) provided participatory training and consulting processes in 10 communities to develop fishery rules and create new zonation-based management. However, the project quickly failed. This failure can be partially attributed to key issues within the organizational structures. The governmental institutions and management organizations had opposing priorities and the exchange of knowledge and participatory approaches had failed to develop a common strategy (Windevoxhel and ter Heegde 2008).

Since 2000, with the increasing popularity of ecotourism, a greater numbers of conservation minded visitors and residents have had a positive impact on attitudes and approaches to tourism. This is especially true for the diving industry where there have been many positive developments. Demand for more legitimate habitat and resource protection has also led to seasonal fishing bans (i.e., bans on lobster fishing between May and June implemented in 2015). Similarly, the increased awareness of

Table 11.1 Overview of selected management approaches for each region with goals, successes and failures

Area	Management approach	Name of site	Method	Jurisdiction	Goal	Pro	Contra
Gulf of Panamá	National level and community	Las Perlas archipelago	Spatial management zone*	Ministry of Environment—MiAmbiente-DICOMAR	Sustainable artisanal fisheries and ecotourism	– Communities and local authorities work together – Participatory governance – Protected by law	– Weak participation of locals, poor education, lack of knowledge of laws and environmental policies, lack of governance – Lack of monitoring and evaluations from local authorities – Lack of financial support – Management plan not approved
	Ramsar guidelines	Bay of Panama	Ramsar site**	MiAmbiente-DAPVS	Conservation of wetland	– Communities are working together with local NGOs – Part of sanitation project to decrease the sewage disposal – Existing action plan and funding for a management plan available – Protected by a law	– Continuous development of urban areas – Sewage system not completed – No management plan yet
	Ramsar guidelines	Punta Patiño (gulf of San Miguel)		ANCON (NGO), community,		– Sustainable use of local products	– Limited financial support

	with NGO and community guidelines		Ramsar Site & Private Reserve**	MiAmbiente-DAPVS	Biocommerce, sustainable artisanal fishery	– Monitoring program for key species – Mostly managed by an NGO and the community – Recognition of the importance of the ecosystem from the community	– Lack of interest from local authorities – Old management plan
Gulf of Chiriquí	International and national level, legal level	Coiba National Park and its special zone of marine protection (SZMP)	Marine protected area (restricted zone)*	Board of directors, Scientific committee, Management commission for fisheries, MiAmbiente	Conservation of ecosystem, research, sustainable ecotourism, Sustainable fisheries, sustainable development	– Linked ecosystem approach (coast-land integration) – National and international interest and protection – Strong research component – Sustainable of ecotourism, fisheries and community activities – Participatory management plans – Protected by a law	– Lack of enforcement of protection status and implementation of management plans – Lack of resources – Prioritization of the development of tourism and economic and political interests – Lack of environmental education, insufficiently trained staff – No integration between institutions
	National level	Manglares de Davíd	Municipal agreement**	Government, NGO's and community based	Conservation of ecosystem	– Community participation – NGOs and government working	– No defined limits – Expansion of the city – No management

(continued)

Table 11.1 (continued)

Area	Management approach	Name of site	Method	Jurisdiction	Goal	Pro	Contra
						together – Private sector supporting activities of forest restoration	plans – Critically endangered tree species – Mangrove tannin extraction
Bocas del Toro	National, legal level	Isla Bastimentos National Marine Park (IBNMP)	Marine protected area (no-take zone)*	MiAmbiente	No take area to restore and conserve marine resources	– Linked ecosystem approach (coast-land integration) – Use for tourism, which moved some fisherman to touristic businesses	– Lack of scientific justification – Lack of involvement of local communities – No enforcement of protection status and implementation of the management plan
	Community/municipal level	PROARCA/Costas, ADEPESCO (association for fishery development and conservation)	Ecosystem approach management program with no-take and access zones*	USAID, CCAD & ARD, implemented by TNC, WWF, the University of Rhode Island & local NGOs	Design a program to recover and restore the fish stocks and maintain people's livelihood	– Definition of no-take areas with local fisherman – High acceptance through local leadership – Use of local knowledge – High education level of people involved	– Insufficient experience to be able to manage complex institutional and technical inputs without external support – Weak institutional links – Interests more linked to tourism than to conservation – Lack of resident advisor

	Community level	Private businesses & local representatives	Citizen approach for a sustainable use of resources**	Volunteer, community based	Ecotourism for the sustainable use of resources, garbage concept	– Citizens are take responsibility to solve local problems – High acceptance in community – High outreach and education level through citizens dialog	– Small scale – Success depends on private resources – Private priorities
Gunayala	National, legal level	Área Silvestre Corregimiento de Narganá	Guna general congress autonomous decision*	MiAmbiente and Guna general congress	For the sustainable development of the Guna territory an incorporating into the process the communities, social, cultural, and economic activities	– Within an autonomous indigenous area and controlled by Guna people – Use for tourism	– Lack of management plan – High demand of improperly managed tourism can impact environmental resources – Coral mining to enlarge islands
	Community level	Armila	Citizen approach**	Community based	Protection effort of local community to protect leatherback turtles from fishery (eggs and meat, mostly from Colombian fisherman)	– Bottom-up citizen approach of the local community – Involvement of scientists (mostly from Colombia), which monitor the turtle nesting success regularly	– Protection effort not supported on a legal level by MiAmbiente or Guna general congress

(continued)

Table 11.1 (continued)

Area	Management approach	Name of site	Method	Jurisdiction	Goal	Pro	Contra
	National, legal level, community level	Gunayala	Guna general congress**	ARAP and Guna General Congress, fisherman (ARAP 2015)	Management of populations of spiny lobster	– Within an autonomous indigenous area and controlled by Guna people – Major economic income source for the region improves the enforcement	– Does not follow the central American agreements/ legal regulations elsewhere (4 month), instead it implements an own regulation (3 months ban) – Still local consumptions during closed season

Asterisks indicate if methods are more (**) or less (*) successful environmental degradation has also fostered harvesting fish species more sustainably (i.e., the invasive lionfish, *Pterois volitans*, or the local aquaculture of Pompano, *Trachinotus carolinus*). Additionally, increasing tourism, research, and conservation activities in the archipelago have fostered livelihood diversification opportunities, as many former fishermen have become tourist guides, boat drivers, MPA rangers or research assistants (Smith et al. 2016). Increasing awareness may be related to the successful implementation of an effective waste management program between citizens and the municipal government. Privately funded bins were installed and are emptied by the governmental garbage trucks, also encouraging waste separation and recycling. Citizen awareness of environmental problems is increasing with regular beach cleans and a plastic straw ban being carried out in some restaurants.

The history of management strategies at the Bocas del Toro archipelago is complex. A large proportion of the struggles relate to ineffective management; but also, to the social structures and hierarchies present, creating and exacerbating conflicts, distrust and reciprocal blaming on a community level. However, recently, local identity and pride have fostered a new participatory approach with citizens, which supports bottom-up natural resource management.

2.4 Study Site 4: Guna Yala, Caribbean

2.4.1 Description of the Study Site

Guna Yala Comarca is an area exclusively inhabited by Guna indigenous communities, except for the border town of Puerto Obaldia (Castillo and Lessios 2001). The Guna have had autonomy and authority over the region since 1938 (Andrefouet and Guzman 2005), and the Guna General Congress (GGC) is recognized as the maximum authority (Howe and McDonald 2015). Additionally, the elected leader from the community called "Sáhila" is also key to the governance of the Guna. The Guna Yala region has approximately 365 coral islands (Ventocilla et al. 1995) and extends about 480 km along the Caribbean eastern seaboard of Panama to the Colombian border (Andrefouet and Guzman 2005). The low river discharge and the influence of clean and clear open ocean waters allow the development of 638 km^2 diverse coral reef system that is considered the best on the Caribbean coast of Panama (Andrefouet and Guzman 2005; D'Croz et al. 1999).

2.4.2 Historical Development of Coastal Use

Tourism, lobster fisheries, mola embroidering, and coconut export are the main economic activities in Guna Yala. Marine resource extraction includes fish such as sardines, groupers, snappers, bonito, mackerel, and jacks, as well as other seafood such as spiny lobsters, spider crabs, conch, and other large snails, and octopus (Colton 2011). Traditional artisanal fishing gear is used (i.e., hand lines and hook, hand, gill nets, and others). Lobsters are the most important seafood resource, contributing largely to the Guna economy. However, slightly less than half of the export consists of pre-reproductive lobster individuals (Castillo and Lessios 2001). The Goliath grouper (*Epinephelus itajara*), a critically endangered species included on the IUCN Red Species List, is speared by young Gunas to be sold at restaurants and hotels in Guna Yala.

2.4.3 Management Efforts and Challenges

Enforcement of Panamanian regulations related to marine resource exploitation by the GCC focus on what is landed on the islands and seizing the product or even imposing fines or other punishments to those contravening the rules. There are no regulations concerning fish species or size classes, thus fishermen extract whatever is available and can be harvested. However, the spiny lobster (*Panulirus argus)* has a three-month fishing ban from March 1 to June 30 (ARAP AR N° 004 of February 26, 2018), which is one month less than the general agreement throughout Central America partially enforced by the GGC. Lobster protection and commercialization is strictly enforced. Only local consumption occurs during the ban. While newly paved roads have contributed to an exponential increase in tourism in the last eight years (Howe and McDonald 2015), the revenue from this activity does not appear to benefit the region ecologically. The increase in tourism has further encouraged the Guna to extract fish and other reef organisms (Guzman 2003) and to build infrastructures to accommodate touristic demands (CENDAH 2018). This increase in tourism, as well as the growth of the Guna population, has resulted in an increase of oil contaminants, garbage and human waste (CENDAH 2018; Colton 2011; Howe and McDonald 2015). Mainland landfills and associated recycling activities are attempting to reduce the impact of waste on the islands. The 4.8 km beach around the community of Armila have the highest abundance and density of leatherbacks (*Dermochelys coriacea*) nesting sites in the Central American Caribbean and is considered the fourth largest nesting aggregation for this species in the world (Patino-Martinez et al. 2008). This community does not allow coastal construction, egg consumption or capture of adult female turtles (Patino-Martinez et al. 2008), in stark contrast to other areas in the Caribbean Panama where hunting, consumption, commercialization of different parts of the turtle, destruction or alteration of nesting habitats do occur. The Area Silvestre Corregimiento de Narganá is the only formally recognized protected area (established in 1987 by the GGC and recognized in 1999 by the Gaceta Oficial 25, 116 of 7 September 1999). Guna people demand local empowerment, outside the national legislations (Guzmán et al. 2003). By establishing smaller local management areas, the Guna can protect and preserve marine areas close to their communities (Colton 2011; Guzmán et al. 2003). While some communities adopted this strategy (Paulson 2017), surveys should be conducted to validate the effectiveness of the measure and to provide data sets to upscale such successful methods.

Nevertheless, coral mining, land-reclamation practices as result of population expansion, mismanagement of natural resources, sedimentation and nutrient enrichment from deforestation of coastal watersheds are still the main anthropogenic causes for local reef degradation (Guzmán et al. 2003). Other threats include mass mortality events of the sea urchin *Diadema antillarum* (Guzman 2003; Lessios 2005; Ogden and Ogden 1996). Additionally, other global changes are increasing the pressure on marine ecosystems, thus it is questionable if the existing management will be able to cope with additional stressors from coral bleaching events and sea level rise and protect the indigenous community. Sea level rise has been estimated at 2 cm per year (Guzmán et al. 2003), and floods erode the sandy beaches and islands, impacting coconut plantations, turtle nesting beaches, and the communities that live in the area (CENDAH 2018).

3 Discussion and Conclusions

The coastal management approaches described a variety of attempts for protection and should help identify opportunities and practices for success as well as approaches to avoid. Management efforts range from community-based approaches, NGO and multi-stakeholder systems, governmental, top-down approaches, research-driven approaches, and citizen science approaches. Likewise, a variety of categories of protection are described, including Marine Protected Areas, Special Management Zones, International RAMSAR Sites (Ramsar 1993), Private Reserves, and Autonomous Indigenous protected area declaration. Our comparative analysis of 4 study areas, summarized in Table 11.1 suggests some key factors that affect the management outcome:

1. Historical and cultural heritage (i.e., UNESCO world heritage sites or long-established indigenous comarcas) can offer some initial protection to key areas. Such areas and systems have much better preconditions for a successful management since resources have not been exploited to a point of scarcity, and sustainable strategies can be implemented much more easily.
2. The implementation and enforcement of a management concept and the widely agreed need for management and action are essential for the success of protection and sustainable use of resources. Coastal management failed in several of our study sites due to either the pure lack of management, or the lack of the enforcement of existing management plans.
3. The engagement of the local communities is essential for success. However, participation depends on the quality of the collaboration between the different stakeholders, their ownership in the processes and their flexibility for adjustments to achieve a common goal. Common strategies require flexibility and the potential for modifications to the process itself and the initially agreed outcomes.
4. NGOs can be essential mediators between communities and authorities, although both, the implementation of management concepts and the enforcement of

conservation efforts goes beyond their capabilities for enforcement if areas are not directly owned by the NGO. Common efforts between NGOs and governmental institutions can be promising, provided the NGO and the governmental institution have common priorities and a strong collaboration leads to the development of a common strategy.

5. Effective coastal management requires good communication and understanding between all institutions and stakeholders, otherwise personal interests can become predominant and may cause the failure of the effort. Negotiations or discussions should be supported by appropriate structures and processes (i.e., with boards and committees), so that stakeholder feel sufficiently represented.
6. Community efforts are the most promising strategy at a small scale and developing responsibility of citizens is a strong bottom-up measure for successful coastal management, as was shown in several examples discussed here. However, especially on larger scales, where governmental enforcement is expected and needed, communities cannot substitute governmental tasks.
7. Lack of knowledge causes a lack of understanding of the need for any protection effort. The success of an efficiently managed ecosystem is often related to the understanding and the economic interest of the local community and all stakeholders.
8. Science plays an important role to support effective management and conservation efforts. It can help to determine areas and possible measures, to ensure that stakeholders are involved in receiving and providing information and to benefit from the conservation efforts. Also, research can be an important tool to help collect information to provide long-term data sets, which can help to generate compliance to the need for environmental protection and to maintain ecological benefits.

This comparison of sites could help to sort out some lessons learned, success stories and failures, which should not be repeated. There are many positive examples in place, which have the potential to be scaled up. However, an intensified exchange of knowledge and strong cooperation is needed to make failures and successes transparent for stakeholders involved and to learn for the future.

References

Acuerdo Municipal Número 7 (2019) Por el cual se adopta la Estrategia de Resiliencia para la Ciudad de Panamá. https://www.gacetaoficial.gob.pa/pdfTemp/28710_B/71387.pdf

Allison GW, Lubchenco J, Carr MH (1998) Marine reserves are necessary but not sufficient for marine conservation. Ecol Appl 8(1):S79–S92. https://doi.org/10.2307/2641365

Almanaque A (2010) Identificación de atracciones, adopción de mejores prácticas y promoción de turismo sustentable en la ZEPM Las Perlas. Final Report to the Conservation International ETPS Program

Altieri AH, Harrison SB, Seemann J, Collin R, Diaz RJ, Knowlton N (2017) Tropical dead zones and mass mortalities on coral reefs. Proc Natl Acad Sci U S A 114(14):3660–3665. https://doi.org/10.1073/pnas.1621517114

Alvarado JJ, Aburto-Oropeza O, Abad R, Barraza E, Brandt M, Cantera J, Estrada P, Gaymer CF, Guzman-Mora AG, Herlan JJ, Mate JL (2017) Coral reef conservation in the eastern tropical Pacific. Coral Reefs of the Eastern Tropical Pacific: Persistence and Loss in a Dynamic Environment 8:565–591. https://doi.org/10.1007/978-94-017-7499-4_21

ANAM (2014) Geo Panama 2014: Informe del Estado del Ambiente

ANCON (2017) Reserva Punta Patiño. http://ancon.org/reserva-de-punta-patino/

Andrefouet S, Guzman HM (2005) Coral reef distribution, status and geomorphology–biodiversity relationship in Kuna Yala (san Blas) archipelago, Caribbean Panama. Coral Reefs 24(1):31–42

Angehr G, Rosabel MR (2009) Panama. In: Devenish C, Díaz Fernández DF, Clay RP, Davidson I, Yépez Zabala I, eds. Important Bird Areas Americas - Priority sites for biodiversity conservation. Quito, Ecuador. BirdLife International. Bird Life Conservation, vol 16, pp 289–298

ARAP (2015) Boletín estadístico de pesca y acuicultura años 2013–2014:52

Asamblea Nacional (1959) Law 17 of 9 July 1959. Regulates Fishing and Approves the Export of Fish Products in the Republic of Panama

Carey K (2001) An assessment of Icthyofauna and artisanl fishing from the port of Pedregal in the Golfo de Chiriquí. Independent Study Project (ISP) Collection 1179

Castellanos-Galindo GA, Kluger LC, Tompkins P (2017) Panama's impotent mangrove laws. Science 355(6328):918–919. https://doi.org/10.1126/science.aam6909

Castillo A, Lessios HA (2001) Lobster fishery by the Kuna Indians in the san Blas region of Panama (Kuna Yala). Crustaceana 74:459–475. https://doi.org/10.1163/156854001750243045

CEASPA (2009) Establecimiento de un Comité Local de Pescadores Artesanales en la ZEPM Las Perlas. Final Report to the ETPS Program of Conservation International

CENDAH (2018) Estado actual de los recursos marinos y costeros ante el cambio climático y las medidas que se están tomando en la región de Gunayala. Inedit document: 4 Centro Regional Ramsar para la Capacitación e Investigación sobre Humedales para el

COI-UNESCO/CPPS (2016) Experiencias Locales de Manejo Costero Integrado: Caso Piloto SPINCAM en el Pacífico Sudeste. Serie Técnica 127 - Dossier ICAM 9. UNESCO, Paris, p 112

Collin R, Diaz MC, Norenburg J, Rocha RM, Sanchez JA, Schulze A, Schwartz M, Valdes A (2005) Photographic identification guide to some common marine invertebrates of Bocas del Toro, Panama. Caribbean Journal of Science 41(3):638–707

Colton HM (2011) El Manejo de Recursos Marinos en el Área de Yandub-Narganá, Kuna Yala: Estrategias, Objetivos y Dificultades

Conroy JL, Overpeck JT, Cole JE, Shanahan TM, Steinitz-Kannan M (2008) Holocene changes in eastern tropical Pacific climate inferred from a Galapagos lake sediment record. Quat Sci Rev 27(11–12):1166–1180. https://doi.org/10.1016/j.quascirev.2008.02.015

Cooperlas R (2010) Promoviendo una Pesca Responsable en el Archipiélago de Las Perlas. Resolución DRC/PJ/N°19/2010, tomo 945 del IPACOOP, el 8 de noviembre del 2010

D'Croz L (1988) Survey and monitoring of marine pollution in the bay of Panama. UNEP Regional Seas Rep Stud 97:115–123

D'Croz L, O'Dea A (2007) Variability in upwelling along the Pacific shelf of Panama and implications for the distribution of nutrients and chlorophyll. Estuar Coast Shelf Sci 73(1–2): 325–340

D'Croz L, Del Rosario JB, Gondola P (2005) The effect of fresh water runoff on the distribution of dissolved inorganic nutrients and plankton in the Bocas del Toro archipelago, Caribbean Panama. Caribb J Sci 41:414–429

D'Croz L, Ross Robertson D, Martínez JA (1999) Cross-shelf distribution of nutrients, plankton, and fish larvae in the san Blas archipelago, Caribbean Panama. *Revista de Biología Tropical* 47(1–2):203–215

Glynn PW (1990) Coral mortality and disturbances to coral reefs in the tropical eastern Pacific. In: *Elsevier oceanography series*, vol 52. Elsevier, New York, pp 55–126

Glynn PW, Manzello DP (2015) Bioerosion and coral reef growth: a dynamic balance. In: Coral reefs in the Anthropocene. Springer, Dordrecht, pp 67–97

Glynn PW, Gassman NJ, Eakin CM, Cortes J, Smith DB, Guzman HM (1991) Reef Coral Reproduction in the Eastern Pacific - Costa-Rica, Panama, and Galapagos-Islands (Ecuador) .1. Pocilloporidae. Mar Biol 109(3):355–368. https://doi.org/10.1007/Bf01313501

Glynn PW, Mate JL, Baker AC, Calderon MO (2001) Coral bleaching and mortality in Panama and Ecuador during the 1997–1998 El Nino-southern oscillation event: spatial/temporal patterns and comparisons with the 1982-1983 event. Bull Mar Sci 69(1):79–109

Greb L, Saric B, Seyfried H, Broszonn T, Brauch S, Gugau G, Wiltschko C, Leinfelder R (1996) Ökologie und Sedimentologie eines rezenten Rampensystems an der Karibikküste von Panamá. Profil 10:1–168

Guzman HM (2003) Caribbean coral reefs of Panama: present status and future perspectives. In: Latin American coral reefs. Elsevier, Amsterdam, pp 241–274

Guzmán H, Breedy O (2008) Distribución de la diversidad y estado de conservación de los arrecifes coralinos y comunidades coralinas del Pacífico Occidental de Panamá (Punta Mala, Punta Burica). The Nature Conservancy, 40

Guzmán HM, Guevara CA (1998) Arrecifes coralinos de Bocas del Toro, Panamá: distribución, estructura y estado de conservación de los arrecifes continentales de la Laguna de Chiriquí y la Bahía Almirante. Rev Biol Trop 46(3):601–623

Guzmán H, Guevara C (2001) Arrecifes coralinos de Bocas del Toro, Panamá: distribución, estructura y estado de conservación de los arrecifes continentales de Península Valiente. Rev Biol Trop 49:53–66

Guzmán HM, Guevara C, Castillo A (2003) Natural disturbances and mining of Panamanian coral reefs by indigenous people. Conserv Biol 17(5):1396–1401

Guzman HM, Barnes PA, Lovelock CE, Feller IC (2005) A site description of the CARICOMP mangrove, seagrass and coral reef sites in Bocas del Toro, Panama. Caribbean J Sci 41:430–440

Guzman HM, Benfield S, Breedy O, Mair JM (2008) Broadening reef protection across the marine conservation corridor of the eastern tropical Pacific: distribution and diversity of reefs in las Perlas archipelago, Panama. Environ Conserv 35(1):46–54. https://doi.org/10.1017/S0376892908004542

Harding RC (2006) The history of Panama. Greenwood Publishing Group, Westport, CT

Harper S, Guzman HM, Zylich K, Zeller D (2014) Reconstructing Panama's total fisheries catches from 1950 to 2010: highlighting data deficiencies and management needs. Mar Fish Rev 76(1–2):51–65

Hemisferio Occidental (2009) In: Flores De GE, Gallardo M, Núñez E, eds. Inventario de los humedales continentales y costeros de la República de Panamá

Howe J, McDonald L (2015) Trash in the water: an indigenous people confronts waste

INEC (2010) Censo de Población y Vivienda. Contraloría General de la República

INEC (2017) Censo de Población y Vivienda. Contraloría General de la República

Jackson JBC, Kirby MX, Berger WH, Bjorndal KA, Botsford LW, Bourque BJ, Bradbury RH, Cooke R, Erlandson J, Estes JA, Hughes TP, Kidwell S, Lange CB, Lenihan HS, Pandolfi JM, Peterson CH, Steneck RS, Tegner MJ, Warner RR (2001) Historical overfishing and the recent collapse of coastal ecosystems. Science 293(5530):629–638. https://doi.org/10.1126/science.1059199

Johnson MD, Rodriguez LM, Altieri AH (2018) Shallow-water hypoxia and mass mortality on a Caribbean coral reef. Bull Mar Sci 94(1):143–144

Kaufmann K (2012) Nuestros humedales, nuestro futuro. Plan de conservación para los humedales de la Bahía de Panamá. Sociedad Aubudon de Panamá, 73

Kleypas JA (1997) Modeled estimates of global reef habitat and carbonate production since the last glacial maximum. Paleoceanography 12(4):533–545. https://doi.org/10.1029/97pa01134

Lachniet MS, Burns SJ, Piperno DR, Asmerom Y, Polyak VJ, Moy CM, Christenson K (2004) A 1500-year El Nino/southern oscillation and rainfall history for the isthmus of Panama from speleothem calcite. J Geophys Res-Atmos 109(D20):D20117. https://doi.org/10.1029/2004jd004694

Larson CL, Albertin W (1984) Controlling erosion and sedimentation in the Panama Canal watershed. Water Int 9(4):161–164

Law No.1 (2015) Gaceta Oficial de la República de Panamá

Lessios HA (2005) Diadema antillarum populations in Panama twenty years following mass mortality. Coral Reefs 24(1):125–127. https://doi.org/10.1007/s00338-004-0443-5

Little P, Horowitz M, Nyerges A (1987) Lands at risk in the third world: local level perspectives. Westview Press, Boulder, p 426

Manzello DP (2010) Ocean acidification hot spots: spatiotemporal dynamics of the seawater CO2 system of eastern Pacific coral reefs. Limnol Oceanogr 55(1):239–248. https://doi.org/10.4319/lo.2010.55.1.0239

Manzello DP, Eakin CM, Glynn PW (2017) Effects of global warming and ocean acidification on carbonate budgets of eastern Pacific coral reefs. Coral Reefs of the Eastern Tropical Pacific: Persistence and Loss in a Dynamic Environment 8:517–533. https://doi.org/10.1007/978-94-017-7499-4_18

Marviva (2014) Informe elaborado para el Department of the Environmental of Canada representado por el Minister of the Environment of Canada 94

Maté J (2003) Corals and coral reefs of the Pacific coast of Panamá. In: Latin American coral reefs. Elsevier, Amsterdam, pp 387–417

Maté J (2006) Análisis de la situación de la pesca en los golfos de Chiriquí y de Montijo. The Nature Conservancy – Panamá. 68

Mendizábal A (2004) Panama Viejo: an analysis of the construction of archaeological time in eastern Panama. PHD Thesis, University of London

Ogden J, Ogden N (1996) The coral reefs of the san Blas Islands: revisited after 20 years. Biol Conserv 2(76):215

Patino-Martinez J, Marco A, Quinones L, Godley B (2008) Globally significant nesting of the leatherback turtle (Dermochelys coriacea) on the Caribbean coast of Colombia and Panama. Biol Conserv 141(8):1982–1988. https://doi.org/10.1016/j.biocon.2008.05.012

Paulson S (2017) Coral species distribution and percent cover of sessile organisms on protected and non-protected coral reefs in Digir, Buga, Dubbir, and Kanir Kinnidup, Guna Yala, Panama

PNUD-MiAmbiente (2017a) Resultados del proyecto "Protección de reservas y sumideros de carbono en los manglares y áreas protegidas de Panamá. p 14

PNUD-MiAmbiente (2017b) Resultados finales de la implementación del protocolo de medición de carbono en ecosistemas de manglares en los distritos de Remedios, San Félix y San Lorenzo, Provincia de Chiriquí. Proyecto: Protección de Reservas y Sumideros de Carbono en los Manglares y Áreas Protegidas de Panamá, PNUD, Ciudad del Saber, Panamá, p 56

Ramírez-Ortiz G, Calderon-Aguilera LE, Reyes-Bonilla H, Ayala-Bocos A, Hernández L, Fernández Rivera-Melo F, López-Pérez A, Dominici-Arosamena A (2017) Functional diversity of fish and invertebrates in coral and rocky reefs of the eastern tropical Pacific. Mar Ecol 38(4): e12447

Ramsar (1993) Information sheet on Ramsar wetlands (San-San Pond Sak). Wetlands International Ramsar Sites Information Service. www.wetlands.org/rsis/. Viewed 26 Apr 2008

Resuelto ARAP No. 10 (2008) de 22 de Diciembre de 2008. Por medio del cual se declara la zona de reserve Matumbal. El administrador general de la autoridad de los recursos aquáticos de Panamá

Scodelaro F, Gaitán N, Terraza H, Leaño J, Banfield R, Treuherz A, Trute M (2015) Panamá Metropolitana: Sostenible, Humana y Global. Municipio de Panamá and Banco Interamericano de Desarrollo

Seemann J, Gonzalez CT, Carballo-Bolanos R, Berry K, Heiss GA, Struck U, Leinfelder RR (2014) Assessing the ecological effects of human impacts on coral reefs in Bocas del Toro, Panama. Environ Monit Assess 186(3):1747–1763. https://doi.org/10.1007/s10661-013-3490-y

Seemann J, Yingst A, Stuart-Smith RD, Edgar GJ, Altieri AH (2018) The importance of sponges and mangroves in supporting fish communities on degraded coral reefs in Caribbean Panama. Peerj 6:e4455. https://doi.org/10.7717/peerj.4455

Shepherd G (2008) The ecosystem approach: learning from experience. IUCN, Gland
Smith TB, Glynn PW, Mate JL, Toth LT, Gyory J (2014) A depth refugium from catastrophic coral bleaching prevents regional extinction. Ecology 95(6):1663–1673. https://doi.org/10.1890/13-0468.1
Smith J, Dalman K, Deaton D, Barnes A (2016) The watchman. http://vimeo.com/162564459
Smith TB, Mate JL, Gyory J (2017) Thermal refuges and Refugia for stony corals in the eastern tropical Pacific. Coral Reefs of the Eastern Tropical Pacific: Persistence and Loss in a Dynamic Environment 8:501–515. https://doi.org/10.1007/978-94-017-7499-4_17
Spalding AK, Suman DO, Mellado ME (2015) Navigating the evolution of marine policy in Panama: current policies and community responses in the Pearl Islands and Bocas del Toro archipelagos of Panama. Mar Policy 62:161–168. https://doi.org/10.1016/j.marpol.2015.09.020
Strassnig C (2010) Rediscovering the Camino real of Panama: archaeology and heritage tourism potentials. J Lat Am Geogr 9(2):159–168. https://doi.org/10.1353/lag.2010.0012
Suman D (2002) Evolution of coastal Management in Panama. The Dante B. Fascell North-South Center Working Paper Series, Paper(9)
Suman D (2007) Development of an integrated coastal management plan for the Gulf of San Miguel and Darien Province, Panama: lessons from the experience. Ocean Coast Manage 50(8): 634–660. https://doi.org/10.1016/j.ocecoaman.2007.03.007
Toth LT, Aronson RB, Vollmer SV, Hobbs JW, Urrego DH, Cheng H, Enochs IC, Combosch DJ, van Woesik R, Macintyre IG (2012) ENSO drove 2500-year collapse of eastern Pacific coral reefs. Science 337(6090):81–84. https://doi.org/10.1126/science.1221168
Valiela I, Camilli L, Stone T, Giblin A, Crusius J, Fox S, Barth-Jensen C, Monteiro RO, Tucker J, Martinetto P, Harris C (2012) Increased rainfall remarkably freshens estuarine and coastal waters on the Pacific coast of Panama: magnitude and likely effects on upwelling and nutrient supply. Glob Planet Chang 92–93:130–137. https://doi.org/10.1016/j.gloplacha.2012.05.006
Valverde A (2013) Producción y comercialización de la pesca artesanal o de pequeña escala en Panamá desde 1995 al 2008. Centros 2(1):115–131
Van Oosterzee P, Duke N (2017) Extreme weather likely behind worst recorded mangrove dieback in northern Australia. The Conversation 14:1–6
Vega ÁJ, Robles YA, Maté JL (2016) La pesca artesanal en el Parque Nacional Coiba y zona de influencia: biología y pesqueria de sus principales recursos, con recomendaciones de manejo. Fundación MarViva
Ventocilla J, Herrera H, Nuñez V (1995) Plants and animals in the life of the Kuna. University of Texas Press, Austin
Viana IG, Valiela I, Martinetto P, Pierce RM, Fox SE (2015) Isotopic studies in Pacific Panama mangrove estuaries reveal lack of effect of watershed deforestation on food webs. Mar Environ Res 103:95–102
Windevoxhel N, ter Heegde M (2008) Bocas del Toro archipelago, Panama. The ecosystem approach: learning from experience, 132

Chapter 12
Philippines Case Study Two

Looking into the Management Strategies of Three Philippine National Integrated Protected Area System (NIPAS) Sites

Kristina S. A. Cordero-Bailey, L. T. David, T. L. P. dela Cruz, A. T. Almo, S. Martinez, H. E. Amihan, W. Y. Licuanan, P. Z. Mordeno, V. S. Ticzon, C. L. Nanola, J. B. Cabansag, H. M. Nacorda, R. Rollon, C. L. Villanoy, E. Magdaong, M. J. R. Pante, G. Perez, A. Blanco, T. M. Lim, K. Rodriguez, M. Mendoza, DENR Regional Executive Director XIII, Protected Area Superintendent (PASu) SIPLAS, DENR Regional Executive Director VI, Protected Area Superintendent (PASu) SMR, Local Government of Sagay, Negros Occidental, DENR Regional Executive Director III, and Protected Area Superintendent (PASu) MOBMR

Abstract Philippines is famous for its rich natural marine resources and was among the first countries in the region to create marine protected areas (MPAs) that addressed the need to conserve and protect these resources. The National Integrated

K. S. A. Cordero-Bailey (✉)
Marine Science Institute, University of the Philippines Diliman, Quezon City, Philippines

Present Address: Department of Community and Environmental Resource Planning, University of the Philippines Los Banos, Los Baños, Laguna, Philippines
e-mail: kcordero@msi.upd.edu.ph; kscordero@up.edu.ph

L. T. David · T. L. P. dela Cruz · A. T. Almo · H. E. Amihan · C. L. Villanoy · E. Magdaong · M. J. R. Pante
Marine Science Institute, University of the Philippines Diliman, Quezon City, Philippines

S. Martinez
Department of Geography, University of the Philippines Diliman, Quezon City, Philippines

W. Y. Licuanan · P. Z. Mordeno
Br. Alfred Shields Ocean Research Center, De La Salle University, Manila, Philippines

V. S. Ticzon
Institute of Biological Sciences, University of the Philippines Los Banos, Los Baños, Laguna, Philippines

C. L. Nanola
Department of Biological Sciences and Environmental Studies, University of the Philippines Mindanao, Davao, Philippines

M. Wolff et al. (eds.), *Challenges in Tropical Coastal Zone Management*,
https://doi.org/10.1007/978-3-031-17879-5_12

Protected Areas System (NIPAS) Act implemented in 1992, along with its updated 2018 version—Enhanced NIPAS Act-, provide a comprehensive framework that brings together essential agencies under the government sector, local communities and other stakeholders to the table to discuss how to manage the coastal environment which local populations are highly dependent on. This chapter introduces three NIPAS sites, namely Siargao Integrated Protected Landscape and Seascape, Sagay Marine Reserve, Masinloc Oyon Bay Marine Reserve and the status of marine resources vis-à-vis the site-specific management practices developed by local stewards responsible for the sustainable use of these coastal resources.

J. B. Cabansag
University of the Philippines Visayas – Tacloban College, Tacloban, Leyte, Philippines

H. M. Nacorda
School of Environmental Science and Management, University of the Philippines Los Banos, Los Baños, Laguna, Philippines

R. Rollon · G. Perez
Institute of Environmental Sciences and Meteorology, University of the Philippines Diliman, Quezon City, Philippines

A. Blanco
Department of Geodetic Engineering, University of the Philippines Diliman, Quezon City, Philippines

T. M. Lim
Department of Environment and Natural Resources – Biodiversity Management Bureau, Quezon City, Philippines

ASEAN Center for Biodiversity, Los Banos, Laguna, Philippines

K. Rodriguez · M. Mendoza
Department of Environment and Natural Resources – Biodiversity Management Bureau, Quezon City, Philippines

DENR Regional Executive Director XIII
Department of Environment and Natural Resources – CARAGA, Butuan City, Philippines

Protected Area Superintendent (PASu) SIPLAS
DENR – PASU SIPLAS, Dapa, Surigao del Norte, Philippines

DENR Regional Executive Director VI
Department of Environment and Natural Resources Region 6 Western Visayas, Iloilo City, Philippines

Protected Area Superintendent (PASu) SMR
PASU SMR, Sagay City, Philippines

Local Government of Sagay, Negros Occidental
LGU, Sagay City, Negros Occidental, Philippines

DENR Regional Executive Director III
Department of Environment and Natural Resources Region 3 Central Luzon, Pampanga, Philippines

Protected Area Superintendent (PASu) MOBMR
DENR – PASU MOBMR, Iba, Zambales, Philippines

Keywords Marine protected areas · Coastal management · Management strategies

1 Introduction

Efforts to preserve the marine environment in the Philippines began as early as the 1970s—one of the first countries in South East Asia to establish marine protected areas (Alcala and Russ 2006). As of May 1, 2019, the MPA database (Cabral et al. 2014; MPA Support Network 2014) provides details of 1401 existing MPAs in the Philippines. Within this list, there exist two categories of MPAs: the locally managed MPAs, declared by local governments under the Philippine Fisheries Code (Republic Act [RA] 8550) and the Local Government Code (RA 7160), and the nationally managed MPAs under the National Integrated Protected Areas System (NIPAS) Act.

The NIPAS Act (RA 7586) was enacted in 1992 for the purpose of establishing protected areas found to be remarkable and biologically important public lands (terrestrial, wetland, or marine) with habitats of rare and endangered plant and animal species. Within this Act, the Protected Area Management Board (PAMB) is designated to be the responsible body for the proper implementation of the NIPAS Management Plan. It is a multi-sectoral body composed of the Department of Environment and Natural Resources (DENR)'s Regional Executive Director, the Protected Area Superintendent (PASu), representatives from the local provincial and municipal government, local non-government organizations (NGO)/People's Organizations (POs), the indigenous cultural community (ICC), the Bureau of Fisheries and Aquatic Resources BFAR (for jurisdiction over fishery resources), the Coast Guard (for coastal areas), and, if necessary, one representative from the Mines and Geosciences Bureau (MGB) (for mining activities). The efficient coordination and cooperation of the PAMB is crucial in the successful management of the NIPAS sites. All development and protection of the protected area is decided by the PAMB and issued through specific policies and regulations. Since the declaration of the 1992 NIPAS Act, 33 sites were affirmed as marine NIPAS areas. The NIPAS Act was updated in 2018 through the Enhanced NIPAS Act (RA 11038), declaring an additional sixty-one (61) MPAs, totaling ninety-four (94) marine NIPAS sites.

We present different management approaches of three NIPAS sites (Siargao Integrated Protected Landscape and Seascape [SIPLAS], Sagay Marine Reserve [SMR], Masinloc Oyon Bay Marine Reserve [MOBMR] (Fig. 12.1). These sites are exposed to both monsoons and typhoons and each site also experiences varying levels of anthropogenic threats. Thus, this chapter aims to present how each PAMB individually recognizes site-specific natural and human induced pressures and their approach in addressing these threats. In recent years, these sites have also become famous eco-tourist destinations making it imperative that management of the marine resources in each site be strengthened. All three sites were visited by the DENR-funded Coral Reef Visualization and Assessment (CoRVA) program as part of a

Fig. 12.1 Location of selected NIPAS sites (1) Siargao Island Protected Landscape and Seascape (SIPLAS). (2) Sagay Marine Reserve (SMR). (3) Masinloc Oyon Bay Marine Reserve (MOBMR)

national assessment on the coral reefs and associated habitats between 2014 and 2017. Here we present the data that was collected during the CORVA program to present the current status of these NIPAS sites.

In this chapter, thresholds to specifically categorize Philippine coral reef and reef fish communities by Licuanan et al. (2017a) and Hilomen et al. (2000), respectively, are used. Gomez et al. (1981) had introduced a scale based on live coral cover (i.e., hard and soft coral) which had been long used as the standard scale in the assessment of Philippine coral reefs. However, Licuanan et al. (2017a) introduced a new scale based solely on hard coral cover (HCC) taking into account that soft corals are not considered important reef builders (Licuanan and Gomez 2000). The new scale characterized HCC as poor (0–22%), fair (>22–33%), good (>33–44%) and excellent (>44%), with the exceptional Tubbataha Reefs as the benchmark in the Philippines (Licuanan et al. 2017b). Hilomen et al. (2000) utilized the fish abundance and biomass to describe the reef fish communities. Reef fish assemblages are characterized into very poor (<201 individuals/1000 m^2), poor (202–676 individuals/1000 m^2), moderate (677–2267 individuals/1000 m^2), high (2268–7592 individuals/1000 m^2) and very high (>7592 individuals/1000 m^2) according to reef fish abundance. In terms of biomass, reef assemblages are categorized into very poor (<5.0 mt/km^2), poor (5.1–20 mt/km^2), moderate (20.1–35.0 mt/km^2), high (35.1–75 mt/km^2) and very high (>75 mt/km^2).

2 Siargao Islands Protected Landscape and Seascape

The Siargao Islands Protected Landscapes and Seascape (SIPLAS) is located in the southern province of Surigao del Norte, Mindanao Island (Fig. 12.2). It was declared a NIPAS site on October 10, 1996, by Proclamation No. 902 and is one of the largest contiguous protected areas in the Philippines, covering 278,914 hectares of terrestrial, wetland, and marine areas. The geographic location of Siargao Island, bordered to the east by the Pacific Ocean and with the strong southward Mindanao current producing great surfing waves, has led to SIPLAS becoming known as the surfing capital of the Philippines.

Nine municipalities comprising 132 barangays (villages) can be found within the SIPLAS, with a total population of 116,587 (Philippine Statistics Authority 2015).

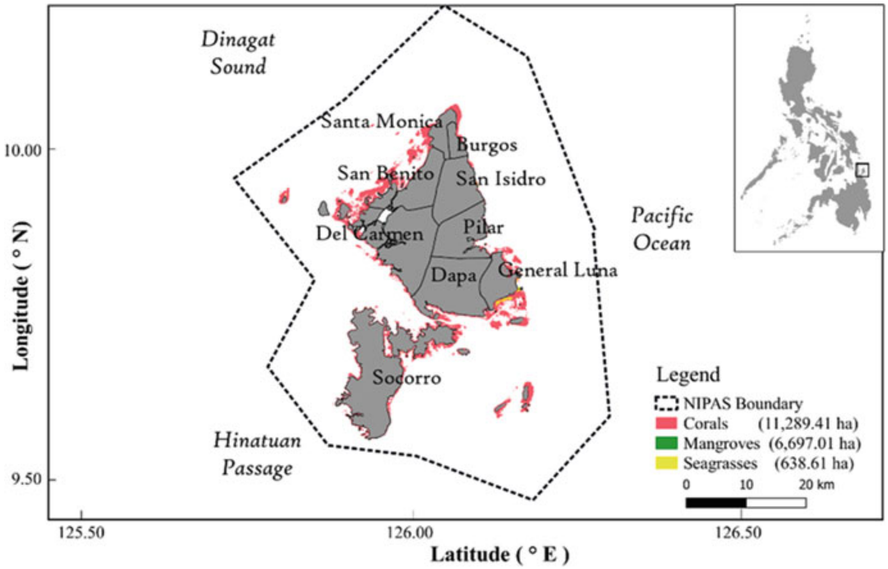


Fig. 12.2 Coastal habitats within Siargao Islands Protected Landscape and Seascape (data from CORVA9 report 2017, 2019)

Table 12.1 Typhoon Data from October 1998 to January 2015 of selected NIPAS site (Japan. . .)

NIPAS Area	No. of Typhoons passed within 200 km
Siargao Islands Protected Landscape And Seascape	24
Sagay Marine Reserve	16
Masinloc—Oyon Bay Marine Reserve	35

The municipalities are classified to be fourth to sixth class[1] with agriculture, mainly coconut, as the primary source of income. Twenty-four percent of the population is directly dependent on fishing, the second main source of income (Philippine Climate Change Adaptation Project 2015). SIPLAS experiences pronounced rainy seasons from November to January and are exposed to both the southwest (Habagat) and northeast (Amihan) monsoons. Its location also makes SIPLAS vulnerable to oncoming cyclonic typhoons that develop in the Pacific and enter Philippine territory from the east (Table 12.1).

Out of the 278,914 ha of the protected area, 76% (216,118 ha) are marine area, of which coral reefs and its associated habitats comprise only 9.14% (25,497 hectares) (Fig. 12.2). Hard coral cover (HCC) was observed to be varied in different sites within SIPLAS, with a mean HCC of 20% (Fig. 12.3). This is equivalent to a poor reef health status, according to Licuanan et al. (2017a). A high percentage of algal assemblages was present at all sites, possibly due to the high sediment load. The rare fox coral (*Nemenzophyllia turbida),* an important evolutionarily distinct, globally endangered (EDGE) species was found in Socorro (CORVA2 2017).

A total of 248 reef fish species were identified in SIPLAS. Fish assemblage inside the marine protected areas of Siargao were moderately abundant (1568 individuals/ 1000 m^2), while fish biomass within the MPAs was moderately high (40 mt/km^2). Reefs outside the MPAs had poor to high reef fish biomass (CORVA3 2017). SIPLAS is famous for one of the largest mangrove areas in the Philippines, covering

[1]The Department of Finance Order 23–08 (released 2008) prescribed the income classification of Provinces, Cities, and Municipalities in the Philippines to determine the financial capability of Local Government Units (LGUs). Funding requirements for developmental projects and priority needs in their locality are based on this classification. Every four years, the LGUs are re-classified based on their average annual income. For municipalities, the income classes are as follows:

Class	Average Annual Income
1st	Php 55 M or more
2nd	Php 45 M or more but less than Php 55 M
3rd	Php 35 M or more but less than Php 45 M
4th	Php 25 M or more but less than Php 35 M
5th	Php 15 M or more but less than Php 25 M
6th	Below Php 15 M

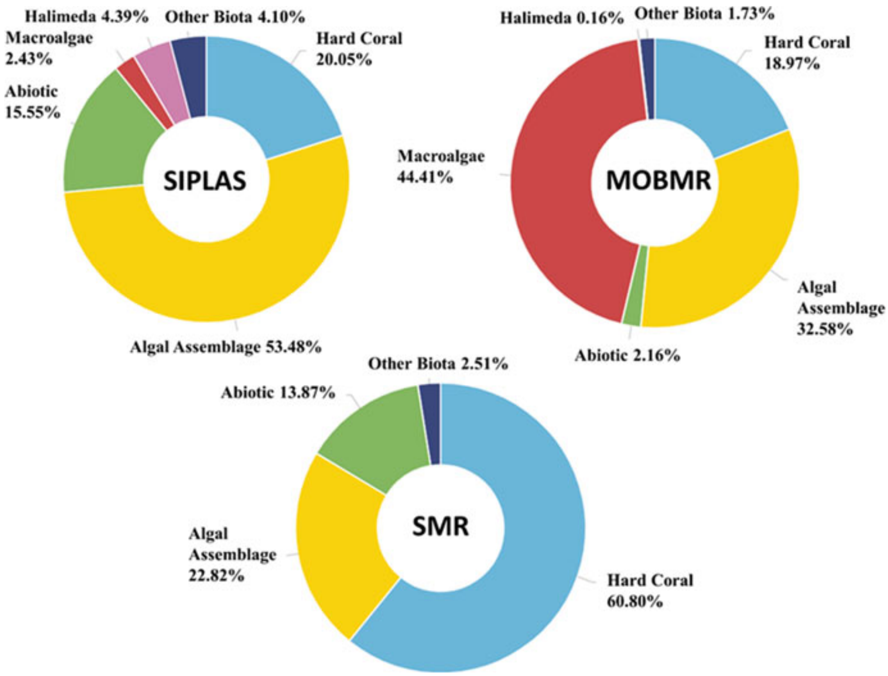


Fig. 12.3 Relative coral abundance in (1) Siargao Island Protected Landscape and Seascape (SIPLAS). (2) Sagay Marine Reserve (SMR). (3) Masinloc Oyon Bay Marine Reserve (MOBMR) (data from CORVA database, CORVA2 2017, 2019 report)

approximated 6697.01 ha (CORVA9 2019). The most abundant species was observed to be *Rhizophora stylosa*, while the most dominant species in terms of basal area was *Sonneratia alba* (CORVA4 2019). The seagrass beds are also extensive with an estimated area of 638.61 ha, dominated by *Cymodocea rotundata*. Marine megafauna such as turtles and saltwater crocodiles have been observed to visit or reside within these habitats (CORVA4 2019).

2.1 Threats and Issues within SIPLAS

The SIPLAS management plan (Philippine Climate Change Adaptation Project 2015) identified a decrease in mangrove cover from 9779.3 ha in 1988 to 7768.6 ha in 2011, either by the conversion of mangrove areas to settlement or fishponds or for use in housing or fuelwood/charcoal. CORVA9 (2019) reported a similar trend, however recent images showed there has been an increase in mangrove area (Table 12.2). This could be attributed to natural regrowth, decreased illegal deforestation or reforestation efforts from the launch of the Mangrove Protection and Information Center in Brgy. Del Carmen. These efforts stemmed from increased

Table 12.2 Change in mangrove areas in selected NIPAS sites based on Land Use Land Cover maps derived from Landsat images (CORVA9 2019)

NIPAS Area	Area (ha)			
	1990s	2000s	2010s	Present
Siargao Islands Protected Landscape And Seascape	6765.30	6433.57	6196.17	6697.01
Sagay Marine Reserve	140.04	154.62	511.38	349.47
Masinloc-Oyon Bay Marine Reserve	72.88	80.39	76.64	87.76

awareness of the natural protection provided by mangroves from storm surges after the 2013 Super Typhoon Yolanda (Haiyan).

Another threat to marine biodiversity is illegal fishing (dynamite fishing and intrusion of commercial fisheries), overfishing and the illegal collection or slaughter of marine turtles and turtle eggs. Other issues that need to be addressed in the coming future include water pollution from farming and improper waste disposal that could come about from the continued expansion of settlement areas, and proliferation of commercial and tourism establishments.

Generally, typhoons in the western Pacific are formed about east of the Philippines, ranging from 130° to 180° East and 5° to 15° North (Mei et al. 2015). In the recent years, these typhoons have been recorded to be stronger and wetter, with more southerly trajectory than normal (Holden and Marshall 2018). As such, SIPLAS' location in southern Philippines, directly exposed to the Pacific, makes it very vulnerable to climate change. Vulnerability assessments by the Philippine Climate Change Adaptation Project (2015) revealed that increases in temperature leading to erratic rainfall patterns could induce landslides, as agriculture and mangrove deforestation have denuded watersheds of the main island. Landslides would not only affect the local population but also biodiversity. Increased temperature may cause the extinction of native plants and animals. The coastal and low-lying communities would be highly prone to storm surges in light of increased storm intensities due to climate change.

2.2 Management Strategies

The PAMB and partner LGUs in SIPLAS acknowledged there is a need to strengthen climate change resilience and enhance the adaptive capacity of the communities of the nine municipalities. To fulfill this need, SIPLAS aims to focus its management strategies on five key points: management zoning, climate change adaptation, collaborative management, community-based resource management and sustainable financing. Management zoning addresses biodiversity conservation issues as well as livelihood and socio-economic development needs. In both the

Table 12.3 SIPLAS Management programs (PCCAP 2015)

Programs	Target activities
Terrestrial management program	Biodiversity conservation
	Socio-economic development
Coastal and marine management programs	Coastal habitat and species conservation
	Fisheries management
	Socio-economic development/alternative livelihood support
Cross-cutting management programs	Ecotourism development
	Waste management
	Disaster risk reduction planning and preparedness
	IEC campaign
	Sustainable financing development
Governance enhancement and institutional strengthening	Knowledge and capacity building
	PAMB meetings/policy support
	Monitoring and evaluation
General Administration & Management	Personnel services
	Capital outlay
	Maintenance and office operating expenses

terrestrial and coastal and marine zones, sustainable eco-tourism is promoted as a livelihood alternative.

Due to the high vulnerability of SIPLAS to impacts of climate change, the integration of climate change adaptation measures and disaster risk reduction is a priority. By using an integrated ecosystem approach, management programs (see Table 12.3) were developed to address short- and long-term adaptation measures.

Collaborative management of the protected area will ensure continuance of the management programs. Strengthening stakeholder partnerships, LGU participation, inter-LGU alliances and networks and co-management with willing stakeholders will encourage local communities to be active in the PA management activities. Such an approach is important for stakeholders to have direct involvement in the sustainable use and management of their resources.

One priority concern of the PAMB, PASu office and LGUs is the protection and conservation of terrestrial and marine resources. By assigning the community residents as the primary custodians, they develop a sense of responsibility for the natural resources of which they are the direct beneficiaries. To encourage sustainable alternative livelihood, the PAMB provides assistance and guidance in development of biodiversity-friendly livelihood activities and community-oriented eco-tourism programs that are initially identified by the communities based on their knowledge of the local resources.

Although the NIPAS Act and the implementing rules and regulations provide for an integrated protected area fund (IPAF), this provision is insufficient for the full implementation of the management plan. Hence, SIPLAS needs to augment this budget by generating internal funds, e.g., through levies on development and resource use, and concessions and conservation fees for associated tourism development. Payment for ecosystem services, such as the use of water, is also explored as a sustainable funding mechanism.

2.3 Management Structure

Being one of the largest NIPAS sites with nine LGUs, the SIPLAS PAMB currently consists of 156 members, with different sectors and interests well-represented in the PAMB. Agreements between the PAMB and LGUs provide clear responsibilities and accountabilities of all parties. Administrative and financial transactions are handled by the PASu Office, with a designated Special Collecting Officer (SCO) responsible for revenues generated and received. The Provincial Environment and Natural Resources Office stands as the custodian for the IPAF PA accounts and is responsible for the accounting and administrative support of the management fund. To ease periodic reporting as well as monitoring and evaluate on of the Management Plan, the PAMB has clustered the LGUS into three groups based on location and biophysical features: a northwest cluster (Del Carmen, San Benito, Sta. Monica), northeast cluster (Burgos, San Isidro, Pilar and General Luna) and a southern cluster (Dapa and Socorro). The current management plan that has been presented here was targeted for implementation from 2015 to 2020 and is therefore due for updating.

3 Sagay Marine Reserve

The Sagay Marine Reserve (SMR) is located in the municipality of Sagay City on the northeast tip of Negros Occidental. SMR covers a total area of 32,000 hectares, consisting of the islands of Molocaboc, Diutay, Matabas and Suyac and extending to the Carbin, Macahulom, and Panal Reefs. It was declareded a NIPAS site on June 1, 1995 by Proclamation No. 592 and further enacted on April 14, 2001, by Republic Act No. 9106.

Six coastal barangays of Sagay City are located opposite the SMR, with a total population of 44,895 (Philippine Statistics Authority 2015). Sagay City is considered to be a first-class municipality, with agriculture as the main source of income. Within the coastal barangays, fishing and collection of shells are the main sources of livelihood. Backyard farming is highly encouraged, thereby providing alternative food sources for these barangays.

SMR is exposed more to the northeast monsoon between November to February but can also be affected by the southeast monsoon from July to October. Being at the center of the Visayan region, SMR occasionally experiences typhoons that may traverse towards the northwestern part of the country. The coastal habitats constitute approximately 23% (7317 ha) of the protected area (Fig.12.4). Relative hard coral

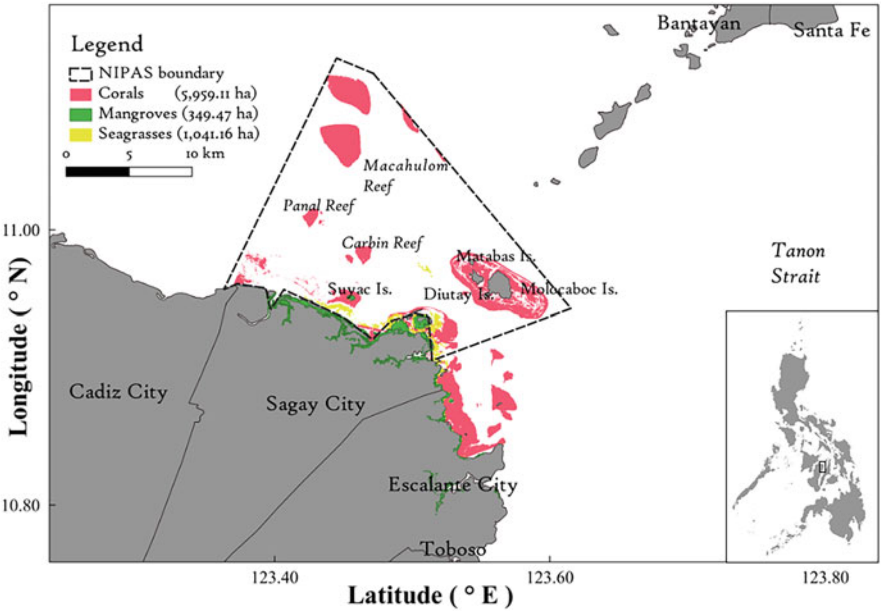


Fig. 12.4 Coastal habitats mapped within Sagay Marine Reserve (data from CORVA9 report 2017, 2019)

cover in the SMR is reported to be high at 60% (CORVA database), corresponding to the excellent category (Licuanan et al. 2017a, 2017b), with a dominance of fast-growing *Echinopora* species in the Macahulom reef while Carbin reef is dominated by massive *Porites* (CORVA2 2019). Macroalgae in Carbin reef were observed to be low, indicating the reefs may be highly resilient and have increased chances of recovery after natural disturbances such as bleaching. These reefs were severely affected by the 1998 bleaching event and were able to recover successfully (J.R. Togle, pers. comm.) The coastal barangays of SMR are lined by mangroves, with old growth of mangroves along Barangays Taba-ao, Bulanon and Vito, and extensive mangrove reforestation projects are present in the island of Molocaboc and Suyac (SMRGMP 2015). Similarly, seagrass meadows are also abundant in the coast of Sagay (1041.16 ha, (CORVA9 2019)).

3.1 Threats and Issues in SMR

The main threat within the SMR includes poaching activities and the enroachment of fishermen from neighboring cities and municipalities that use destructive or illegal fishing practices such as dynamite fishing and the use of fine fish nets. The man-power of the local coast guards, known as "Bantay Dagat," is insufficient to monitor the entire protected area. Potable water supply is an important issue for the island barangays of Molocaboc and Sugay, which do not have any natural water source as these islands are naturally accreted sand bars. As in most parts of the country, effects of climate change such as rising sea level and increased storm intensities are already being felt in SMR. The need to direct efforts for mitigation and adaptation, and for disaster risk reduction, is an urgent issue.

A potential development for the city of Sagay was the development of a port to increase the livelihood opportunities for the local population. The city requested for the establishment and construction of a fishing port to cater to small and big fishing vessels, and the request was approved by the PAMB in 2005. Although the port could potentially increase the city's overall income, the presence of the port has led to increased environmental stress from tourist influx into SMR and a higher potential of oil spill pollution from operational spills or the grounding of vessels in SMR's coastal waters.

3.2 Management Strategies

According to the SMRGMP (2015), the SMR considers the following two strategies to address management issues, namely site management strategy and sustainable financing. The management strategy would integrate current management activites in SMR. The empowerment of the community residents and fisherfolks and establishment of an institutionalized community-based law enforcement unit would, as in SIPLAS, provide local residents with a sense of responsibility for the protection and monitoring of the reserve. The community-based enforcement unit is supposed to be capacitated through training and support from the LGU.

Sustainable financing is a key issue for SMR, as it does not receive any allocation from the DENR to finance its management programs. Ideally, the IPAF provides each PAMB a general management fund but unfortunately, this has not trickled down to the SMR. Revenues from the user fees and eco-tourism activities such as visits to Carbin Reef and the Suyac Island Mangrove Eco-Park are collected by the LGU for sustainability of the NIPAS. Additionally, the city of Sagay has generously augmented the funds for the continued management of SMR.

To address biodiversity protection, the SMR actually has two management plans in place, formulated by the Sagay City Environment and Natural Resources Office (SCENRO), namely the Initial Protected Area Plan (IPAP) and the Coastal Fisheries Resources Management (CFRM) Plan. The IPAP was prepared by the SCENRO in 1997 to address the protection and sustainability of the marine areas and to enhance the awareness of the local community of Sagay on environmental protection. The CFRM plan, designed to complement IPAP, was crafted in 2008 with the Fisheries and Aquatic Resources Management Council (FARMC) to focus on sustainable management of marine resources within the SMR by enhancing capabilities of the local government units (LGUs) and to include other government agencies such as the BFAR and DENR.

The PAMB recognizes the need for science-based policies, hence they admit the need for a scientific research station. Altough climate change is identified as a threat, the 2015 management plan of SMR lacks approaches on how to address climate change adaptation. Moreover, the CORVA program recommended that ecotourism activities, such as visits of the giant clam colony in Carbin Reef, within the reserve be regulated to ensure protection of the coastal resources.

3.3 Management Structure

The Sagay Marine Reserve PAMB is chaired by the DENR Regional Director. However, the SMR Protected Area Superintendent (PASu), who is in charge of day-to-day supervision, is sustained by the local government of Sagay, while a PASu from the DENR exists only at a deputized level. This arrangement has resulted in a ongoing conflict between the LGU and the DENR, as the LGU of Sagay appears to be managing the SMR independently. The Sagay City LGU, despite of the lack of financial and managerial support from the DENR, has made the best of the situation and appears to have been effectively managing SMR as the status of the coastal habitats has been observed to be in good to excellent condition.

4 Masinloc-Oyon Bay Marine Reserve

The Masinloc-Oyon Bay Marine Reserve (MOBMR) in the western province of Zambales was declared a protected area on August 18, 1996 (Proclamation No. 231). MOBMR has a total area of 7568 ha, covering eleven western coastal barangays in the municipality of Masinloc and three barangays in the northern portion of the Palauig municipality. The reserve has a land area of 680.97 ha comprising six islands (San Salvador, Magalawa, Luan, Panglit and Pilapir) and a marine area of 6887.53 ha.

There is a total population of 52,590 individuals living in the barangays adjoining the MOBMR (Philippine Statistics Authority 2015). Masinloc is a first-class municipality, while Palauig is a third-class municipality. The primary income source for the coastal barangays is fishing. There is an existing coal-fired thermal power plant managed by AES-MPPCL, Philippines in the northern barangay of Bani that employs at least 30% of its workforce from the local population. The company contributes a percentage of its earnings to an Environmental Guarantee Fund. Other industries in the MOBMR are generally small- or medium-scale enterprises. MOBMR is exposed directly to the Habagat (SW monsoon) from June to October. Its location also makes it prone to more typhoons coming from both the Pacific and the West Philippine Sea (see Table 12.1).

The coastal habitats comprise 16.9% of the protected area (1279.19 ha) (Fig. 12.5). Of this, about 10% has been placed under strict protection through

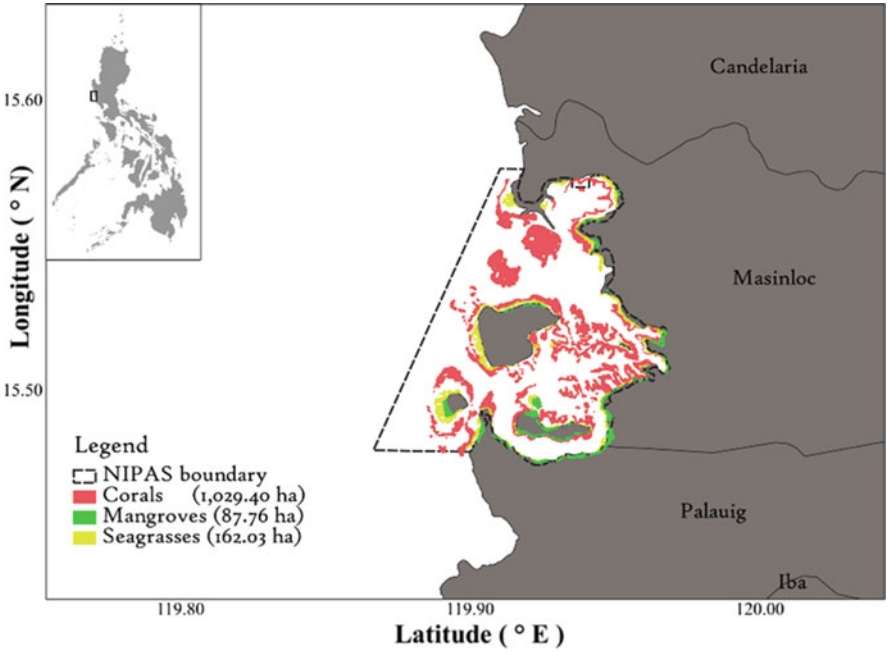


Fig. 12.5 Coastal habitats within Masinloc-Oyon Bay Marine Reserve (data from (CORVA3 2017; CORVA9 2019))

four MPAs, namely Panglit MPA, Bani MPA, San Salvador MPA and Taclobo (Giant clam) Farm. Relative hard coral cover was reported to be 19% (poor). Vulnerable corals such as *Acanthastrea ishigakiensis* and a Nemenzo coral,[2] *Echinopora mammiformis*, were found in MOBMR. The reefs were found to have a high *Acropora*—low *Porites* typology, with relative covers of 55% and 27%, respectively, indicative that the reef is prone to coral bleaching (Cantin and Lough 2014; Hoogenboom et al. 2017). Additionally, the high proportion of macroalgae (44%) is an indicator of high eutrophication in the reserve (CORVA2 2019; Flower et al. 2017).

The reef fish communities were found to have higher species richness within the MPAs (48 species/500 m^2) over stations outside MPAs (46 species/500 m^2), with an abundance of mobile invertebrate feeders and herbivores. Average total fish abundance was 331 ind/500 m^2. Herbivores are the highest contributors to the estimated biomass. The lowest biomass was found in the Panglit MPA (6 mt/km^2), while the highest was observed in the Taklobo MPA (34 mt/km^2). The mangroves of the

[2]Nemenzo corals are among the 375 Philippine coral species that were described by Prof. Francisco Nemenzo, the father of Philippine coral taxonomy. The complete listing may be found in Nemenzo (1986) with an online photo collection at https://www.dlsu.edu.ph/research-1/centers/shore/coenomap/

MOBMR (estimated 87.76 ha) are a famous eco-tourism attraction, particularly the mangrove-formed island of Yaha. The most abundant species of mangrove was found to be *Rhizophora apiculata*. Seagrass meadows are also vast in MOBMR (167.03 ha), with *Cymodocea rotundata* as the most abundant species.

4.1 Threats and Issues in MOBMR

The PAMB of MOBMR identified illegal fishing (use of dynamite, cyanide, and illegal fishing nets) to be one of the main threats to the biodiversity of the marine habitats. Mining and deforestation activities are strictly prohibited within the municipality of Masinloc. However, the MOBMR shares the watershed of the Masinloc River with the neighboring municipality of Candelaria, and MOBMR still receives a significant sediment load from the small-scale mining allowed in Candelaria.

To augment the food supply of the municipality, several fish cage operators have been allowed in MOBMR. Excessive feeds from these mariculture activities have decreased water quality within the reserve. Another source of pollution is the indiscriminate waste disposal of coastal communities and informal settlers. The heat and ash fall from the thermal power plant in Bani also threaten nearby coral reefs. Conversion of mangrove areas to aquaculture ponds was previously an issue in MOBMR. Recent findings of the CORVA9 project show that this may been competently mitigated by the PAMB, with a decrease in aquaculture structures and a corresponding increase in mangrove areas (Table 12.2) in recent Landsat satellite images.

As the population in the municipality of Masinloc increases, the issue of human encroachment into protected area becomes more substantial. A larger population would put more pressure on the marine resources as food source, and the possibility of mangrove deforestation increases in line with an increased need for lumber and space for settlement.

4.2 Management Strategies

The MOBMR PAMB aims to protect and conserve the marine biodiversity and promote sustainable development for both commercial and community-based resource enterprises. To achieve this, management strategies aim to address the following: management zoning, ecological consciousness of local communities and capability strengthening of the MOBMR management.

Management zoning permits human activities within the reserve while continuing the protection of biodiversity in the ecosystem. Proper zoning also allows restoration of degraded areas. For this purpose, there is a prescribed strict protection zone (2617 ha) wherein all human activities are prohibited except for scientific studies

Table 12.4 MOBMR management programs (MOBMR Management Plan 2017)

Programs	Target activities
Biodiversity and protection program	Habitat and biodiversity conservation
	Resource extraction regulations
	Research documentation
Economic support program	Alternative livelihood
	Ecotourism
Community organizing and empowerment program	Environmental consciousness
	Community participation in PA management
Institutional development program	Establishment of the integrated protected area fund (IPAF)
	Management institutionalization
	Formation of management system
	Supportive LGUs
Law enforcement and protection	Protection
	Wildlife/fisheries management
	Protected area administration
Climate change mitigation and adaptation	
Sustainable financing	
Research and development	

and a multiple-use zone for settlement, sustainable land use and other income-generating or livelihood activities.

A study by Dizon et al. (2013) found that there was a low level of community awareness of the existing MPAs within MOBMR Increasing the ecological consciousness of the communities within the MOBMR could possibly improve the perception of the MPAs and enlighten the locals on the potential benefits they could receive from the proper protection of the habitats.

To further improve the management of MOBMR, strengthening the capacity of the coastal and marine managers is essential. This would assist the PAMB in implementing targeted management programs specified in the MOBMR management plan (Table 12.4).

A connectivity model simulation in the CORVA-7 project (2019) showed that the entire province of Zambales is self-seeding, i.e., both coral and fish larval recruits simulated to be released in Zambales tended to settle not far from release points ("Zambales for Zambales"). This finding provides the MOBMR PAMB the validation to push for firmer policies for habitat protection and to enhance the networking of the marine protected areas within the entire province to ensure sustained coral and fish larval supply. CORVA also reiterated recommendations on proper management of the watershed leading the MOBMR, specifically involving the neighboring municipality of Candelaria, which contributes to the sediment and nutrient input into the bay.

4.3 Management Structure

Although the MOBMR covers only two municipalities, the PAMB includes representatives from all fourteen barangays. Additionally, fisher folk organizations are also actively involved in PAMB meetings as they are the primary beneficiaries of a well-managed MPA. In the account of Vera (2004), he detailed conflicts between the fisherfolks, LGU, DENR and the Bureau of Fisheries and Aquatic Resources (BFAR) over the proliferation of mariculture cages in the reserve are described. Although the issue has been partially contained (O. Gregorio, pers. comm 2018), it is still a cause for concern for all involved parties.

5 Conclusion

The three NIPAS sites were chosen for this study primarily to represent each of the island regions, i.e., Luzon (MOBMR), Visayas (SMR) and Mindanao (SIPLAS). Each NIPAS site encompasses coral reef, mangrove, and seagrass habitats; thus, they could serve as excellent study sites for research on the interconnectivity of the coral reef and its adjacent habitats, which are currently lacking for the Philippines. The sites have been selected to have similarly vast coastal marine habitats that not only support an incredible biodiversity of marine life but also support the productive fishing industry of the nearby coastal communities. All sites were mainly rural municipalities with agriculture and/or fishing as the main occupation, and the communities in each site thus rely heavily on the marine resources either for daily sustenance or income. As in most locations in the Philippines, the three sites are all prone to the impact of typhoons, only varying in degrees of exposure.

In spite of the similarities in natural and economic resources, the main difference among the three sites that determines whether the management of the NIPAS is effective pertains to the effective exchange among the local stakeholders. The SIPLAS PAMB, being one of the largest NIPAS, consists of numerous agencies and stakeholders from nine municipalities. It was evident that good communication appears to be an important success factor in the proper management of protected areas. The open lines among the involved parties have contributed significantly to achieving management goals.

The internal conflicts involving political, financial and jurisdictional boundaries between the LGU and the local DENR office in Sagay City has been ongoing for quite some time. However, among the three sites, the status of the coral reef system was best in SMR, which was surprising given the controversies over the protected area. We observed in this case that the local government was fully conscious of the reserve's resources, and its direct involvement in the management of the MPA, independent of the governing board, appears to have contributed to optimal state of the reefs.

In the MOBMR, we observed a lack of awareness and participation of the local communities in the PAMB, which is likely to have contributed to the poor condition of the reefs in Masinloc. To address this, the PAMB has actively promoted the protected area and its ecological and economic benefits in schools and through municipal events. It is hoped that an increased recognition of these benefits would lead to active participation in the management of the local resources. Furthermore, there is an urgent need for a watershed (Ridge-to-Reef) approach to control the sediment load into Masinloc Bay. We suggest that this could be achieved by including the neighboring municipality of Candelaria as a member of the PAMB.

As the Philippines are among the countries most susceptible to climate change (OML and PAGASA 2019), climate adaptation should be a priority across all sites. However, this was not evident in the current management plans in SMR and MOBMR. Management plans at all sites were due to be updated as this chapter was being written and are expected to be climate ready.

There was a consensus at all NIPAS sites, including those not discussed here, that the carrying capacity of the ecosystem is rarely considered in management planning. These sites are becoming famous for the excellent beaches and other tourist attractions, especially with the increased affordability of airfare and better road systems in the country. Although the Department of Tourism (DoT) is technically included within PAMB, it primarily has a vested economic interest in the sites, with less consideration for ecological implications of the influx of tourists. The DENR needs to take more stringent measures to define the environment's maximum load so as not to jeopardize the state of these protected coastal habitats.

References

Alcala AC, Russ GR (2006) No-take marine reserves and reef fisheries management in the Philippines: a new people power revolution. Ambio 35(5):245–254. https://doi.org/10.1579/05-a-054r1.1

Cabral RB, Aliño PM, Balingit ACM, Alis CM, Arceo HO, Nañola CL Jr, Geronimo RC, Partners M (2014) The Philippine marine protected area (MPA) database. Philipp Sci Lett 7(2):300–308

Cantin NE, Lough JM (2014) Surviving coral bleaching events: Porites growth anomalies on the great barrier reef. PLoS One 9(2):e88720. https://doi.org/10.1371/journal.pone.0088720

CORVA2 (2017) Mapping and impact research on resilience of reefs. UP Diliman, Quezon City. CORVA Year 1 Terminal Report

CORVA2 (2019) Mapping and impact research on resilience of reefs. UP Diliman, Quezon City: CARE-CADRES Terminal Report Vol. 1 Annex 2

CORVA3 (2017) Reef fish resiliency and productivity. UP Diliman, Quezon City. CORVA Year 1 Terminal Report

CORVA4 (2019) Mapping and assessment of coral reef associated habitats. UP Diliman, Quezon City : CARE-CADRES Terminal Report Vol. 1 Annex 2

CORVA9 (2019) Remote sensing of coastal habitats and stressors. UP Diliman, Quezon City: CARE-CADRES Terminal Report Vol. 1 Annex 2

Dizon E, Geronimo R, Quicho R (2013) Benchmarking the management effectiveness of nationally-managed marine protected areas in the Philippines with policy recommendations:

final report. Final report for USAID coral triangle support partnership (CTSP) and Conservation International–Philippines
Flower J, Ortiz JC, Chollett I, Abdullah S, Castro-Sanguino C, Hock K, Lam V, Mumby PJ (2017) Interpreting coral reef monitoring data: a guide for improved management decisions. Ecol Indic 72:848–869. https://doi.org/10.1016/j.ecolind.2016.09.003
Gomez ED, Alcala AC, San Diego AC (1981) Status of Philippine coral reefs–1981. In Proceedings of the Fourth International Coral Reef Symposium, Manila
Hilomen V, Nañola Jr C, Dantis A (2000) Status of Philippine reef fish communities. Licuanan WY, Gomez ED (eds) Philippine coral reefs, reef fishes, and associated fisheries: status and recommendations to improve their management. GCRMN Report Appendix B
Holden WN, Marshall SJ (2018) Climate change and typhoons in the Philippines: extreme weather events in the Anthropocene. Integrating Disaster Science and Management: Global Case Studies in Mitigation and Recovery 2018:407–421. https://doi.org/10.1016/B978-0-12-812056-9.00024-5
Hoogenboom MO, Frank GE, Chase TJ, Jurriaans S, Alvarez-Noriega M, Peterson K, Critchell K, Berry KLE, Nicolet KJ, Ramsby B, Paley AS (2017) Environmental drivers of variation in bleaching severity of Acropora species during an extreme thermal anomaly. Front Mar Sci 4(376):1–16. https://doi.org/10.3389/fmars.2017.00376
Licuanan W, Gomez E (2000) Philippine coral reefs, reef fishes and associated fisheries: status and recommendations to improve their management. Australian Institute of Marine Science, Townsville, Australia
Licuanan AM, Reyes MZ, Luzon KS, Chan MAA, Licuanan WY (2017a) Initial findings of the nationwide assessment of Philippine coral reefs. Philippine J Sci 146(2):177–185
Licuanan WY, Robles R, Dygico M, Songco A, van Woesik R (2017b) Coral benchmarks in the center of biodiversity. Mar Pollut Bull 114(2):1135–1140. https://doi.org/10.1016/j.marpolbul.2016.10.017
Mei W, Xie SP, Primeau F, McWilliams JC, Pasquero C (2015) Northwestern Pacific typhoon intensity controlled by changes in ocean temperatures. Sci Adv 1(4):e1500014. https://doi.org/10.1126/sciadv.1500014
MPA Support Network (2014) Philippine MPA database. http://www.mpa.msi.upd.edu.ph
OML, & PAGASA (2019) State of the Philippine climate. *March 2019*. http://www.omlopezcenter.org/state-of-the-philippine-climate/
Philippine Climate Change Adaptation Project (2015) Siargao Islands protected landscapes and seascapes management plan: strengthening climate change resilience through improved watershed and coastal resources management in protected areas in Peñablanca and Siargao. http://faspselib.denr.gov.ph/sites/default/files//Publication%20Files/C2.4%20SIPLAS%20Management%20Plan.pdf
Philippine Statistics Authority (2015) 2015 census of population. Retrieved from https://psa.gov.ph/
SMRGMP, S. M. R. G. M. P (2015) Sagay City, Negros Occidental. Report submitted to DENR-BMB
Vera CA (2004) Struggle of the small-scale fisherfolk of Masinloc and Oyon bay for good governance in a protected seascape

Chapter 13
Bangladesh Case Study

Impacts of Climate Change and Anthropogenic Pollution on the Occurrence and Pathogenic Potential of *Vibrio* spp. in the Coastal Zone of the Bengal Delta

Sucharit Basu Neogi, Shinji Yamasaki, Rubén José Lara, and Matthias Wolff

Abstract Hydro-climatic extremities together with aquatic pollution are bringing enormous health hazards, particularly by multi-drug resistant (MDR) waterborne pathogens in the Bengal delta. This chapter highlights selected issues of anthropogenic pollution and climatic stigmas influencing coastal *Vibrio* spp., which play important role in nutrient turnover but some are disease-causing. Seasonality and variations in salinity, temperature, tidal amplitude, precipitation, and occurrence of cyclone and flood substantially modulate estuarine *Vibrio* dynamics. Increased anthropogenic discharges may induce phytoplankton and zooplankton blooms in coastal waters, enriching suspended particulates, chitinous and organic compounds, and eventually stimulate *Vibrio* populations. The abundance of potentially pathogenic *Vibrio cholerae* is higher in anthropologically polluted estuaries, especially in regions receiving sewage or aquaculture effluents. Interestingly, the occurrence of MDR *V. cholerae* has been observed to spread at a similar scale in both the polluted estuary and pristine Sundarban wetland. Ecosystem-based understanding of the

S. B. Neogi (✉)
Coastal Development Partnership, South Pirerbagh, Mirpur, Dhaka, Bangladesh

International Centre for Diarrhoeal Disease Research, Bangladesh, Mohakhali, Dhaka, Bangladesh

S. Yamasaki
Graduate School of Veterinary Science, Osaka Metropolitan University, Osaka, Japan

Asian Health Science Research Institute, Osaka Metropolitan University, Osaka, Japan

International Research Center for Infectious Diseases, Osaka Metropolitan University, Osaka, Japan

R. J. Lara
Argentine Institute of Oceanography, Bahía Blanca, Argentina

M. Wolff
Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany

M. Wolff et al. (eds.), *Challenges in Tropical Coastal Zone Management*,
https://doi.org/10.1007/978-3-031-17879-5_13

compounding processes and multi-faceted consequences of anthropogenic pollution and climate change to waterborne pathogens would be integral to facilitate multidisciplinary actions. Holistic approaches integrating ecohydrological interventions, water and waste treatment, wise use of natural antimicrobial compounds, maintenance of adequate hygiene, and socio-economic perspectives are required to cope with the alarming future hazards to health and ecosystem services.

Keywords *Vibrio* · Pathogenicity · Antimicrobial resistance · Hydro-climatic variations · Plankton · Nutrients · Estuarine dynamics · Anthropogenic pollution

1 Introduction

The Bengal delta is one of the most vulnerable regions to climate change impacts where the intrusion of saline water to further inland and changes in rainfall patterns will inevitably affect the supply and quality of fresh water, consequently increasing the risks of waterborne diseases in the low-lying coastal regions (Cruz et al. 2007). Enteric infections caused by pathogenic *Vibrio* spp. are the predominant waterborne diseases, including more than 100,000 cases of cholera per year in the Bengal delta (Ali et al. 2015). *Vibrio* spp. are Gram-negative, rod-shaped, facultatively anaerobic and motile bacteria, which are autochthonous to estuarine, coastal and marine environments. Over 100 species of *Vibrio* have been documented and the majority play important roles in nutrient turnover by degrading a variety of organic matters, including a huge amount of chitin produced by shrimps and crustacean zooplankton, as well as pollutants like polycyclic aromatic hydrocarbons (Thompson et al. 2004). In the water column, *Vibrio* cells are mostly found as free-living in the nano-plankton fraction (<20 μm), but also attached to larger organisms (Neogi et al. 2012). Although most *Vibrio* spp. are commensal to aquatic hosts and some act as symbionts, a number of them are pathogenic to humans, aquaculture species and are also implicated in coral bleaching (LeRoux et al. 2015; Thompson et al. 2004). Concerning human infections, cholera-causing *Vibrio cholerae* is responsible for millions of episodes and thousands of deaths worldwide annually (WHO 2020). Among other important pathogenic species are *Vibrio parahaemolyticus*, one of the leading pathogens of seafood-borne gastroenteritis causing tens of thousands of cases each year worldwide and *Vibrio vulnificus*, which can cause gastroenteritis, necrotizing fasciitis and wound infections with a high fatality rate among immuno-compromised patients (Chakraborty et al. 1997).

The regular occurrence of intense monsoon rainfall, floods, and cyclones is instrumental to induce the estuarine ecosystems of the Bengal delta as endemic hotspots to major waterborne diseases. Apart from hydro-climatic stressors, poor hygiene status, low water and food security, and geographical dispositions, social disparities define the risks and vulnerabilities to water-related diseases in this region, one of the most densely populated and burdened with pollution impacts (Hashizume et al. 2008). The Ganges-Brahmaputra delta, particularly the Bengal coast, is considered as the pivotal base for not only the previous six cholera pandemics

(1823–1923), each lasting 6–24 years, but also the ongoing seventh pandemic since 1961 (Mutreja et al. 2011; Pollitzer 1954). As early as 1884, endemic occurrence of the cholera bacterium in the world's largest mangrove wetland, the Sundarban in the Bengal coast was reported by Dr. Robert Koch (Pollitzer 1954). In the recent decade, the majority of the low-altitude regions of coastal Bangladesh are experiencing a sea level rise (SLR)-mediated increase in the salinity of groundwater, and millions of people have no option but to use contaminated natural surface waters for household purposes including drinking, and therefore, are highly vulnerable to waterborne diseases (Wu et al. 2014).

Along with dense settlements, intensive agriculture, and aquaculture practices, the impacts of anthropogenic pollution to water security are enormous in the Bengal delta. In the context of climate change, manifold socio-economic complexities due to acute freshwater scarcity, rapid environmental changes and water-related hazards, especially *Vibrio*-related diseases, are posing immense challenges to public health among the poverty-ridden coastal populations (Rahman Talukder et al. 2015). Moreover, health intervention programs need to divulge effective strategies to resist the increasing occurrence of multi-drug resistance (MDR) among waterborne pathogens, including *Vibrio* spp. (Nair et al. 2010). Many attributes of aquatic ecosystems, including the dynamics in biodiversity, water quality, and pollutant loads, have implications for waterborne disease transmission and health of human and animals (Neogi et al. 2016). An in-depth understanding of the driving socio-ecological mechanisms and the multidimensional impacts of anthropogenic pollution and hydro-climatic changes to coastal ecosystem dynamics and associated health risks is integral to formulate ecosystem-based adaptation strategies for millions of disaster-prone coastal residents in the Bengal delta.

2 Major Ecosystem Factors Driving the Occurrence and Spread of *Vibrio* spp.

2.1 Physicochemical Properties of Water

Among the climate-influenced physicochemical properties of coastal waters, the increase in salinity is the most influential factor stimulating *Vibrio* populations in the Bengal estuaries (Batabyal et al. 2014; Lara et al. 2011b; Neogi et al. 2012). Higher occurrence of *V. cholerae* has been reported to coincide with an increase in water pH, usually observed after plankton blooms in lentic ecosystems inland (Islam et al. 1994). A positive correlation of temperature (both atmospheric and sea surface) and increased cholera incidences after a time lag of several weeks was observed at regional scale in Bangladesh. This might be indirectly attributable to temperature impacts on composite ecosystem processes inducing toxigenic *V. cholerae* populations (Islam et al. 2009; Lobitz et al. 2000; Neogi et al. 2018).

2.2 Aquatic Biota Acting as Reservoirs or Antagonists

Vibrio cells are found associated with zooplankton (copepods, cladocerans, rotifers), phytoplankton (filamentous algae, diatoms), chlorophytes (seaweeds), macrophytes (water hyacinth, duckweed), crustaceans (prawns, oysters, crabs), insect larvae (chironomids), corals and fish spp. (Hossain et al. 2018; Islam et al. 1994; Tamplin et al. 1990; Thompson et al. 2004). Association with diverse groups of aquatic organisms, including migratory fishes, provides an ecological advantage for the epiphytic *Vibrio* populations, including nutrition, enhanced survival, escape from predators, and transport to distant places (Tamplin et al. 1990). Ingestion of a few plankton cells, contaminated with epiphytic *V. cholerae*, while drinking untreated surface water is considered a potential mode of primary infection initiating cholera (Colwell et al. 2003). However, a number of aquatic biota, e.g., amoebic protozoans and ciliates may act as antagonist for the survival and dispersal *Vibrio* spp. (Neogi et al. 2014). The self-limiting nature of cholera outbreaks may be partially explained by the bacteriophage-mediated regulation of *V. cholerae* O1 populations in the aquatic ecosystems of the Bengal delta (Faruque et al. 2005).

2.3 Role of Particulate and Dissolved Organic Matter

Plankton-degraded materials, including chitinous substrates, eventually accumulate in the nutrient pool of suspended particulate matter (SPM). At least 1–2 log higher numbers of *Vibrio* spp. were observed for the <20 μm fraction containing sediment and organic nanodetritus when compared to the larger microplankton fractions in the estuarine waters of the Bengal coast (Lara et al. 2011b). Both SPM and chitin were observed to correlate with toxigenic *V. cholerae* populations in the Karnaphuli estuary (Fig. 13.1). Dissolved organic carbon (DOC) and nitrogen (DON), generated from degradation of SPM, potentially act as a growth stimulant for *Vibrio* spp. (Neogi et al. 2011). Suspended particulates (<20 μm) in the water column eventually settle down and accumulate in the benthic sediment of aquatic ecosystems. Observations obtained from the beach, river, canal, and pond ecosystems at the Kuakata coast, Bangladesh, showed that independent of salinity, benthic sediments with more culturable *Vibrio* counts than surface water serve as an important environmental reservoir (Neogi et al. 2018).

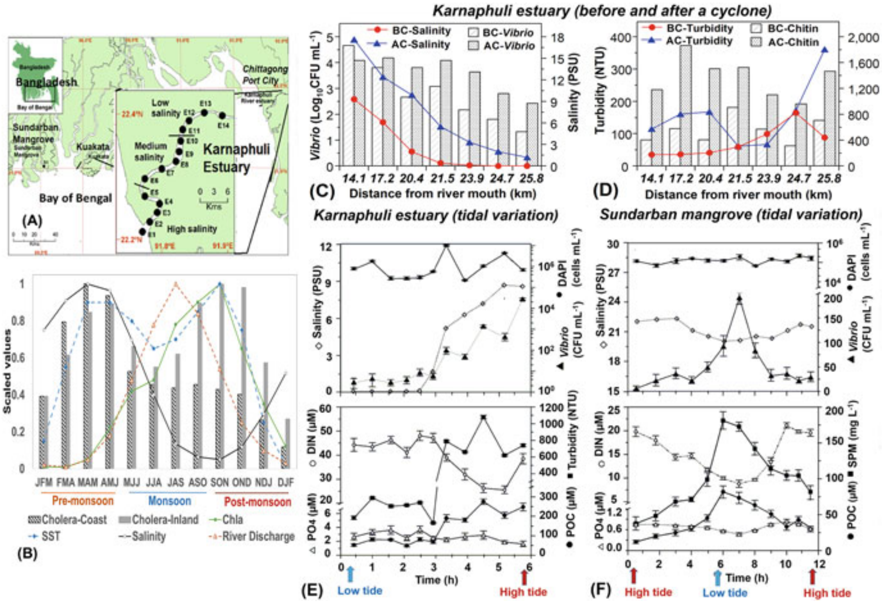


Fig. 13.1 Influence of hydro-climatic factors on cholera outbreaks and salient roles of cyclone and tide on aquatic physicochemical properties and *Vibrio* populations. (**a**) Map showing the study regions including the sampling sites (closed circles) in the Karnaphuli estuary (**b**) Comparative variation of cholera incidences in coastal and inland areas of Bangladesh with riverine discharge, sea surface temperature (SST), chlorophyll (Chla), and water salinity in nearby offshore region of the Bengal coast. Data were in accordance to Jutla et al. (2011) and Akanda et al. (2011). All values, representing the mean of three consecutive months (JFM, FMA, etc.), have been scaled between 0 and 1. (**c**, **d**) Variations in *Vibrio* occurrence along with water salinity, turbidity, and chitin in the Karnaphuli estuary before and after a cyclone (BC and AC, respectively) (Neogi et al. unpublished). (**e**, **f**) Tide mediated variation in *Vibrio* occurrence and physicochemical factors in water samples collected at a stationary point of the Karnaphuli river estuary and Sundarban mangrove creek. DAPI count, number of total prokaryotes; DIN, dissolved inorganic nitrogen; POC, particulate organic carbon, SPM, suspended particulate matter. Data are presented as Mean ± SD ($n = 3$)

3 Diversified Impacts of Climatic Factors on the Occurrence of *Vibrio* spp.

3.1 Climatic Regulations on the Metamorphic States of Vibrio *Populations*

After being expelled from an animal host, most *V. cholerae* cells become transformed from highly active culturable form into a viable but non-culturable (VBNC) state upon exposure to stressful aquatic conditions, e.g., low nutrient, salinity, and temperature (Roszak and Colwell 1987). Most (>90%) populations of *Vibrio* spp. in the Bengal estuaries usually persist in VBNC state, detectable by fluorescent microscopy (Neogi et al. 2012). Intriguingly, VBNC cells of *V. cholerae* may regain culturability upon availability of conducible environmental or host factors (Senoh et al. 2014; Sultana et al. 2018). In the Bengal coast, VBNC cells of the pandemic *V. cholerae* O1 serogroup are reported to occur throughout the year within aquatic biofilms, which may aid in the bacterial resistance to physicochemical stressors or biotic (Matz et al. 2005; Sultana et al. 2018). Increased availability of Ca^{2+} from intruding seawater may influence biofilm development of *Vibrio* spp. in estuarine waters (Kierek and Watnick 2003).

3.2 Drastic Impacts of Cyclone Driven Hydro-ecological Alterations

The coastal Bay of Bengal regularly embraces cyclones, at least several in number during both pre- and post-monsoon seasons each year, with an increasing frequency of ca. 26% between 1881 and 2001 (Singh 2002; Unnikrishnan et al. 2011). Frequent outbreaks of cholera epidemics after a cyclone reported for the Bengal coast can be related to the drastic increase of estuarine *Vibrio* populations, coinciding with seawater intrusion (Fig. 13.1; Lara et al. 2009). Biogeochemical analyses revealed that the increased *Vibrio* abundance post-cyclone could be attributable to the significant increases in SPM (turbidity), chitin, POC and DOC in estuarine waters (Neogi et al. 2018).

3.3 Influence of Tidal Dynamics and Sea Surface Height

In comparison to a low count ($<10^1$ CFU mL^{-1}) at low tide, *Vibrio* populations in the Karnaphuli estuary, Bangladesh were observed to increase significantly ($>10^2$–10^4 CFU mL^{-1}) during high tide with increasing salinity (Fig. 13.1). A synchronous influence of tides and water salinity on *Vibrio* populations in benthic sediment and surface water was observed at the Hoogly estuary, West Bengal (Batabyal et al. 2014). Year-long sampling in this estuary showed culturable *Vibrio* populations are influenced by a combined interaction of environmental conditions of the current and previous tides (flood or ebb), and depend on the lunar phases (Batabyal et al. 2014). Apart from tidal influence, sea level rise (SLR) induces incursion of seawater containing a higher number of *Vibrio* spp. Moreover, SLR-mediated inundation may cause degradation of halophobic organisms and damage sanitation facilities, thus increasing the load of organic nutrients in estuarine waters. The mean sea surface height of the Bengal coast has been increasing at least twice faster rate than the global average of 2.0 mm per year (Singh 2002). Together with a riverine discharge of sediments and nutrients, seasonal variation in sea surface height may have compounding impacts on estuarine bio-physicochemical properties, influencing the population dynamics and ecological fitness of *Vibrio* spp. in the Bengal coast.

3.4 Influence of Global Warming

In the Bay of Bengal, the mean sea surface temperature (SST) has been increasing at ca. 0.05 °C/year, which is much higher than the tropical Pacific and Atlantic Oceans (0.01–0.02 °C/year) (Mitra et al. 2009). An average temperature of <23 °C corresponded to the lowest average of cholera incidences at Matlab, Bangladesh where the highest frequency of cholera occurred at temperatures >28 °C, in conjecture with a synergistic impact of sunshine hours (Islam et al. 2009). A positive relationship between chlorophyll (phytoplankton) concentration and SST, attributable to increased riverine discharge mediated nutrient input during the warmer months, and a strong impact of the El Niño Southern Oscillation (ENSO)-mediated variations in SST and rainfall on cholera incidences post-monsoon in Bangladesh have been reported (Fig. 13.1; Pascual et al. (2000)). Increasing atmospheric temperature is causing faster melting of the Himalayan glaciers, and eventually increasing riverine discharge mediated nutrient input to the coastal waters (Ghosh et al. 2015), which may favor the growth of plankton and *Vibrio* populations. Intensified UV-ray with higher sunshine hours may induce natural mutation and horizontal transfer of pathogenic traits, e.g., cholera toxin gene (*ctxAB*), in *V. cholerae* (Faruque et al. 2000).

3.5 Salient Impact of Monsoon Rainfall

A strong influence of monsoon rainfall on aquatic *V. cholerae* populations is reflected by the spatio-temporal variability in cholera outbreaks. There is a pre-monsoon (March-May) peak at the coastal regions, whereas, one smaller pre-monsoon and a larger post-monsoon (September-November) peak at the inland regions of Bangladesh (Fig. 13.1). During pre-monsoon, a progressive intrusion of saline water due to the reduction in riverine flow may favor the growth and spread of halophilic *Vibrio* spp. Along with the advent of monsoon, increasing precipitation causes a substantial reduction in water salinity, and consequently, *Vibrio* populations in the Bengal estuaries (Lara et al. 2009). Despite the dilution impact of increasing water level, the cholera incidences during monsoon can be attributable to a large-scale secondary contamination and increased contamination of sewage materials, as observed in the Hoogly estuary near Kolkata (Batabyal et al. 2014). On the other hand, the post-monsoon cholera peak in inland regions has been related to the predisposed large-scale inundation, the concentration of washed materials with receding flood water, interrupting drinking water access, damaging sanitation infrastructure, and dispersal of sewage materials contaminated with toxigenic *V. cholerae* (Akanda et al. 2013).

4 Anthropogenic Impacts Influencing *Vibrio* Populations

In addition to climate-mediated influences on coastal *Vibrio*s, the incidences of cholera and other *Vibrio*-related diseases in the Bengal delta have been attributed largely to the booming human settlement without adequate waste management and safe water facilities. This densely populated region (ca. 1200 km^{-2}) accounts for the highest water pollution level, in terms of nitrogen and phosphorus inputs, compared to other major riverine coasts (Liu et al. 2012). The prevalent social, behavioral, livelihood, health, and development activities related to human settlements are increasingly polluting coastal environments and have salient impacts on aquatic biodiversity, influencing the persistence of *Vibrio* spp. in the Bengal delta.

4.1 Influence of Aquaculture Practices

Aquaculture is the most important sector meeting people's protein need in the Bengal delta. High stocking density and use of fertilizers and artificial feed increases disease risk in aquaculture settings. For example, the occurrence of *V. vulnificus* pathogen in the rapidly growing tilapia aquaculture in Bangladesh was attributed to the use of phosphate and urea fertilizers (Mahmud et al. 2010). In recent years, acute hepatopancreatic necrosis disease (AHPND) caused by the binary-toxin (PirAvp/PirBvp) producing *V. parahaemolyticus* strains is posing a severe threat to shrimp industries globally including the Bengal delta (Eshik et al. 2017). High abundance of organic load, chitinous and mucilaginous plankton, and biofilms grown in aquaculture settings are potential growth-promoting factors for *Vibrio* spp. (De Bodt and Defoirdt 2018; Tamplin et al. 1990). In the upstream region of the Sundarban mangrove, a relative increase in *Vibrio* populations near shrimp farms (Fig. 13.2) could be attributable to aquaculture discharge mediated increase in organic nutrients and chitinous shrimp exuviae. Untreated effluents from aquacultures, including shrimp farming, are known to cause water quality deterioration, chemical and biological pollution, sedimentation, and loss of aquatic biodiversity in the region (Didar-Ul Islam and Bhuiyan 2016). However, systematic holistic investigations are required for a better understanding of the multifaceted impacts of aquaculture discharges to coastal ecosystems with comparison to the occurrence of aquatic *Vibrio* spp. and related diseases.

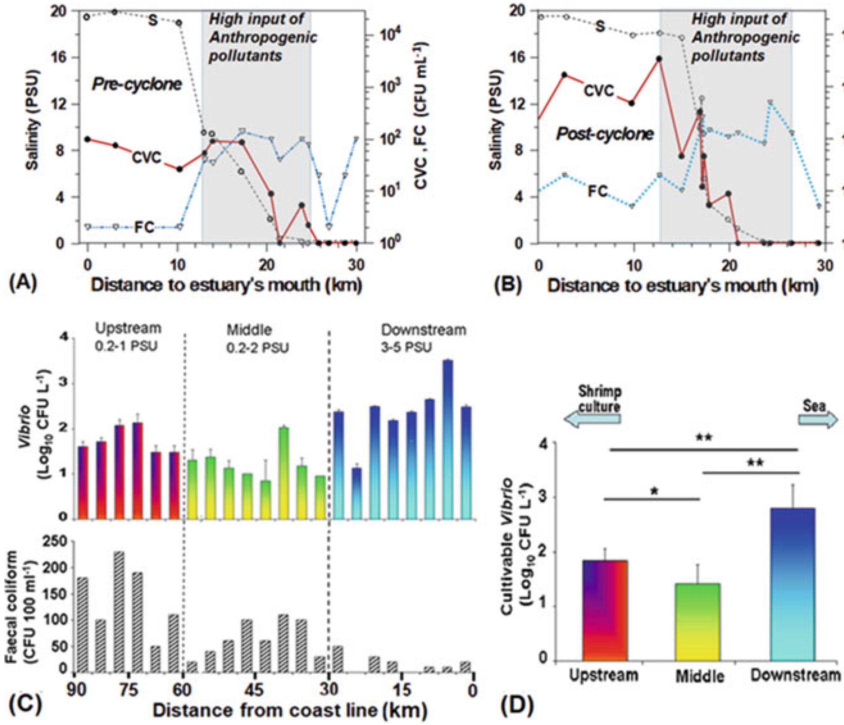


Fig. 13.2 Probable influence of anthropogenic discharge and shrimp aquaculture on coastal *Vibrio* populations (Neogi et al. unpublished). (**a**, **b**) Distribution of *Vibrio* spp. and fecal coliform, indicator of sewage contamination, with variation in water salinity, and anthropogenic pollution in the Karnaphuli estuary surface water before and after a cyclone. CVC, culturable *Vibrio* counts; FC, fecal coliform counts. (**c**, **d**) Occurrence of culturable *Vibrio* and fecal coliform bacteria in the creek waters at different sampling sites in the upstream, middle and downstream regions of the Sundarban wetland. *Vibrio* populations were influenced by anthropogenic discharges, including shrimp aquaculture in the upstream, and intruding seawater with higher salinity in the downstream regions. Mean bacterial counts ($n = 3$) are shown and the significant differences ($p < 0.05$) are indicated by asterisks

4.2 Impacts of Agriculture Effluent

In the estuarine regions of Bangladesh, the use of fertilizers and agrochemicals has increased a lot to produce high agriculture yield, as part of adaptive livelihood for the climate refugees. High input of agriculture run-off, particularly after the wet monsoon, has been related to nutrient enrichment stimulating higher algal production and zooplankton blooms, which may trigger pathogenic *Vibrio* populations in the coastal Bay of Bengal (Huq et al. 2005). Upon availability of extracellular phosphate *V. cholerae* cells can survive better withstanding acidic, osmotic, and oxidative stresses in the aquatic environment (Jahid et al. 2013). Agrochemicals derived from agriculture sources, including livestock and poultry industries, may also bring salient changes to aquatic biodiversity, influencing *Vibrio* populations, although a lack of systematic quantitative studies in this regard still remains.

4.3 Sewage Pollution Impacts

The drainage of anthropogenic wastes including sewage materials not only increases the indicator coliform bacteria but also pathogenic *Vibrio* spp. of clinical origin in the natural waterways, e.g., at the upstream region of the Sundarban mangrove wetland (Fig. 13.2). Similarly, the peak of pathogenic *V. cholerae* populations at a comparatively low salinity region of the Karnaphuli estuary, coincided with higher abundance of fecal coliform and independently of the temporal changes in physico-chemical factors of surface water (Fig. 13.2). Climatic catastrophes, e.g., cyclones and intensive precipitation mediated flooding, may cause drastic overflow or disruption of sewerage system and wastewater treatment plants, potentially magnifying chemical and biological (including *Vibrio* pathogens) pollutants in freshwater reservoirs and coastal surface waters, with subsequent increase in waterborne disease incidences (Batabyal et al. 2014; Lara et al. 2009).

4.4 MDR Spread

Due to a lack of awareness among the people in the Bengal delta, antimicrobials are mostly applied as instructed by the drug sellers, without justifying the type of illnesses, e.g., common flu and self-regulated *Vibrio* infections. Such unwise use, together with truncated therapy of antimicrobials, are resulting in an alarming rise in MDR pathogens and treatment failures. Moreover, the widespread application of antimicrobials in aquaculture, poultry and animal husbandry, is eventually polluting the aquatic environment with MDR pathogens, and residual antimicrobial compounds. A large fraction (30–95%) of the clinical pathogens, including *Vibrio* spp., has been reported to become resistant to all classes of antimicrobials (Nair et al. 2010). Antimicrobial residues, at sub-inhibitory concentrations, potentially induce biological responses promoting MDR occurrence among aquatic bacteria (Allen et al. 2010). Interestingly, a comparatively similar occurrence of MDR *V. cholerae* populations in the Karnaphuli estuary, which is highly polluted with anthropogenic effluents, and the pristine Sundarban wetland, distantly located from human settlements, has been observed despite a higher incidence of potentially pathogenic populations in the polluted estuary (Fig. 13.3). Therefore, a probable role of migratory wild fauna, including birds and fishes, in the spread of MDR pathogens to remote coastal locations cannot be ruled out.

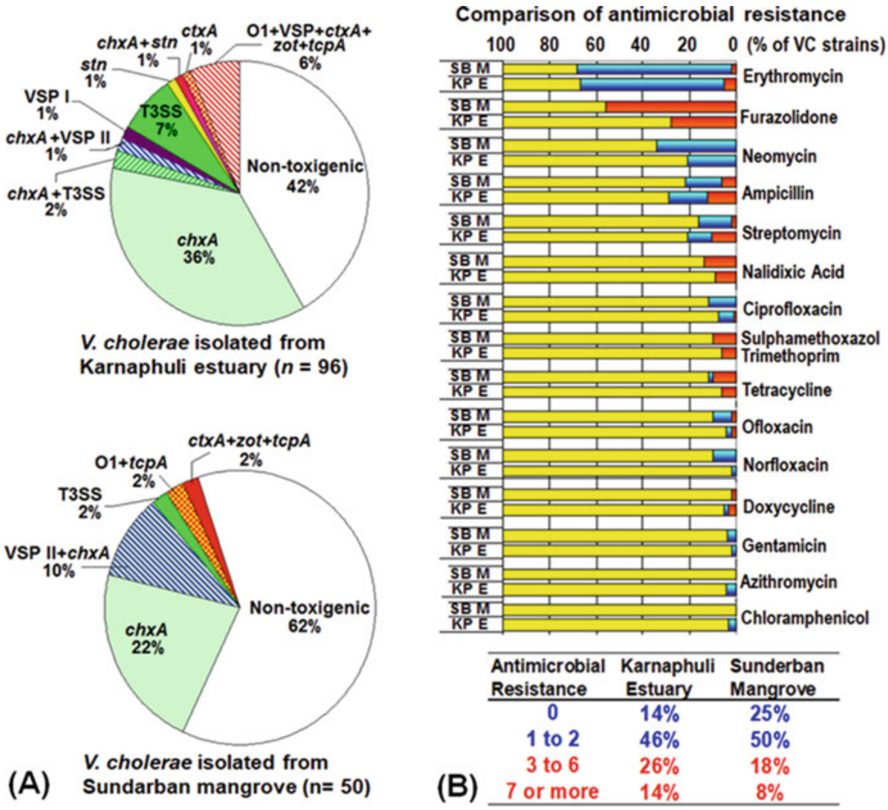


Fig. 13.3 Comparative occurrence of virulence and MDR traits in *V. cholerae* strains isolated from a highly polluted and anthropogenically less influenced coastal zones in the Bengal delta (Neogi et al. unpublished). (**a**) Higher occurrence of virulence genes in the Karnaphuli estuary (KP E) with heavy anthropogenic pollution from the adjacent port city, Chittagong, in comparison to the comparatively pristine Sundarban mangrove wetland (SB M). Colony blot hybridization with radio-labeled probes was used to detect the pathogenic genes, encoding cholera toxin (*ctxA*), zonula occluden toxin (*zot*), toxin co-regulated pilus (*tcpA*), serogroup O1 (O1), NAG stable toxin (*stn*), cholix toxin (*chxA*), *Vibrio* Seventh Pandemic islands (VSP I and II) and Type III secretion system (T3SS). (**b**) Comparison of antimicrobial resistance patterns, determined by disc diffusion method, in *V. cholerae* strains isolated from the heavily polluted Karnaphuli estuary and pristine Sundarban wetland. Top panel showing resistance patterns in *V. cholerae* strains in each horizontal bar, filled with red, blue, and yellow, indicating full, intermediate, and no resistance (% of total strains), respectively, to a particular antimicrobial agent. Bottom panel showing a summary of comparative variations in MDR patterns of the *V. cholerae* strains isolated from these two categories of coastal ecosystems

4.5 Influence of Socio-economic and Behavioral Factors

Apart from the climatic and pollution-mediated impacts, the occurrence and spread of waterborne diseases greatly depend on human behavior, particularly related to water management. Inadequate sanitation, improper disposal of waste materials, including children's feces, lack of hand washing practice, and poor personal and environmental hygiene are considered as the major factors inducing secondary transmission of cholera and waterborne diseases at household level (Huda et al. 2012). For the extremely poor in coastal areas, efforts to climb up the income ladder are hindered by periodical push-backs due to water-related health hazards. Promoting community resilience to health disasters has been challenging due to prevalent social disparities involving gender, socio-economic status, and behavioral ill practices (Nasreen and Tate 2007). The pivotal role of water, sanitation, hygiene interventions, environmental risk perceptions, and behavioral changes to prevent *Vibrio* infections is widely acknowledged yet it needs to be effectively promoted in the Bengal coast (Hoque et al. 1996; Rabbi and Dey 2013).

5 Discussion

Waterborne diseases, predominantly caused by *Vibrio* infections, are among the most important causes of morbidity and mortality in the low-lying Bengal coast. Global warming may induce a series of hydro-climatic extremities, including a temperature increase of 2–5 °C during warmer months, intensification of southwest monsoon, accompanied by more rainfall (>10%), riverine discharge, and floods, and SLR-mediated seasonal inundation of almost one-third of the Bengal coast by the end of this century (Caesar et al. 2015). An increase in the frequency of cyclones post-monsoon, and higher intensity of storms pre-monsoon during 2070–2100 has been projected (Unnikrishnan et al. 2011). These predicted scenarios will most likely bring large-scale alteration in hydro-geological processes, including riverine discharge, tidal height and amplitude, salinity, and nutrient dynamics in the Bengal delta. Increased salinity-mediated enrichment of estuarine *Vibrio* populations may coincide with substantial alteration in the bacterial diversity, depending on the ecological fitness of individual species at particular salinity range. Hydro-climatic extremities, compounded with anthropogenic pollution, in this heavily populated (over 270 million) delta may bring enormous modifications to coastal bio-physicochemical processes influencing *Vibrio* populations and 'One health', which includes human, animal, and environment perspectives (Atlas et al. 2010).

The Bengal coast, serving as the main outlet of the Ganga-Brahmaputra riverine discharges, is among the world's highest sediment discharge zones, depositing ca. 500–1100 million MT year^{-1} of sediment into the Bay of Bengal (Darby et al. 2015). Resuspension of benthic sediments, e.g., by strong tide or cyclones, may substantially enrich *Vibrio* populations by providing nutritional substrates, or through a direct input of particle-attached bacteria into the water column (Lara et al. 2009). The amount and quality of dissolved nutrients in coastal waters influencing *Vibrio* populations are compositely influenced by climate regulated variations in estuarine turbulence, riverine discharge, rainfall, water salinity, tide, wind flow, coastal current, plankton bloom, chitinous particles, and also pollutants

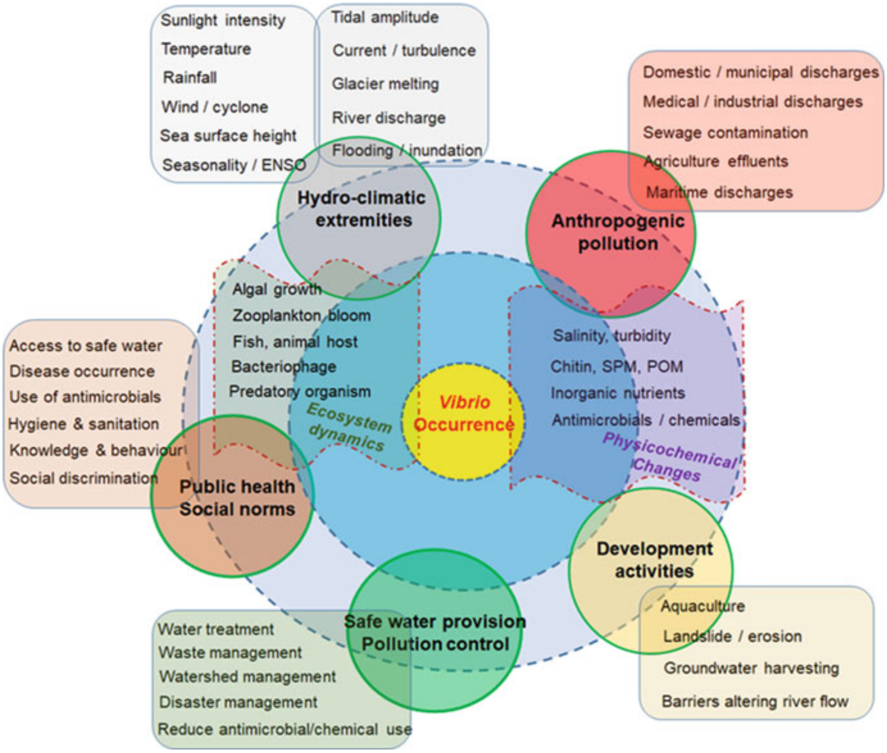


Fig. 13.4 Interactive multidimensional drivers associated with the health hazards and vulnerabilities to *Vibrio*-related infections. Hydro-climatic and anthropogenic drivers are distinguished as five management domains (encircled in green border). The interactive framework of the major drivers is listed in the rectangle boxes, overlapped with the management domains. The occurrence of pathogenic and MDR traits of *Vibrio* populations in coastal waters are compositely governed by these hydro-climatic and anthropogenic factors involving ecosystem dynamics at multiple levels (dotted circles): aquatic physicochemical properties, ecosystem processes. Seasonality in climatic factors, e.g., temperature, rainfall, cyclone occurrence, wind flow and coastal currents, riverine discharges and tide-driven hydro-dynamics regulate not only the aquatic bio-physicochemical factors but also the intrusion of anthropogenic pollutants in coastal waters. *Vibrio*-related disease outbreaks also depend on the associated spatio-temporal differences in socio-environmental risks and vulnerabilities

from anthropogenic discharges (Fig. 13.4). Hydro-climatic alterations predicted for the near future, together with increased coastal pollution, may favor pathogenic *Vibrio* species to cause more health hazards. However, increased *Vibrio* occurrence may facilitate oceanic carbon sequestration by aiding the conversion of organic matter into refractory DOC (Neogi et al. 2011). The turnover of complex organic compounds, including chitin and PAH, into simple forms by *Vibrio* spp. is an important contribution to the aquatic food web; otherwise, a large fraction of organic carbon and nitrogen would remain inaccessible to most organisms (Meibom et al.

2005). Intriguingly, while growing on chitinous particles, *Vibrio* cells may not only neutralize antagonistic organisms but are also induced for natural transformation to acquire new genes, including those responsible for toxigenic and ecological fitness (Matz et al. 2005; Meibom et al. 2005).

Anthropogenic activities may perturb the natural dynamics and diversity of aquatic *Vibrio* populations in a number of ways, including rampant discharge of pollutants (microbiological and chemical) through domestic, agriculture, aquaculture and industrial effluents, barrier construction to alter riverine flow, deforestation-mediated soil erosion and improper management of aquatic resources (Fig. 13.4; Lara et al. 2011a). Anthropogenic discharge-mediated enrichment of organic and inorganic nutrients may instigate plankton blooms and eventually stimulate *Vibrio* populations in coastal waters (Huq et al. 2005; Liu et al. 2012). Although effluent-derived residual antimicrobials can potentially induce the spread of MDR *Vibrio* populations, detailed knowledge on such influences is scarce. In the Bengal basin, saltwater intrusion favoring the spread of *Vibrio* populations is not only facilitated by climate-influenced factors but also improper management of coastal polders, shrimp culture, and large-scale extraction of groundwater for agriculture and industrial purposes (Mahmuduzzaman et al. 2014). Discharge of ships' ballast water contaminated with pathogenic *Vibrio* spp. into coastal waters has been related to the global spread of *Vibrio*-related diseases (Ruiz et al. 2000). At the Baltic coast, *V. cholerae* and *V. parahaemolyticus* cells have been observed to survive within biofilms grown on microplastics (<5 mm), which have recently been recognized as the most ubiquitous pollutants (Kirstein et al. 2016). Aquatic biofilms on plankton and SPM, serving as an important niche for *Vibrio* populations, may also facilitate intra- or inter-species horizontal transfer of genes related to pathogenicity, antimicrobial resistance, and adaptive features (Bari et al. 2013; Neogi et al. 2019; Sultana et al. 2018). Estuarine microplastics and maritime activities with hydro-climatic changes potentially play a vital role in the transmission dynamics and spread of *Vibrio* spp. in the Bengal coast, not yet been studied in detail.

Availability of safe water is a critical public health issue, particularly when coastal aquifers are exposed to salinity intrusion and the natural surface waters become heavily contaminated by anthropogenic pollutants. Various categories of anthropogenic factors at household or community levels are also attributable to enhancing the risk of *Vibrio*-related diseases (Fig. 13.4). A number of interventions, e.g., provision of safe drinking water, improved sanitation, point-of-use water treatment, adequate cooking, desalination of brackish water, seasonal rainwater harvesting, vaccination and adequate treatment of infected persons, filtration with eightfold "shari" clothes, good hygiene practices, and behavioral changes to reduce cross-contamination can be opted to prevent or reduce *Vibrio* related diseases at household or community level in rural Bangladesh (e.g., Colwell et al. 2003; Hoque et al. 1996; Hossain et al. 2015; Islam et al. 2014; LeRoux et al. 2015). With the support of field-based sampling, remote sensing technology observing chlorophyll concentration, SST, SLR, tidal height, riverine discharge, salinity and turbidity of coastal waters can be employed in prediction models considering the relationships among the disease outbreaks and climate-influenced coastal ecosystem dynamics

(Lobitz et al. 2000; Neogi et al. 2018). However, an integrative effort combining all these potential interventions to reduce *Vibrio* infection is lacking in the Bengal delta. Therefore, management policy should incorporate ecohydrological tools, e.g., regulating water flow to reduce sediments, sequestration of nutrients, protection of watersheds and freshwater flows through proper management and disposal of sewage, biosolids, pharmaceutical and animal wastes (Lara et al. 2011a). As a potential alternative against MDR infections, extracts from a number of culinary spices (e.g., red chili, sweet fennel, ginger, and garlic) and plant leaves (e.g., neem and guava plants) have been experimentally observed to inhibit the growth and cholera toxin production in *V. cholerae* (Yamasaki et al. 2011). Recent studies have claimed the superiority of using extracts from particular plants (e.g., drumstrick and red seaweed) over the synthetic antibiotic to reduce *Vibrio* infection and promote the growth of aquaculture species (Kaleo et al. 2019; Karnjana et al. 2019). Organic farming using natural antimicrobials to reduce chemical pollution, and application of probiotics, or phage therapy to prevent vibriosis may also be considered as environmentally friendly interventions (Faruque et al. 2000; Quiroz-Guzman et al. 2018). Observations noted in this chapter suggest the need of holistic interdisciplinary efforts, including participatory actions of community members, natural and social scientists, development managers, and policymakers, to promote dynamic intervention approaches, interactively integrating ecosystem, climatic and socio-anthropogenic domains influencing the spatio-temporal risks and vulnerabilities of harmful *Vibrio* populations.

6 Conclusion

Climatic variation, particularly changes in salinity and precipitation, and pollution-mediated impacts on aquatic nutrient dynamics may have cascading effects on the biodiversity and *Vibrio* abundance in the Bengal delta. Re-suspension of benthic sediments, especially under the influence of strong tide, wind, and river flow, causes a substantial increase of SPM, chitin, and other particulate or dissolved nutrients, which may stimulate estuarine *Vibrio* populations. The observed increasing scale of SLR-mediated brackish water intrusion, coupled with reduced river flows, during winter will eventually intensify the magnitude of seasonal inundation of the low-lying coastal areas and *Vibrio*-related disease outbreaks. Synergistically, anthropogenic discharge-derived pollutants, including organic nutrients and agrochemicals, may not only favor an increased occurrence but also confer drug resistance, virulence, and ecological fitness in coastal *Vibrio* populations. In this context, collaborative actions would be integral to promote peoples' knowledge and participatory adaptation measures, involving the vulnerable groups, policymakers, and managers at multidisciplinary sectors, e.g., health of humans and animals, water and sewage, agriculture, industry, biodiversity and environment, disaster response and watershed management. Holistic assessment, following ecosystem- and basin-based approaches, of the "climate-pollution induced variations" in toxigenic and MDR *Vibrio* populations, disease outbreaks, and peoples' vulnerability in diverse geo-socio-environmental contexts would vitally contribute to the multi-dimensional and dynamic intervention strategies for tackling the anticipated future disasters to health and environment in the Bengal coast.

Acknowledgments The authors are thankful to the environmental surveillance team of the icddrb (www.icddrb.org) and Coastal Development Partnership, Bangladesh (www.cdpbd.org) for their kind facilitation and valuable comments.

References

Akanda AS, Jutla AS, Alam M, de Magny GC, Siddique AK, Sack RB, Huq A, Colwell RR, Islam S (2011) Hydroclimatic influences on seasonal and spatial cholera transmission cycles: implications for public health intervention in the Bengal Delta. Water Resour Res 47. https://doi.org/10.1029/2010wr009914

Akanda AS, Jutla AS, Gute DM, Sack RB, Alam M, Huq A, Colwell RR, Islam S (2013) Population vulnerability to biannual cholera outbreaks and associated macro-scale drivers in the Bengal delta. Am J Trop Med Hyg 89(5):950–959. https://doi.org/10.4269/ajtmh.12-0492

Ali M, Nelson AR, Lopez AL, Sack DA (2015) Updated global burden of cholera in endemic countries. PLoS Negl Trop Dis 9(6). https://doi.org/10.1371/journal.pntd.0003832

Allen HK, Donato J, Wang HH, Cloud-Hansen KA, Davies J, Handelsman J (2010) Call of the wild: antibiotic resistance genes in natural environments. Nat Rev Microbiol 8(4): 251–259. https://doi.org/10.1038/nrmicro2312

Atlas R, Rubin C, Maloy S, Daszak P, Colwell R, Hyde B (2010) One health—attaining optimal health for people, animals, and the environment. Microbe 5(9):383–389

Bari SMN, Roky MK, Mohiuddin M, Kamruzzaman M, Mekalanos JJ, Faruque SM (2013) Quorum-sensing autoinducers resuscitate dormant *Vibrio cholerae* in environmental water samples. Proc Natl Acad Sci U S A 110(24):9926–9931. https://doi.org/10.1073/pnas.1307697110

Batabyal P, Einsporn MH, Mookerjee S, Palit A, Neogi SB, Nair GB, Lara RJ (2014) Influence of hydrologic and anthropogenic factors on the abundance variability of enteropathogens in the Ganges estuary, a cholera endemic region. Sci Total Environ 472:154–161. https://doi.org/10.1016/j.scitotenv.2013.10.093

Caesar J, Janes T, Lindsay A, Bhaskaran B (2015) Temperature and precipitation projections over Bangladesh and the upstream Ganges, Brahmaputra and Meghna systems. Environ Sci Process Impacts 17(6):1047–1056. https://doi.org/10.1039/c4em00650j

Chakraborty S, Nair GB, Shinoda S (1997) Pathogenic vibrios in the natural aquatic environment. Rev Environ Health 12(2):63–80

Colwell RR, Huq A, Islam MS, Aziz KMA, Yunus M, Khan NH, Mahmud A, Sack RB, Nair GB, Chakraborty J, Sack DA, Russek-Cohen E (2003) Reduction of cholera in Bangladeshi villages by simple filtration. Proc Natl Acad Sci U S A 100(3):1051–1055. https://doi.org/10.1073/pnas.0237386100

Cruz RV, Harasawa H, Lal M, Wu S, Anokhin Y, Punsalmaa B et al (2007) Climate change 2007: impacts, adaptation and vulnerability, chapter 10: Asia (Working Group II). In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Fourth assessment report of the Intergovernmental Panel on Climate Change, Issue

Darby SE, Dunn FE, Nicholls RJ, Rahman M, Riddy L (2015) A first look at the influence of anthropogenic climate change on the future delivery of fluvial sediment to the Ganges-

Brahmaputra-Meghna delta. Environ Sci Process Impacts 17(9):1587–1600. https://doi.org/10.1039/c5em00252d
De Bodt J, Defoirdt T (2018) Impact of the organic load on the efficacy of chlorine disinfection against acute hepatopancreatic necrosis disease-causing *Vibrio parahaemolyticus*. J Fish Dis 41(10):1609–1612
Didar-Ul Islam S, Bhuiyan MAH (2016) Impact scenarios of shrimp farming in coastal region of Bangladesh: an approach of an ecological model for sustainable management. Aquacult Int 24(4):1163–1190
Eshik MME, Abedin MM, Punom NJ, Begum MK, Rahman MS (2017) Molecular identification of AHPND positive *Vibrio parahaemolyticus* causing an outbreak in south-west shrimp farming regions of Bangladesh. J Bangladesh Acad Sci 41(2):127–135
Faruque SM, Asadulghani, Rahman MM, Waldor MK, Sack DA (2000) Sunlight-induced propagation of the lysogenic phage encoding cholera toxin. Infect Immun 68(8):4795–4801. https://doi.org/10.1128/Iai.68.8.4795-4801.2000
Faruque SM, Bin Naser I, Islam MJ, Faruque ASG, Ghosh AN, Nair GB, Sack DA, Mekalanos JJ (2005) Seasonal epidemics of cholera inversely correlate with the prevalence of environmental cholera phages. Proc Natl Acad Sci U S A 102(5):1702–1707. https://doi.org/10.1073/pnas.0408992102
Ghosh A, Schmidt S, Fickert T, Nüsser M (2015) The Indian Sundarban mangrove forests: history, utilization, conservation strategies and local perception. Diversity 7(2):149–169
Hashizume M, Wagatsuma Y, Faruque ASG, Hayashi T, Hunter PR, Armstrong B, Sack DA (2008) Factors determining vulnerability to diarrhoea during and after severe floods in Bangladesh. J Water Health 6(3):323–332. https://doi.org/10.2166/wh.2008.062
Hoque BA, Juncker T, Sack RB, Ali M, Aziz KMA (1996) Sustainability of a water, sanitation and hygiene education project in rural Bangladesh: a 5-year follow-up. Bull World Health Organ 74(4):431–437
Hossain MS, Hein L, Rip FI, Dearing JA (2015) Integrating ecosystem services and climate change responses in coastal wetlands development plans for Bangladesh. Mitig Adapt Strat Glob Chang 20(2):241–261. https://doi.org/10.1007/s11027-013-9489-4
Hossain ZZ, Farhana I, Tulsiani SM, Beguml A, Jensen PKM (2018) Transmission and toxigenic potential of *Vibrio cholerae* in Hilsha fish (*Tenualosa ilisha*) for human consumption in Bangladesh. Front Microbiol 9. https://doi.org/10.3389/fmicb.2018.00222
Huda TMN, Unicomb L, Johnston RB, Halder AK, Sharker MAY, Luby SP (2012) Interim evaluation of a large scale sanitation, hygiene and water improvement programme on childhood diarrhea and respiratory disease in rural Bangladesh. Soc Sci Med 75(4):604–611. https://doi.org/10.1016/j.socscimed.2011.10.042
Huq A, Sack RB, Nizam A, Longini IM, Nair GB, Ali A, Morris JG, Khan MNH, Siddique AK, Yunus M, Albert MJ, Sack DA, Colwell RR (2005) Critical factors influencing the occurrence of *Vibrio cholerae* in the environment of Bangladesh. Appl Environ Microbiol 71(8): 4645–4654. https://doi.org/10.1128/Aem.71.8.4645-4654.2005
Islam MS, Drasar BS, Sack RB (1994) The aquatic flora and fauna as reservoirs of *Vibrio cholerae*—a review. J Diarrhoeal Dis Res 12(2):87–96
Islam MS, Sharker MAY, Rheman S, Hossain S, Mahmud ZH, Islam MS, Uddin AMK, Yunus M, Osman MS, Ernst R, Rector I, Larson CP, Luby SP, Endtz HP, Cravioto A (2009) Effects of local climate variability on transmission dynamics of cholera in Matlab, Bangladesh. Trans R Soc Trop Med Hyg 103(11):1165–1170. https://doi.org/10.1016/j.trstmh.2009.04.016
Islam MS, Ansaruzzaman M, Mahmud ZH, Matin MA, Islam MS, Mallik AK, Neogi SB, Jahid IK, Endtz HP, Cravioto A, Sack DA (2014) A novel and simple mixture as point-of-use water treatment agent to produce safe drinking water. Trans R Soc Trop Med Hyg 108(5):290–296. https://doi.org/10.1093/trstmh/tru028
Jahid IK, Hasan MM, Mahmud Z, Neogi S, Uddin M, Islam M (2013) Role of polyphosphate kinase gene (ppk) for survival of *Vibrio cholerae* O1 in surface water of Bangladesh. Pak J Biol Sci PJBS 16(22):1531–1537

Jutla AS, Akanda AS, Griffiths JK, Colwell R, Islam S (2011) Warming oceans, phytoplankton, and river discharge: implications for cholera outbreaks. Am J Trop Med Hyg 85(2):303–308. https://doi.org/10.4269/ajtmh.2011.11-0181

Kaleo IV, Gao Q, Liu B, Sun CX, Zhou QL, Zhang HM, Shan F, Xiong Z, Bo L, Song CY (2019) Effects of *Moringa oleifera* leaf extract on growth performance, physiological and immune response, and related immune gene expression of *Macrobrachium rosenbergii* with *Vibrio anguillarum* and ammonia stress. Fish Shellfish Immunol 89:603–613. https://doi.org/10.1016/j.fsi.2019.03.039

Karnjana K, Soowannayan C, Wongprasert K (2019) Ethanolic extract of red seaweed *Gracilaria fisheri* and furanone eradicate *Vibrio harveyi* and *Vibrio parahaemolyticus* biofilms and ameliorate the bacterial infection in shrimp. Fish Shellfish Immunol 88:91–101. https://doi.org/10.1016/j.fsi.2019.01.058

Kierek K, Watnick PI (2003) Environmental determinants of *Vibrio cholerae* biofilm development. Appl Environ Microbiol 69(9):5079–5088. https://doi.org/10.1128/Aem.69.9.5079-5088.2003

Kirstein IV, Kirmizi S, Wichels A, Garin-Fernandez A, Erler R, Löder M, Gerdts G (2016) Dangerous hitchhikers? Evidence for potentially pathogenic *Vibrio* spp. on microplastic particles. Mar Environ Res 120:1–8

Lara RJ, Neogi S, Islam M, Mahmud Z, Yamasaki S, Nair G (2009) Influence of catastrophic climatic events and human waste on vibrio distribution in the Karnaphuli Estuary, Bangladesh. Ecohealth 6(2):279–286. https://doi.org/10.1007/s10393-009-0257-6

Lara RJ, Islam MS, Yamasaki S, Neogi SB, Nair GB (2011a) Aquatic ecosystems, human health, and ecohydrology. In: Treatise on estuarine and coastal science, vol 10: ecohydrology and restoration, pp 263–299

Lara RJ, Neogi SB, Islam MS, Mahmud ZH, Islam S, Paul D, Demoz BB, Yamasaki S, Nair GB, Kattner G (2011b) *Vibrio cholerae* in waters of the Sunderban mangrove: relationship with biogeochemical parameters and chitin in seston size fractions. Wetlands Ecol Manag 19(1): 109–119. https://doi.org/10.1007/s11273-010-9204-0

LeRoux F, Wegner KM, Baker-Austin C, Vezzulli L, Osorio CR, Amaro C, Ritchie JM, Defoirdt T, Destoumieux-Garzon D, Blokesch M, Mazel D, Jacq A, Cava F, Gram L, Wendling CC, Strauch E, Kirschner A, Huehn S (2015) The emergence of Vibrio pathogens in Europe: ecology, evolution, and pathogenesis (Paris, 11-12th March 2015). Front Microbiol 6. https://doi.org/10.3389/fmicb.2015.00830

Liu C, Kroeze C, Hoekstra AY, Gerbens-Leenes W (2012) Past and future trends in grey water footprints of anthropogenic nitrogen and phosphorus inputs to major world rivers. Ecol Indic 18: 42–49. https://doi.org/10.1016/j.ecolind.2011.10.005

Lobitz B, Beck L, Huq A, Wood B, Fuchs G, Faruque ASG, Colwell R (2000) Climate and infectious disease: use of remote sensing for detection of *Vibrio cholerae* by indirect measurement. Proc Natl Acad Sci U S A 97(4):1438–1443. https://doi.org/10.1073/pnas.97.4.1438

Mahmud ZH, Wright AC, Mandal SC, Dai JL, Jones MK, Hasan M, Rashid MH, Islam MS, Johnson JA, Gulig PA, Morris JG, Ali A (2010) Genetic characterization of *Vibrio vulnificus* strains from Tilapia aquaculture in Bangladesh. Appl Environ Microbiol 76(14):4890–4895. https://doi.org/10.1128/Aem.00636-10

Mahmuduzzaman M, Ahmed ZU, Nuruzzaman A, Ahmed FRS (2014) Causes of salinity intrusion in coastal belt of Bangladesh. Int J Plant Res 4(4A):8–13

Matz C, McDougald D, Moreno AM, Yung PY, Yildiz FH, Kjelleberg S (2005) Biofilm formation and phenotypic variation enhance predation-driven persistence of *Vibrio cholerae*. Proc Natl Acad Sci U S A 102(46):16819–16824. https://doi.org/10.1073/pnas.0505350102

Meibom KL, Blokesch M, Dolganov NA, Wu CY, Schoolnik GK (2005) Chitin induces natural competence in *Vibrio cholerae*. Science 310(5755):1824–1827. https://doi.org/10.1126/science.1120096

Mitra A, Gangopadhyay A, Dube A, Schmidt ACK, Banerjee K (2009) Observed changes in water mass properties in the Indian Sundarbans (northwestern Bay of Bengal) during 1980-2007. Curr Sci 97(10):1445–1452

Mutreja A, Kim DW, Thomson NR, Connor TR, Lee JH, Kariuki S, Croucher NJ, Choi SY, Harris SR, Lebens M, Niyogi SK, Kim EJ, Ramamurthy T, Chun J, Wood JLN, Clemens JD, Czerkinsky C, Nair GB, Holmgren J et al (2011) Evidence for several waves of global transmission in the seventh cholera pandemic. Nature 477(7365):462–U111. https://doi.org/10.1038/nature10392

Nair GB, Ramamurthy T, Bhattacharya MK, Krishnan T, Ganguly S, Saha DR, Rajendran K, Manna B, Ghosh M, Okamoto K, Takeda Y (2010) Emerging trends in the etiology of enteric pathogens as evidenced from an active surveillance of hospitalized diarrhoeal patients in Kolkata, India. Gut Pathog 2. https://doi.org/10.1186/1757-4749-2-4

Nasreen M, Tate S (2007) Social inclusion: gender and equity in education swaps in South Asia: Bangladesh case Study. UNICEF Regional Office for South Asia

Neogi SB, Koch BP, Schmitt-Kopplin P, Pohl C, Kattner G, Yamasaki S, Lara RJ (2011) Biogeochemical controls on the bacterial populations in the eastern Atlantic Ocean. Biogeosciences 8(12):3747–3759. https://doi.org/10.5194/bg-8-3747-2011

Neogi SB, Islam MS, Nair GB, Yamasaki S, Lara RJ (2012) Occurrence and distribution of plankton-associated and free-living toxigenic *Vibrio cholerae* in a tropical estuary of a cholera endemic zone. Wetlands Ecol Manag 20(3):271–285. https://doi.org/10.1007/s11273-012-9247-5

Neogi SB, Yamasaki S, Alam M, Lara RJ (2014) The role of wetland microinvertebrates in spreading human diseases. Wetlands Ecol Manag 22(5):469–491. https://doi.org/10.1007/s11273-014-9373-3

Neogi SB, Dey M, Lutful Kabir S, Masum SJH, Kopprio GA, Yamasaki S, Lara RJ (2016) Sundarban mangroves: diversity, ecosystem services and climate change impacts. As J Med Biol Res 2:488–507

Neogi SB, Lara R, Alam M, Harder J, Yamasaki S, Colwell RR (2018) Environmental and hydroclimatic factors influencing Vibrio populations in the estuarine zone of the Bengal delta. Environ Monit Assess 190(10). https://doi.org/10.1007/s10661-018-6925-7

Neogi SB, Chowdhury N, Awasthi SP, Asakura M, Okuno K, Mahmud ZH, Islam MS, Hinenoya A, Nair GB, Yamasaki S (2019) Novel cholera toxin variant and ToxT regulon in environmental *Vibrio mimicus* isolates: potential resources for the evolution of *Vibrio cholerae* hybrid strains. Appl Environ Microbiol 85(3). https://doi.org/10.1128/AEM.01977-18

Pascual M, Rodo X, Ellner SP, Colwell R, Bouma MJ (2000) Cholera dynamics and El Nino-Southern oscillation. Science 289(5485):1766–1769. https://doi.org/10.1126/science.289.5485.1766

Pollitzer R (1954) Cholera studies: 1. History of the disease. Bull World Health Organ 10(3):421

Quiroz-Guzman E, Pena-Rodriguez A, Vazquez-Juarez R, Barajas-Sandoval DR, Balcazar JL, Martinez-Diaz SF (2018) Bacteriophage cocktails as an environmentally-friendly approach to prevent *Vibrio parahaemolyticus* and *Vibrio harveyi* infections in brine shrimp (Artemia franciscana) production. Aquaculture 492:273–279. https://doi.org/10.1016/j.aquaculture.2018.04.025

Rabbi SE, Dey NC (2013) Exploring the gap between hand washing knowledge and practices in Bangladesh: a cross-sectional comparative study. BMC Public Health 13. https://doi.org/10.1186/1471-2458-13-89

Rahman Talukder MR, Rutherford S, Chu C (2015) Salinization of drinking water in the context of climate change and sea level rise: a public health priority for coastal Bangladesh. Int J Climate Change Impacts Responses 8

Roszak DB, Colwell RR (1987) Survival strategies of bacteria in the natural-environment. Microbiol Rev 51(3):365–379. https://doi.org/10.1128/Mmbr.51.3.365-379.1987

Ruiz GM, Rawlings TK, Dobbs FC, Drake LA, Mullady T, Huq A, Colwell RR (2000) Global spread of microorganisms by ships—Ballast water discharged from vessels harbours a cocktail of potential pathogens. Nature 408(6808):49–50. https://doi.org/10.1038/35040695

Senoh M, Ghosh-Banerjee J, Mizuno T, Shinoda S, Miyoshi S, Hamabata T, Nair GB, Takeda Y (2014) Isolation of viable but nonculturable *Vibrio cholerae* O1 from environmental water samples in Kolkata, India, in a culturable state. Microbiologyopen 3(2):239–246. https://doi.org/10.1002/mbo3.164

Singh OP (2002) Interannual variability and predictability of sea level along the Indian Coast. Theor Appl Climatol 72(1–2):11–28. https://doi.org/10.1007/s007040200009

Sultana M, Nusrin S, Hasan NA, Sadique A, Ahmed KU, Islam A, Hossain A, Longini I, Nizam A, Huq A, Siddique AK, Sack DA, Sack RB, Colwell RR, Alam M (2018) Biofilms comprise a component of the annual cycle of *Vibrio cholerae* in the Bay of Bengal Estuary. MBio 9(2). https://doi.org/10.1128/mBio.00483-18

Tamplin ML, Gauzens AL, Huq A, Sack DA, Colwell RR (1990) Attachment of *Vibrio cholerae* Serogroup-O1 to zooplankton and phytoplankton of Bangladesh waters. Appl Environ Microbiol 56(6):1977–1980. https://doi.org/10.1128/Aem.56.6.1977-1980.1990

Thompson FL, Iida T, Swings J (2004) Biodiversity of vibrios. Microbiol Mol Biol Rev 68(3): 403+. https://doi.org/10.1128/Mmbr.68.3.403-431.2004

Unnikrishnan AS, Kumar MRR, Sindhu B (2011) Tropical cyclones in the Bay of Bengal and extreme sea-level projections along the east coast of India in a future climate scenario. Curr Sci 101(3):327–331

WHO (2020) Global Health Observatory (GHO) Data—Cholera [online]. https://www.who.int/gho/epidemic_diseases/cholera/en/

Wu J, Yunus M, Streatfield PK, Emch M (2014) Association of climate variability and childhood diarrhoeal disease in rural Bangladesh, 2000-2006. Epidemiol Infect 142(9):1859–1868. https://doi.org/10.1017/S095026881300277x

Yamasaki S, Asakura M, Neogi SB, Hinenoya A, Iwaoka E, Aoki S (2011) Inhibition of virulence potential of *Vibrio cholerae* by natural compounds. Indian J Med Res 133(2):232–239

Chapter 14
Ghana Case Study Two

Assessment of the Vulnerability of a Small Coastal Community to Climate Change for Adaptation Planning in Ghana

Elizabeth Effah, Denis W. Aheto, Emmanuel Acheampong, and John Blay

Abstract This study contributes to climate change adaptation planning by demonstrating how climate change may impact coastal communities and their livelihood opportunities in fisheries and small-scale crop farming. To assess vulnerability to climate change using flooding and drought indicators, an assessment framework that accounts for interactions between natural and human impacts was adopted, combining historical climate data and local knowledge. Temperature, rainfall, and humidity for the district from 1970 to 2012 were used to calculate the intensity of the indicators. Data from 2000 to 2012 show that rainfall and humidity decreased by 0.2 mm and 2% per year, respectively, while air temperature increased by 0.2 °C per year. This suggests that the community was highly vulnerable to drought and flooding during that period, with few practical strategies to deal with them. From 1970 to 2012, the community's physical assets and livelihoods were thus vulnerable to flooding (13.9 mm m^{-2} h^{-1}) and drought (30.9 mm m^{-2} h^{-1}). Therefore, it appears necessary to pursue community relocation to higher ground to mitigate the adverse effects of climate change-related events.

Keywords Climate variability · Vulnerability · Livelihoods · Adaptation planning · Ghana

E. Effah (✉) · D. W. Aheto · E. Acheampong · J. Blay
Department of Fisheries and Aquatic Sciences, University of Cape Coast, Cape Coast, Ghana

Centre for Coastal Management – Africa Centre of Excellence in Coastal Resilience (ACECoR), University of Cape Coast, Cape Coast, Ghana
e-mail: elizabeth.effah@ucc.edu.gh

M. Wolff et al. (eds.), *Challenges in Tropical Coastal Zone Management*,
https://doi.org/10.1007/978-3-031-17879-5_14

1 Introduction

Global climate change caused by rising concentrations of greenhouse gases in the atmosphere is perhaps the most serious threat confronting the earth in recent times. Various aspects of the environment, such as ocean circulation (McManus et al. 2004), extreme weather events (van Aalst 2006), biodiversity loss, and changes in habitat ranges of organisms (Bellard et al. 2012), are being driven by global climate change. The thermal expansion of ocean waters plus the melting of polar ice and glaciers are raising seawater level and pushing it further inland with devastating effects on coastal habitats such as wetlands, aquifers, as well as agricultural lands, and infrastructure (Allison et al. 2009; Nicholls and Cazenave 2010). The United Nations Intergovernmental Panel on Climate Change (IPCC) projects a sea-level rise of 40–60 cm by the year 2100 (IPCC 2007). It has been noted that these changes will most heavily impact the poorest and most vulnerable countries and disproportionately affect key economic sectors (World Bank 2018).

Global assessments have identified coastal areas in Africa as highly vulnerable to sea-level rise and its consequences (Nicholls et al. 1999). In addition to various socio-economic, demographic, and policy limitations, most coastal communities in Africa are highly dependent on fisheries resources which are also threatened by global climate change, specifically by the warming of coastal waters. Many unsustainable activities, such as fisheries over-exploitation, coastal pollution, and habitat degradation, add to the stress these natural communities are exposed to.

The economy of Ghana in West Africa is highly dependent on climate-sensitive sectors such as agriculture, fisheries, and forestry (World Bank 2018). The marine fisheries sector employs as many as 2.2 million people and generates about US$1 billion in revenue annually (World Bank 2018). The Environmental Protection Agency (EPA) of Ghana determined that should reach the sea level increase by one meter, an estimated area of 1100 km^2 of Ghana's coastal areas could be inundated (GCCP 2012). Projections by Appeaning Addo et al. (2011) suggest that low-lying coastal communities in Ghana will be permanently flooded by 2100 due to sea-level rise. This presents grave implications, given that one-third of the Ghanaian population lives within 3 km of the coast (GCCP 2012). These impacts could exacerbate the already precarious state of coastal biodiversity, fisheries, and physical infrastructure of Ghanaian coastal communities (Appeaning Addo et al. 2011; Armah et al. 2005).

Unfortunately, developmental efforts in Ghana do not give sufficient priority to climate change issues (GCCP 2012) for several reasons. First, societal and individual awareness of climate change effects on the ecosystems and adaptation initiatives is low. For example, in some low-lying coastal communities, as many as 84% of the local dwellers do not know of any practical measures that can be adopted to prevent flooding disasters (Appeaning Addo et al. 2011). Consequently, adaptation to the effects of climate change is not made deliberately and self-consciously. Second, there is a low institutional capacity to conceptualize climate change issues for integration into the country's developmental efforts (GCCP 2012). The financial and technical ability to develop climate change adaptation programs is also limited. Furthermore, coastal governance structures are weak, partly because indigenous institutions (e.g., the "asafo groups") responsible for law enforcement and emergency response and management situations, as well as local norms and taboos limiting access to marine resources, are not fully integrated into contemporary resource management initiatives. As a result, public institutions cannot fully meet their obligations to protect coastal communities against floods and other adverse effects of global climate change.

All in all, it has become necessary to highlight the vulnerability of coastal communities to the impacts of climate change and other associated hazards that eventually result in high levels of poverty, including food insecurity, disease, conflict, marginalization, and poor governance (FAO 2007). Hence, vulnerability assessments that examine the costs and risks of climate change-related events are essential (Fankhauser et al. 1998; Pittock and Jones 2000; Smit et al. 1999; Tol et al. 1998; Yohe et al. 1996). Efforts should also consider adaptation and mitigation import essentials of the strategy (Fankhauser 1996; Kane and Shogren 2000; Smith et al. 1996). This is because developing adaptation strategies to deal with risks associated with climate change is essential for identifying practical mitigation actions (Burton 1997; Parry 1986; Smit et al. 1999). Unfortunately, Ghana's climate change models and policy discussions have focused more on reducing greenhouse gas emissions with little attention to adaptation planning (GCCP 2012); a similar concern has been raised by others working in other poor and developing countries. Furthermore, the value of local indigenous knowledge on climate change adaptation has received little attention globally despite the communities often being the first to experience the effects of climate change (IPCC 2014). Several studies have demonstrated that local indigenous knowledge can be utilizable for adaptation strategies including early warning systems (Ajibade and Shokemi 2003), risk recognition, and response measures (Thomas et al. 2004).

This paper, therefore, aims to evaluate the vulnerability, in terms of assets and livelihoods, of a small coastal community in Ghana to the long-term impacts of climatic factors such as rainfall and air temperature variations. Here we refer to physical infrastructure as assets and fisheries and non-fisheries' livelihoods related to crop farming.

2 Materials and Methods

2.1 Study Area

This study was conducted at Old Akwidaa (4° 45′ 0 N; 2° 1′ 0 W), a coastal community located on a sand bar in the Western Region of Ghana (Fig. 14.1) with a population of approximately 5000 people (2010). Because of its proximity to the ocean, wetlands, and a lagoon, the area is prone to flooding (Fig. 14.1). The locals' primary occupation is fishing, followed by small-scale crop farming and petty

Fig. 14.1 Map showing the study area in the Western Region of Ghana

trading. The site has tourism development potential near the Slave Fort and a sea turtle nesting beach (Personal observation).

2.2 Theoretical Framework

Vulnerability assessments serve as the foundation for developing adaptation strategies to mitigate the adverse effects of climate change. The approach proposed by Monnereau et al. (2015) for assessing climate vulnerability was used in this study. This approach determines the susceptibility of various sectors to climate change effects, such as livelihoods, species or ecosystems, infrastructures, resources, and assets, based on three measures: (a) the sector's exposure to the threat, (b) the sector's sensitivity to the threat, i.e., the degree to which a system is affected (either adversely or beneficially), and (c) the sector's adaptive capacity to cope with the threat. Figure 14.2 depicts the relationship between these three measures.

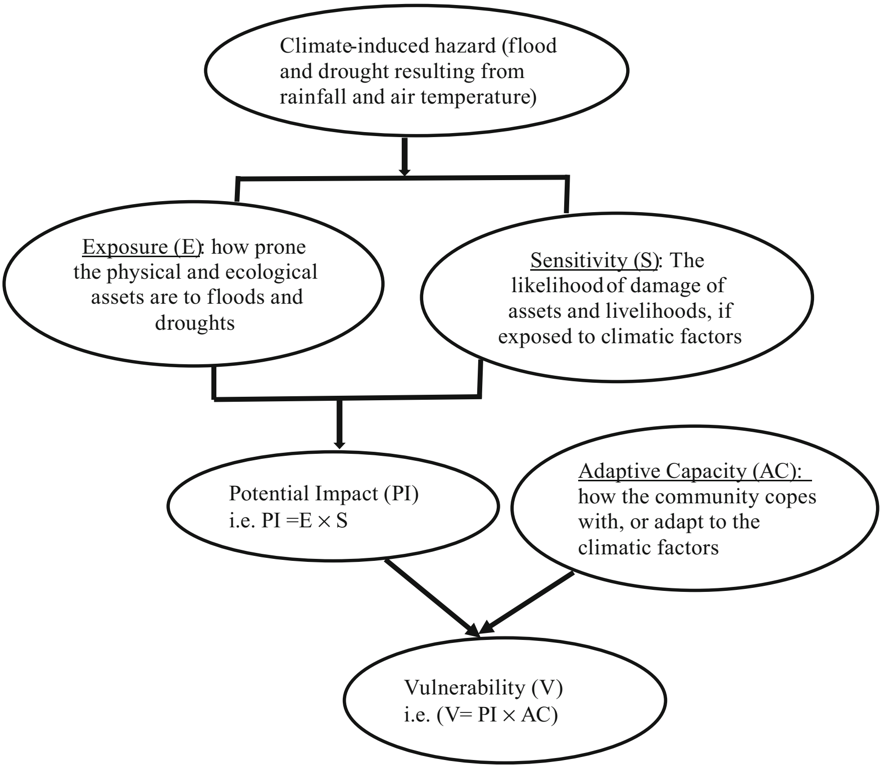


Fig. 14.2 Analytical framework for vulnerability assessment of climate-induced risks (adapted from Monnereau et al. 2015)

2.3 Data Collection

Field surveys were conducted to assess vulnerability based on critical assets and livelihoods, as well as changes that have occurred over a four-decade period. The community's vulnerability was assessed using an open-ended questionnaire. District planning officers and disaster management officials were questioned about climate-related risk adaptation measures implemented in the district and community. In selecting individuals from the community, a purposive sampling approach was used, and a total of 220 people were interviewed. The questionnaire sought the opinions of individual community members to avoid group influence. Interviewees were asked to provide verbal descriptions of the temperature and rainfall changes they had witnessed and the adaptive measures they had taken to deal with them. Climate change impacts on livelihoods and assets, exposure, and factors exacerbating vulnerability were all addressed in the interview questions. The Ghana Meteorological Agency provided rainfall, air temperature, and relative humidity records for

Ahanta West District, where the study site is located, from 1970 to 2012 to illustrate historical trends in climate conditions for the area.

2.4 Assessment of Climate-Induced Risks

Changes in the study area's air temperature, rainfall, and humidity were based on the anomalies associated with each climate variable. The anomalies were calculated according to the approach of Jones et al. (2008). The combined effects of the changes in the climatic variables in the study area were evaluated based on drought and flooding conditions (Eqs. 14.1 and 14.3).

2.4.1 Drought Conditions

The intensity of dry conditions (D) was determined as the difference between the amount of rainfall (R) and the rate of water loss through evaporation (E):

$$D = R\,(1 - E) \tag{14.1}$$

$$E = \frac{\Theta\,(H_s - h)}{h} \tag{14.2}$$

where Θ is the evaporation coefficient of water, H_s is maximum humidity (mm), and h is humidity ratio (mm). A Θ value of 1 was assumed as in Eames et al. (1997).

2.4.2 Flooding Conditions

The research was carried out in a community about 100 m from the sea at low tide (personal observation). The community has no drainage and is built on a muddy clay substrate. Furthermore, the study was conducted during the primary rainy season, when the soil is likely to be saturated. As a result, the level of flooding (F) was assumed to equal the amount of rainfall (R) in the area.

2.5 Assessment of Climate Vulnerability

The vulnerability of the study area to climate-induced risks was evaluated from the potential impact (PI) of the climate-induced conditions and the adaptive capacity (AC) of the community as:

Table 14.1 Sensitivity scores for assessing the vulnerability of physical assets and livelihood opportunities to drought and floods

Community assets	Observed assets	Recommended state of assets	Sensitivity Score	
			Drought	Floods
Roads	Deplorable feeder roads	Accessible tarred roads (IPCC 2001)	0	0
Clinics	Wooden/Mud structures	Concrete structures/Relocation of community (IPCC 2001)	0	0
Bridges	Wooden bridges	Metal or concrete bridges (IPCC 2007)	1	1
Houses (human residence)	Mud/Wooden structures	Concrete structures (IPCC 2007)	1	1
Markets	Unplanned weak market structures	Well-planned enforcement guidelines in coastal locations (IPCC 2001)	0	0
Schools	Mud structures	Concrete structures (IPCC 2007)	1	1
Fish landing sites	No fish landing site	Fish landing sites with storage facilities and Electricity (Adelekan 2010)	1	1
Cold storage facilities	No storage facility	Storage facilities (Adelekan 2010)	1	1
Farmlands	No coping strategies	Diversification of livelihoods (Fosu-Mensah et al. 2010)	0	0
Farm crop	Alternate livelihood	Use of extension services for crop improvement/Diversified livelihoods (Gbetibouo 2009)	1	1
Petty trading centers	Alternate livelihood	Provision of concrete structures/Alternate our livelihoods (Fosu-Mensah et al. 2010)	1	1
Mangrove forests	Degraded ecosystems	Transformed ecosystems (IPCC 2007)	1	1
Total Sensitivity to drought and floods			8	8

$$\text{Vulnerability} = (\text{PI}) \times (\text{AC}) \qquad (14.3)$$

where PI is the product of exposure (E) and sensitivity (S) of community assets to climate change factors (see Monnereau et al. 2015).

In the present study, the climate change factors considered were drought and flooding conditions, and the assets considered were physical infrastructure (e.g., roads, health clinics, etc.), natural ecosystems (e.g., mangrove forests), and livelihood opportunities (e.g., fisheries) (see Tables 14.1 and 14.2).

The exposure of assets to a given factor (drought or flood) was estimated by comparing the prevailing intensity to historic levels in the study area as follows:

$$E_{i,\mathrm{d}} = \frac{\alpha_{i,\ \mathrm{d}}}{\beta_{i,\mathrm{d}}} \quad ; \quad E_{i,\mathrm{f}} = \frac{\alpha_{i,\mathrm{f}}}{\beta_{i,\mathrm{f}}} \qquad (14.4)$$

Table 14.2 Adaptive capacity scores assess the protection of different community assets against drought and floods

Community assets	Observed coping strategy	Recommended coping strategy	Adaptive capacity score	
			Drought	Floods
Roads	No strategy for protection	Accessible tarred roads accessible roads (IPCC 2001)	0	0
Clinics	No strategy for protection	Provision of concrete structures (IPCC 2007)	0	0
Bridges	No strategy for protection	Provision of concrete structures (IPCC 2007)	0	0
Houses (human residence)	No strategy or protection	Provision of concrete structures (IPCC 2007) Relocation and building on stilts (EPA 2000)	0	0
Markets	No strategy for protection	Well-planned markets (accessible with stalls) (IPCC 2007)	0	0
Schools	No strategy for protection	Provision of concrete structures (IPCC 2007)	0	0
Fish landing sites	No fish landing site	Construction of fish landing site made of concrete (Adelekan 2010)	0	0
Cold storage for fish	No cold storage facility	Creation of storage facilities and improved processing techniques (Daw et al. 2005)	0	0
Farmlands	No strategy for protection	Diversification of livelihoods (Fosu-Mensah et al. 2010)	1	1
Farm crops	Alternate livelihood	Improved agricultural practices, e.g., irrigation, provision of improved seed varieties/ Diversification of livelihoods (Daw et al. 2005; Fosu-Mensah et al. 2010)	1	1
Mangrove forest	No strategy for protection	Transformed ecosystems (IPCC 2007)	0	0
Total Adaptive Capacity against drought and floods			2	2

where $E_{i,\mathrm{d}}$ is exposure to drought, $E_{i,\mathrm{f}}$ exposure to flooding, $\alpha_{i,\mathrm{d}}$ and $\alpha_{i,\mathrm{f}}$ the prevailing levels of drought and flooding, respectively, and $\beta_{i,\mathrm{d}}$ and $\beta_{i,\mathrm{f}}$ are the respective average long-term drought and flooding intensities in the study area.

The total exposure of the community to drought ($E_{n,\ \mathrm{d}}$) or flooding ($E_{n,\ \mathrm{f}}$) was calculated from the equations:

$$E_{n,\mathrm{d}} = \frac{\sum_{i}^{n} E_{i,\mathrm{d}}}{n}; \quad E_{n,\mathrm{f}} = \frac{\sum_{i}^{n} E_{i,\mathrm{f}}}{n} \tag{14.5}$$

where n is the total number of community assets assessed.

The sensitivity of the community assets to climate change factors was estimated based on the likelihood of each asset suffering damage if exposed. Some strategies have been recommended for effective mitigation of the effects of global climate change (see Fosu-Mensah et al. 2010; IPCC 2014). The expectations of these strategies about the state of local community assets were used as reference points for assessing the sensitivity of the study area to climate change effects. We assumed that assets that meet the expectations of the recommended measures (Table 14.1) are not likely to be damaged by climate-induced stressors; these were each given a sensitivity score of 0, meaning they are “not prone to the effects” of drought and flooding. Assets were awarded a sensitivity score of 1, meaning “prone to effects” of drought and flooding, if they did not meet the recommendations. These scores were assigned to each community asset regarding drought and flooding conditions; they were represented in our calculation using $S_{i,\mathrm{d}}$, and $S_{i,\mathrm{f}}$ respectively. The sensitivity, $S_{n,\mathrm{d}}$ or $S_{n,\mathrm{f}}$, of the entire community to either drought or flooding, respectively, was then calculated using the relations below:

$$S_{n,\mathrm{d}} = \frac{\sum_{i}^{n} S_{i,\mathrm{d}}}{n}; \quad S_{n,\mathrm{f}} = \frac{\sum_{i}^{n} S_{i,\mathrm{d}}}{n} \tag{14.6}$$

The potential impacts of drought and flooding conditions on the community were then calculated as $E_{n,\mathrm{d}} \times S_{n,\mathrm{d}}$ and $E_{n,\mathrm{f}} \times S_{n,\mathrm{f}}$ respectively.

For the community’s adaptive capacity, an approach similar to that described above for the determination of sensitivity was used. The total adaptive capacity, $A_{n,\mathrm{d}}$ or $A_{n,\mathrm{f}}$, of the entire community to either drought or flooding, respectively, was obtained from the relations:

$$A_{n,\mathrm{d}} = \frac{\sum_{i}^{n} A_{i,\mathrm{d}}}{n}; \quad A_{n,\mathrm{f}} = \frac{\sum_{i}^{n} A_{i,\mathrm{d}}}{n} \tag{14.7}$$

The potential impact of drought and floods on the community was then calculated as $E_{n,\mathrm{d}} \times S_{n,\mathrm{d}}$ and $E_{n,\mathrm{f}} \times S_{n,\mathrm{f}}$ respectively.

The total vulnerability of the study area to drought and flooding events was then estimated in line with the climate vulnerability assessment framework of Monnereau et al. (2015) as:

$$V_{\mathrm{d}} = A_{n,\mathrm{d}} \times (E_{n,\mathrm{d}} \times S_{n,\mathrm{d}}); \quad V_{\mathrm{f}} = A_{n,\mathrm{f}} \times (E_{n,\mathrm{f}} \times S_{n,\mathrm{f}}) \tag{14.8}$$

3 Results

3.1 Climatic Conditions of the Study Area

3.1.1 Temperature Variations

Air temperature changes in the Ahanta West District generally reflect warming over the study period. Maximum air temperatures increased by 6.4% between 1970 and 2012, according to an analysis of mean air temperatures. From an average temperature of 28.97 °C in the first decade, 1970–1979, the average temperature increased to 29.52 °C from 1979 to 2012, a 0.55 °C or 1.8% increase. As a result, temperature records show a gradually increasing trend of about 0.02 °C over the last four decades (Fig. 14.3a, b). These findings are consistent with general trends in global atmospheric temperatures.

3.1.2 Rainfall Variations

Figure 14.4 depicts the rainfall pattern in the study area. The lowest annual rainfall was 100.0 mm in 1983 and 1998, while the highest was 245.9 mm in 1979. Between 1970 and 2012, the average yearly rain fell by 145.9 mm. The amount of rainfall did not change significantly during the period studied. The rainfall anomaly trend is depicted in Fig. 14.4b. The positive anomaly represents an increase in rainfall, while the negative anomaly represents a decrease in rainfall. The trend decreased by 20 mm on average between 1980 and 2012.

3.1.3 Changes in Humidity

The relative humidity pattern measured during the study is shown in Fig. 14.5. The mean annual relative humidity recorded for the district, on the other hand, shows a gradual decline over the period studied. Mean relative humidity was higher in the first decade (from 1970 to 1980) when values ranged from 79 to 79.5 mm, but it fell to 72 mm from 1982 to 1998. From 1999 to 2006, it was slightly higher. Then, between 2006 and 2012, there was a slight decrease. Over the last four decades, average relative humidity has decreased by 0.05 mm. Relative humidity has generally decreased by 0.05 mm over the four decades. Figure 14.5b depicts a relative humidity anomaly trend. The trend shows that humidity increased in the first decade and decreased from 1980 to 2000. Then, it gradually decreased from 2000 to 2012, with an estimated 2 mm decrease.

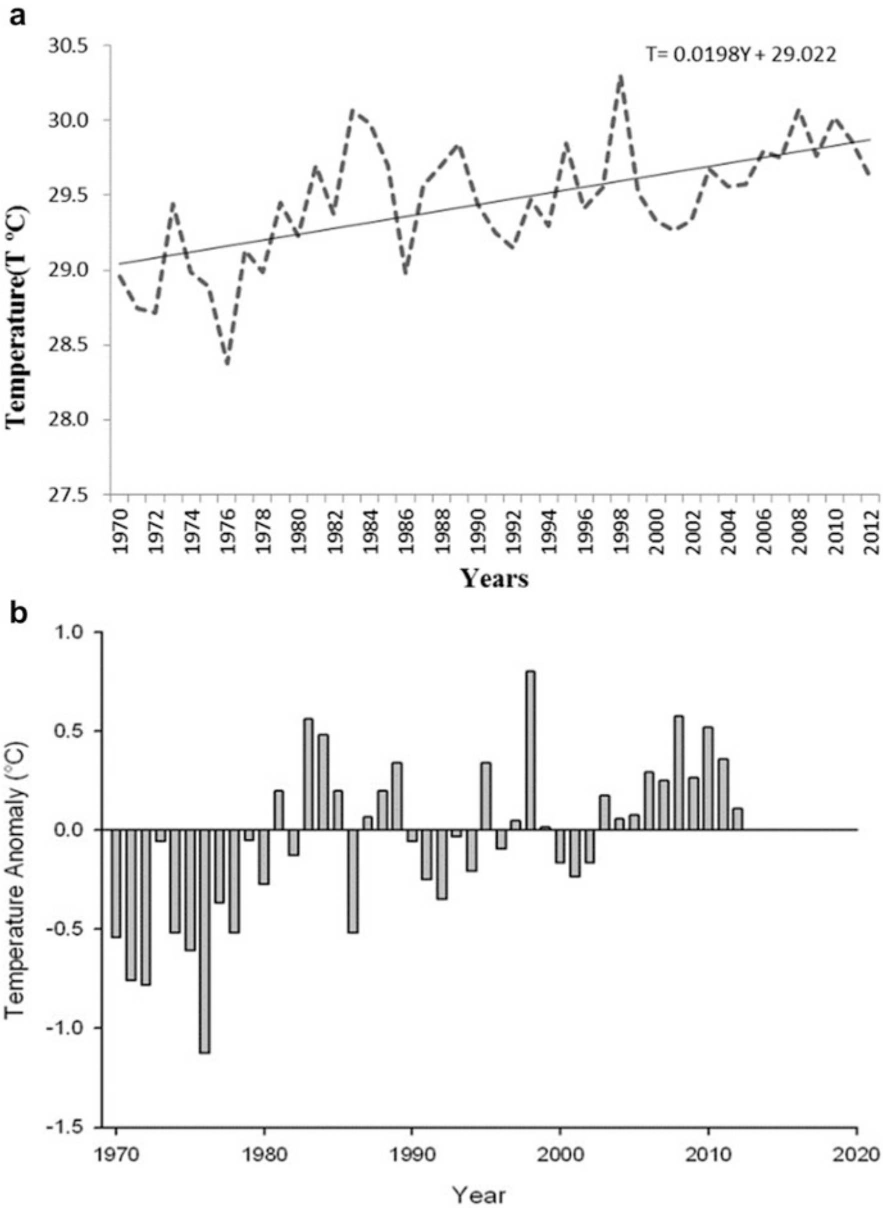


Fig. 14.3 (**a**) Mean annual temperature of Ahata West District (1970–2012). (**b**) Temperature anomaly of Ahata West District (1970–2012)

3.1.4 Changes in the Rate of Evaporation in the Ahanta West District

Figure 14.6 depicts changes in evaporation rate over the period studied. From 1970 to 1982, the rate was generally low. Following that, evaporation increased until

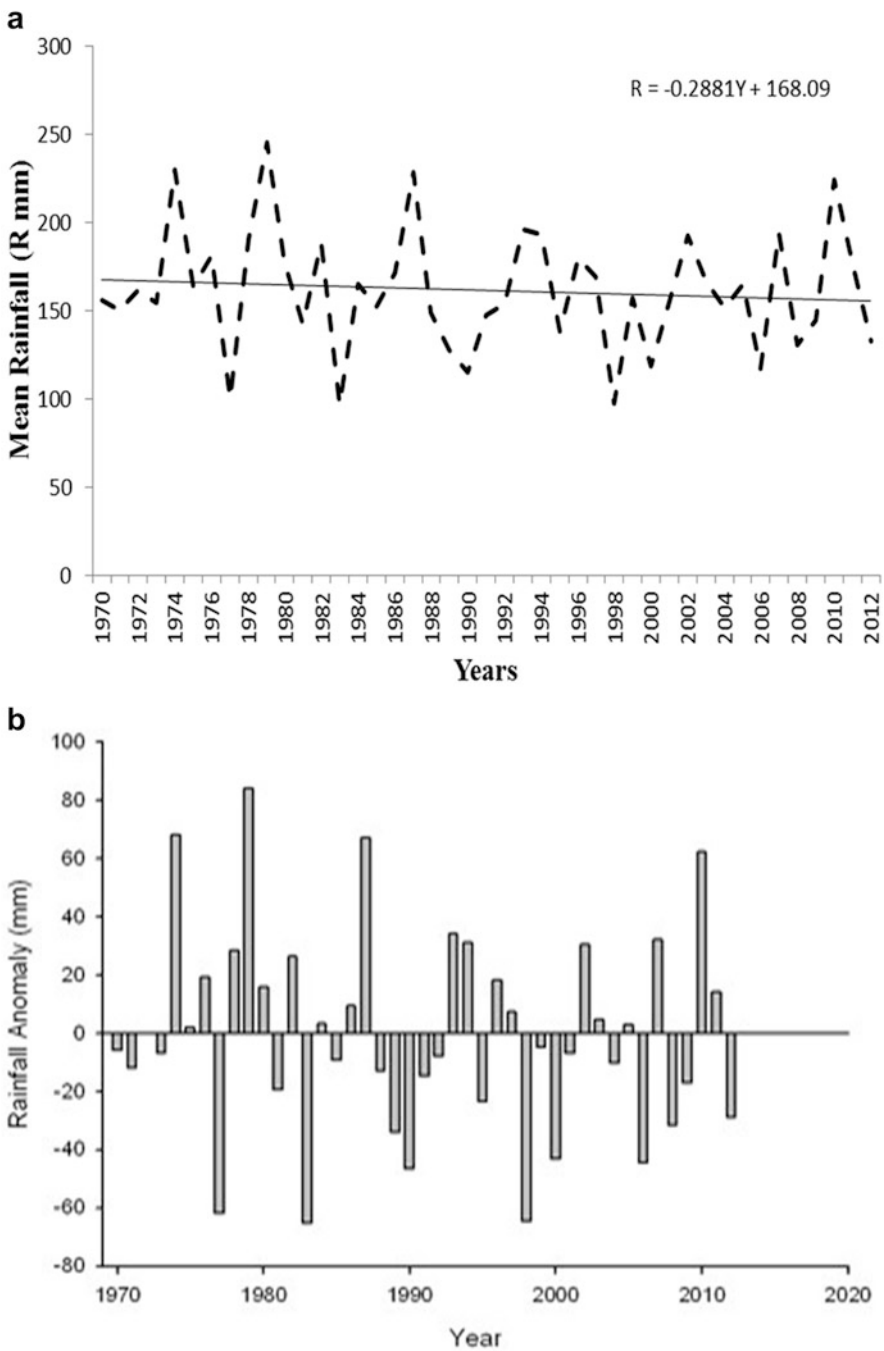


Fig. 14.4 (**a**) Mean annual rainfall of the Ahata West District (1970–2012). (**b**) Rainfall anomalies recorded over the study area between 1970 and 2012

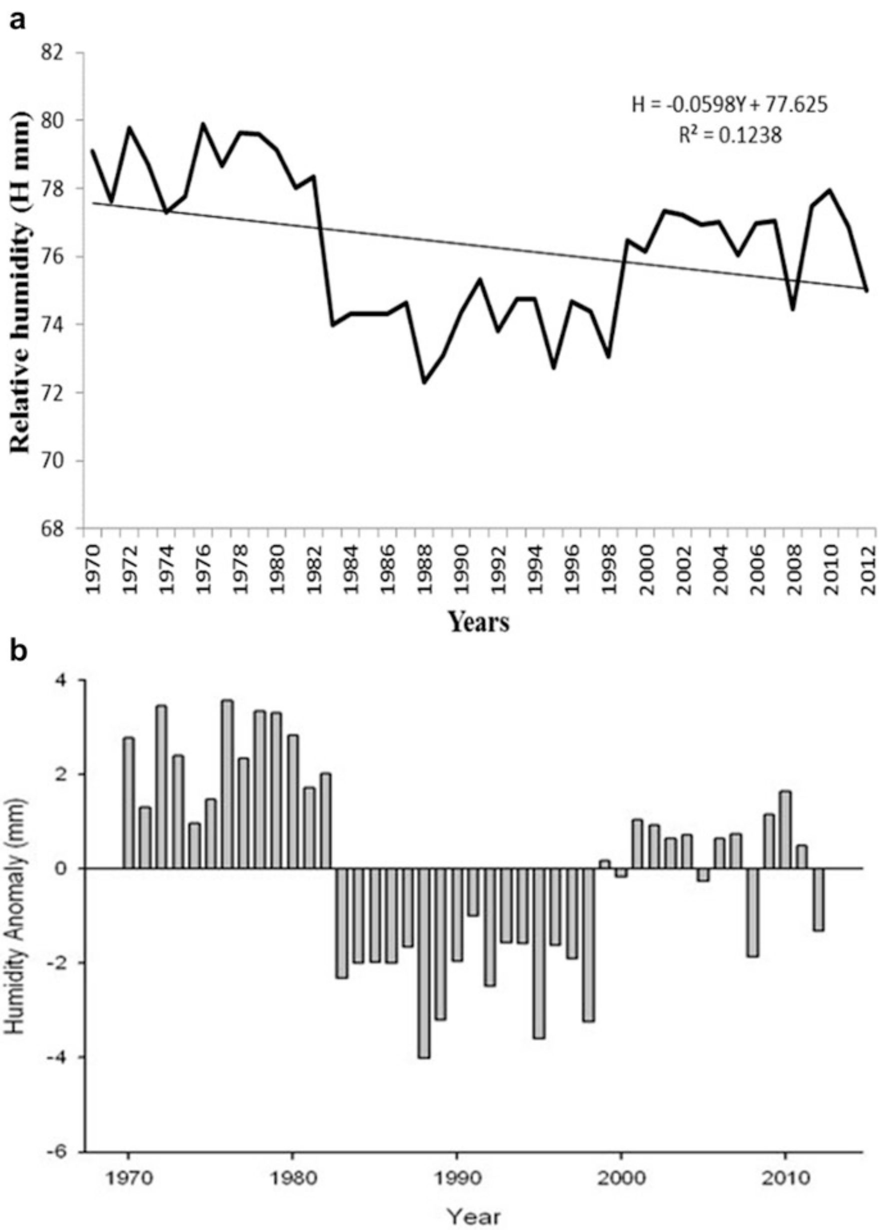


Fig. 14.5 (**a**) Mean annual relative humidity of the study area. (**b**) Anomalies of relative humidity of the study area

1995, then decreased slightly from 1996 to 2005. Finally, the trend gradually increases for the remainder of the observation period, from 2005 to 2012. In general, the rate of evaporation is rising.

Fig. 14.6 Rate of evaporation in the Ahanta West District

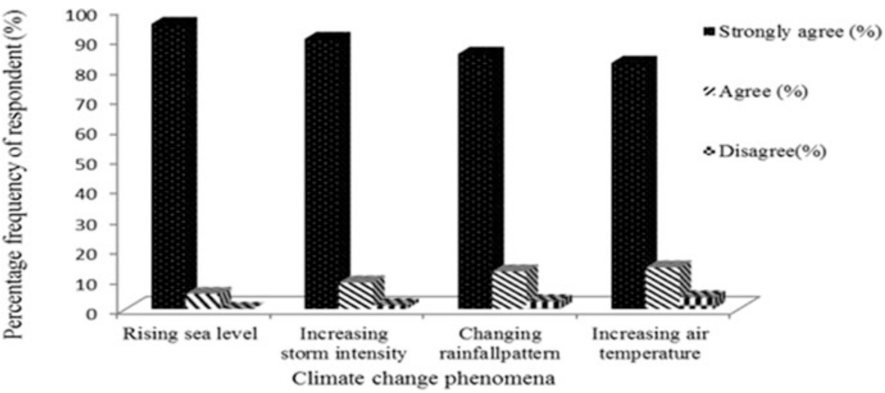


Fig. 14.7 Residents' perception of climate change-related phenomena

3.2 Perception of Climate Change Phenomenon in the Study Area

People's perceptions in the study area confirmed the observed changes in climatic conditions (Fig. 14.7). The majority (85–95%) of those polled strongly agreed that there had been changes in their community's climatic conditions, while 8% disagreed. These opinions were expressed about air temperature, rainfall, and other climate change-related factors like sea-level rise and increased storm intensity.

3.3 Exposure of Community Assets to Climate Change Effects

A trend was observed when evaluating the exposure of the community's assets (physical infrastructure and livelihoods) to floods and droughts over the last four decades (Fig. 14.8). A sharp increase in exposure to floods and droughts occurred between 1970 and 1971, after which the rise slowed down and was gradual until 2012.

3.4 Vulnerability to Climate Change Effects

From 1970 to 2012, we can see an increase in the vulnerability of physical infrastructure and livelihoods to flooding and drought. Over the last four decades, the trend indicates an overall increase. While both factors resulted in low vulnerability scores (10) from 1970 to 1982, higher scores for drought (13.9 mm m^2 h^{-1}) and flood (30 mm m^2 h^{-1}) were estimated for the remaining period. Most importantly, from 2005 to 2012, vulnerability to floods and drought appears to have stabilized (Fig. 14.9).

4 Discussion

It has long been recognized that global climate change is associated with extreme weather events such as storm surges, prolonged droughts, and heavy flooding (IPCC 2014). The effects of these threats are especially dire in Africa, where there is near-total dependence on natural ecosystems for survival and economic development (IPCC 2014). However, these challenges are usually not captured in local planning programs, partly because there is little understanding of the combined effects of the

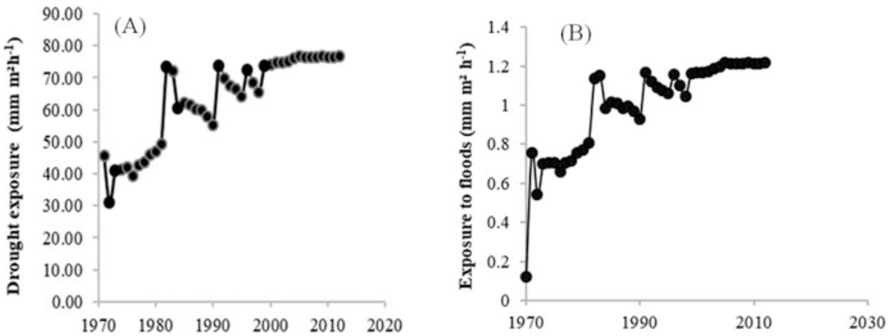


Fig. 14.8 Exposure of assets and livelihoods to flood (**a**) and drought (**b**)

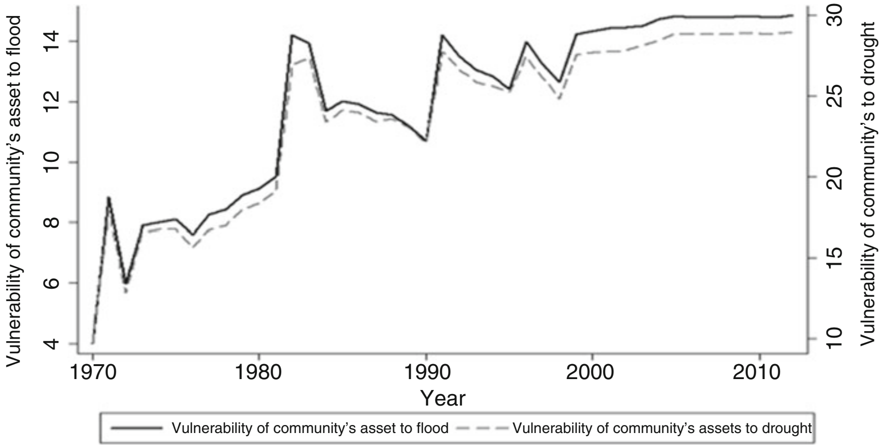


Fig. 14.9 Vulnerability of assets and livelihoods in the community to flood and drought

different climate change factors. In this paper, we evaluated how the interplay between air temperature, humidity, and rainfall exposes a coastal community in Ghana to flooding and drought conditions. The objectives were to estimate the vulnerability of assets and critical livelihoods to drought and floods and assess the community's understanding of climate change and their preparedness to cope with the phenomenon. The study revealed rainfall and humidity decreased by ~0.2 mm and 2% per annum while air temperature increased by 0.02 °C per annum since 1970. These trends in climatic conditions in that coastal community in Ghana were not different from the global picture.

Consequently, particularly from 2000 to 2012, the Akwidaa community was highly exposed to drought and floods at an average exposure value of 0.99 ± 0.21 and 1.0 ± 0.24, respectively. However, despite the recommendations of the IPCC and other authorities, the community had no effective strategies to cope with these risks, making the community's assets vulnerable to drought (~30.9 mm m^2 h^{-1}) and floods (~13.9 mm m^2 h^{-1}). Because of their proximity to the sea, stream, and lagoon, community assets, particularly physical infrastructure, are vulnerable to flooding. Flooding causes physical infrastructure to deteriorate and inundates crop farms, fishing boats, nets, and landing beaches. Homes made of erodible materials may be destroyed, leaving residents homeless and jobless in most cases. The degradation of mangrove forests, which could otherwise protect against coastal erosion, has also contributed to the problem's exacerbation. The effects of climate change-related events on coastal areas are expected to have a particularly negative impact on the structures of artisanal fisheries. According to Ghana's National Climate Change Policy, heavy rains would increase the risk of flooding and its associated problems in Africa. Inundations can cause seawater intrusion into freshwater areas, threatening stabilizing ecosystems such as mangrove forests and fisheries resources (GCCP 2012). Mangroves, which boost fish productivity by serving as breeding and spawning grounds, are already disappearing due to coastal erosion and flooding (Uyigue and Agho 2007).

Over the years, catch levels have declined due to drought conditions associated with extreme temperatures because high temperatures affect fish growth, reproduction, and other metabolic processes, as well as nutrient levels in the water (Ficke et al. 2007). According to Ficke et al. (2007), the temperature is a critical climate factor affecting fisheries globally, influencing fish metabolism, physiology, and behavior. Similarly, it plays a vital role in coastal upwelling, which increases nutrient levels in the oceans and fish productivity (GCCP 2012; World Fish Center 2009). The study's findings suggest that fisheries and livelihoods are vulnerable to various climate-related variability, ranging from changes in aquatic ecosystem structure and productivity to changing patterns and abundance of fish stocks (FAO 2007).

According to some reports, climate change and variability are real (Kankam-Yeboah et al. 2010; National Adaptation Strategy 2008; UNDP 2010), with severe consequences for the country due to their potential impacts on natural and social systems. Climate change has an effect on fishery production in a variety of ways (World Fish Center 2009). Internal and external stressors such as water scarcity, poor infrastructure, and unemployment exacerbate vulnerability. Similarly, (Bohle et al. 1994) argued that developing strategies to cope with future climate change requires a complete understanding of current vulnerability. This school of thought emphasizes the potential benefits and increased resilience resulting from climate-appropriate practices and infrastructure. Given the uncertainty surrounding future conditions under various climate scenarios, effective adaptation may be critical in reducing vulnerability.

5 Conclusions and Recommendations

In conclusion, this study found that, on average, air temperature in the area increased at a rate of 0.02 °C per year. At the same time, rainfall decreased by approximately 0.2 mm/year over the 40-year study period. The relative humidity in the area has also reduced by 0.05 mm/year, indicating a decrease in the atmosphere's moisture content. Over the last 43 years, the local people's assets and livelihoods have become increasingly vulnerable to drought and flood. Changes in environmental conditions have an impact on people's assets and livelihoods. Because floods appear to be the most likely climate-induced factor affecting the area's assets and livelihoods, we recommend that the community consider relocating to higher ground to mitigate its harmful effects.

Acknowledgments The authors are grateful to Mr. Stephen Kankam of Hen Mpoano, an environmental NGO in Ghana, and Ms. Pamela Rubinoff of the Coastal Resources Centre (CRC) of the University of Rhode Island, USA, for their input in the pilot study of this work.

References

Adelekan IO (2010) Vulnerability of poor urban coastal communities to flooding in Lagos, Nigeria. Environ Urbanization 22(2):433–450. https://doi.org/10.1177/0956247810380141

Ajibade LT, Shokemi O (2003) Indigenous approach to weather forecasting in ASA LGA, Kwara State, Nigeria. Indilinga Afr J Indig Knowledge Syst 2(1):37–44

Allison EH, Perry AL, Badjeck MC, Adger WN, Brown K, Conway D, Halls AS, Pilling GM, Reynolds JD, Andrew NL, Dulvy NK (2009) Vulnerability of national economies to the impacts of climate change on fisheries. Fish Fish 10(2):173–196. https://doi.org/10.1111/j.1467-2979.2008.00310.x

Appeaning Addo K, Larbi L, Amisigo B, Ofori-Danson PK (2011) Impacts of coastal inundation due to climate change in a cluster of urban coastal communities in Ghana, West Africa. Remote Sens (Basel) 3(9):2029–2050

Armah AK, Wiafe G, Kpelle DG (2005) Sea-level rise and coastal biodiversity in West Africa: A case study from Ghana. In: Low PS (ed) Climate change and Africa. Cambridge University Press, Cambridge, UK

Bellard C, Bertelsmeier C, Leadley P, Thuiller W, Courchamp F (2012) Impacts of climate change on the future of biodiversity. Ecol Lett 15(4):365–377. https://doi.org/10.1111/j.1461-0248.2011.01736.x

Bohle HG, Downing TE, Watts MJ (1994) Climate-change and social vulnerability—toward a sociology and geography of food insecurity. Global Environ Change Human Policy Dimens 4(1):37–48. https://doi.org/10.1016/0959-3780(94)90020-5

Burton I (1997) Vulnerability and adaptive response in the context of climate and climate change. Clim Change 36(1):185–196

Daw ND, Niv Y, Dayan P (2005) Uncertainty-based competition between prefrontal and dorsolateral striatal systems for behavioral control. Nat Neurosci 8(12):1704–1711

Eames I, Marr NJ, Sabir H (1997) The evaporation coefficient of water: a review. Int J Heat Mass Transf 40:2963–2973. https://doi.org/10.1016/S0017-9310(96)00339-0

EPA (2000) Ghana Initial National Communication under the United Nations Framework Convention on Climate Change

Fankhauser S (1996) The potential costs of climate change adaptation. In: Smith JB et al (eds) Adapting to climate change: an international perspective. Springer, New York, pp 80–96

Fankhauser S, Tol RS, Pearce DW (1998) Extensions and alternatives to climate change impact valuation: on the critique of IPCC Working Group III's impact estimates. Environ Dev Econ 3(1):59–81

FAO (2007) Climate change implications for fisheries and aquaculture: overview of current scientific knowledge. In: Cochrane K, De Young C, Soto D, Bahri T (eds) FAO Fisheries and Aquaculture Technical Paper No. 530. FAO

Ficke AD, Myrick CA, Hansen LJ (2007) Potential impacts of global climate change on freshwater fisheries. Rev Fish Biol Fish 17(4):581–613. https://doi.org/10.1007/s11160-007-9059-5

Fosu-Mensah B, Vlek P, Manschadi A (2010) Farmers' perceptions and adaptation to climate change: A Case Study of Sekyedumase District in Ghana. World Food System—A contribution from Europe. Centre for Development Research (ZEF), University of Bonn, Walter-Flex-Str. 3, 53113, Bonn, Germany

Gbetibouo GA (2009) Understanding farmers' perceptions and adaptations to climate change and variability: The case of the Limpopo Basin, South Africa, vol 849. Intl Food Policy Res Inst

GCCP (2012) Ministry of Environment, Science and Technology, Republic of Ghana

IPCC (2001) Climate change 2001: Impacts, adaptation, and vulnerability: Contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change

IPCC (2007) Climate change 2007—The physical science basis contribution of Working Group I to the fourth assessment report of the IPCC

IPCC (2014) Climate change 2014: Synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change. IPCC

Jones P, Larson A, Couper I (2008) The future, our rural populations and climate change—a special issue of Rural and Remote Health. Rural Remote Health 8(3)
Kane S, Shogren JF (2000) Linking adaptation and mitigation in climate change policy. Clim Change 45(1):75–102. https://doi.org/10.1023/A:1005688900676
Kankam-Yeboah K, Amisigo B, Obuobi E (2010) Climate change impacts in water resource in Ghana
McManus JF, Francois R, Gherardi JM, Keigwin LD, Brown-Leger S (2004) Collapse and rapid resumption of Atlantic meridional circulation linked to deglacial climate changes. Nature 428(6985):834–837. https://doi.org/10.1038/nature02494
Monnereau I, Mahon R, McConney P, Nurse L, Turner R, Vallès H (2015) Vulnerability of the fisheries sector to climate change impacts in Small Island Developing States and the Wider Caribbean. Centre for Resource Management and Environmental Studies, University of the West Indies, Cave Hill Campus, Barbados. CERMES Technical Report (77)
National Adaptation Strategy (2008) Ghana national climate change adaptation strategy
Nicholls RJ, Cazenave A (2010) Sea-level rise and its impact on coastal zones. Science 328(5985): 1517–1520. https://doi.org/10.1126/science.1185782
Nicholls RJ, Hoozemans FMJ, Marchand M (1999) Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses. Global Environ Change Human Policy Dimens 9:S69–S87. https://doi.org/10.1016/S0959-3780(99)00019-9
Parry M (1986) Some implications of climatic change for human development. Sustain Dev Biosphere 378–407
Pittock AB, Jones RN (2000) Adaptation to what and why? Environ Monit Assess 61(1):9–35
Smit B, Burton I, Klein RJ, Street R (1999) The science of adaptation: a framework for assessment. Mitig Adapt Strat Glob Chang 4(3):199–213
Smith J, Ragland S, Pitts G (1996) A process for evaluating anticipatory adaptation measures for climate change. Water Air Soil Pollut 92(1):229–238
Thomas CD, Cameron A, Green RE, Bakkenes M, Beaumont LJ, Collingham YC, Erasmus BF, De Siqueira MF, Grainger A, Hannah L (2004) Extinction risk from climate change. Nature 427(6970):145–148
Tol RSJ, Fankhauser S, Smith JB (1998) The scope for adaptation to climate change: what can we learn from the impact literature? Global Environ Change Human Policy Dimens 8(2):109–123. https://doi.org/10.1016/S0959-3780(98)00004-1
UNDP (2010) National climate change adaptation strategy
Uyigue E, Agho M (2007) Coping with climate change and environmental degradation in the Niger Delta of southern Nigeria. Community Res Dev Centre Nigeria (CREDC) 1(30)
van Aalst MK (2006) The impacts of climate change on the risk of natural disasters. Disasters 30(1): 5–18. https://doi.org/10.1111/j.1467-9523.2006.00303.x
World Bank (2018) Agriculture: Ghana's engine of growth for jobs creation. Online article
World Fish Center (2009) Fisheries and aquaculture can provide solutions to cope with climate change. Issues brief
Yohe G, Neumann J, Marshall P, Ameden H (1996) The economic cost of greenhouse-induced sea-level rise for developed property in the United States. Clim Change 32(4):387–410. https://doi.org/10.1007/Bf00140353

Chapter 15
Ecuador Case Study

Transboundary Marine Conservation and Fisheries Management in Ecuador and Northern Peru

Gabriela Navarrete-Forero, Alonso Del-Solar-Escardó, Eliana Alfaro-Cordova, Leonardo Rodríguez-Escalante, Solange Andrade-Vera, and Demian A. Willette

Abstract Marine fisheries are an important source of food security, livelihood, and employment for coastal communities around the world. However, their sustainability is undermined in contexts of weak institutions at multiple levels of governance, illegal fishing, and poor seafood traceability. Ecuador and Peru share historical, ecological, social, and economic features in terms of marine affairs, conservation, and fisheries development, and therefore face similar challenges to sustainability. The goal of this synthesis is to provide an overview of the aspects in common and to highlight the relevance of bi-national cooperation in scientific research in times of transformation of seafood systems into more sustainable ones. We show that there are important fishery resources in common, and potentially many more that are

G. Navarrete-Forero (✉)
Centro del Agua y Desarrollo Sustentable, Escuela Superior Politécnica del Litoral. Campus Gustavo Galindo, Guayaquil, Ecuador

Resource Management Group, Leibniz Centre for Tropical Marine Research, Bremen, Germany
e-mail: gnavarr@espol.edu.ec

A. Del-Solar-Escardó
Resource Management Group, Leibniz Centre for Tropical Marine Research, Bremen, Germany

E. Alfaro-Cordova
ProDelphinus, Lima, Peru

Carrera de Biología Marina, Universidad Científica del Sur, Lima, Peru

L. Rodríguez-Escalante
Laboratorio de Ensayo de Patología Acuícola. Subsecretaría de Calidad e Inocuidad, Ministerio de Producción Comercio Exterior, Inversiones y Pesca, Guayaquil, Ecuador

S. Andrade-Vera
Charles Darwin Research Station, Charles Darwin Foundation, Puerto Ayora, Galapagos, Ecuador

D. A. Willette
Biology Department, Loyola Marymount University, Los Angeles, CA, USA

M. Wolff et al. (eds.), *Challenges in Tropical Coastal Zone Management*,
https://doi.org/10.1007/978-3-031-17879-5_15

poorly known and monitored. At the national-government level, Ecuador and Peru cooperate through international organizations to manage some shared stocks like tropical tunas, dolphinfish and Chilean jack mackerel. At the community level, members of artisanal fishing associations have participated in bi-national workshops around dolphinfish management. We propose that bi-national academic and scientific research networks can also contribute to this process and suggest some lines of research in which the cooperation could develop.

Keywords Marine fisheries · Regional management · Sustainability · Ecuador · Peru · Transboundary stocks

1 Introduction

Global marine fisheries have grown over the past century, reaching a peak of 90–130 million metric tons per year in the mid-1990s, before the steady decline in recent decades (FAO 2016b; Pauly and Zeller 2016). The availability of diesel-powered vessels and sonar technology after World War II facilitated the development of distant-water fishing fleets by the United States, Japan, China, the Soviet Union/Russia, Taiwan, South Korea, Spain, and France. As their name implies, distant-water fleets fish away from their country's waters in international seas and in the maritime zones of foreign nations, including those of Ecuador and Peru. However, perceiving the threat of exhaustion of local fisheries resources by distant-water fleets, in 1952 the governments of Chile, Peru and Ecuador signed the "Santiago Declaration on the Maritime Zone," claiming exclusive sovereignty and jurisdiction over seas extending 200 nautical miles (nm) from each country's respective coast (Chile Ecuador and Peru 1976). This declaration, however, was not ratified internationally and was largely ineffective in stemming the problem. Following the combined pressure from Asian and African nations, along with others in Latin America (Thorpe and Bennett 2001), the international community agreed on the designation of 200 nm Exclusive Economic Zones (EEZ) of coastal nations in the United Nations Convention on the Law of the Sea in 1974 (UNCLOS; UN 2019). Under UNCLOS, distant-water fleets may harvest unexploited fish in foreign EEZs if they pay a negotiated fee for access. Bolstered by the newly-established zones, and pressured to harvest domestic stocks to exclude foreign fleets, Ecuador, Peru, and other Latin American nations rapidly developed their own fishing fleets and joined the global fishing nations (Thorpe and Bennett 2001).

The race to capture fish led to governmental fuel subsidies and over-capitalization of the fishing industry and unsustainable harvest of local stocks. Consequently, multiple regional stocks have since been designated "fully exploited," "overexploited," or "depleted," including South Pacific hake *Merluccius gayi*, mackerels *Trachurus picturatus*, *Trachurus murphyi* and *Scomber japonicus,* and South American pilchard *Sardinops sagax* (FAO 2016a, b). Other relevant regional pelagic fisheries include those of sharks and tunas, and more recently the rise of the dolphinfish *Coryphaena hippurus* and giant squid *Dosidicus gigas* fisheries (Argüelles et al. 2008; Del Solar et al. 2017).

The decline of stocks due to unsustainable fishing is further compounded by the forecasted deleterious effects of climate change (Defeo et al. 2013; Dueri et al. 2014) and by the global challenge of Illegal, Unreported, and Unregulated (IUU) fishing. IUU fishing relates to unsustainable harvest practices and is linked to organized crime. Its products infiltrate fish and fishmeal distribution channels, particularly in developing countries with low levels of governance (Agnew et al. 2009). The mislabelling of seafood products contributes to cover this malpractice from consumers (Cawthorn et al. 2018; Grillo et al. 2018). As a response, some of the main fish importers in the European Union and United States are improving their standards of seafood traceability (Willette and Cheng 2018).

In this context, the UN Agreement on Port State Measures to combat IUU fishing (FAO 2009) defines the route for national governments to develop more efficient control systems and improve their legislation and the procedures used to detect IUU fishing. This approach targets industrial vessels that land their catch in major ports but does not include small-scale fisheries. Thus, different approaches are needed to improve seafood traceability across fisheries sectors. For Ecuador and Peru, both industrial and artisanal fishing are important contributors to the national economy and food security. In the following sections, we will present arguments in favor of strengthening cooperation between these countries in order to meet the challenges of IUU fishing, market competitiveness and local food security.

2 Historical Development of Fisheries Management and Coastal Conservation in Ecuador and Peru

Ecuador possesses a continental EEZ and an insular EEZ surrounding the Galapagos Archipelago, with marine conservation and fisheries management efforts having historically focused on the Galapagos region. In contrast, Peru has a single, continuous EEZ with no islands located far from the coastline (Fig. 15.1). Both countries

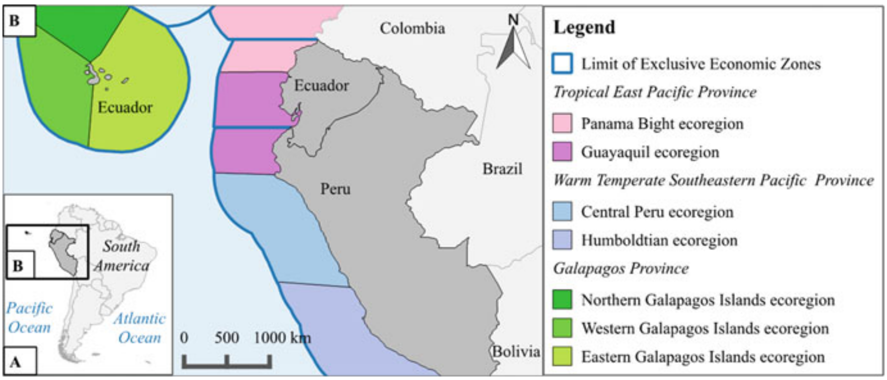


Fig. 15.1 Biogeographic and political subdivisions off the Ecuadorian Peruvian coast (Spalding Mark et al. 2007).

exploit their marine resources in open access regimes, and largely depend on extractive, export-oriented economies.

The first initiative to protect marine biodiversity in Ecuador occurred in 1934 when the Galapagos Archipelago was declared a “conservation area” (Varea 2004). The oldest institutions conducting research for the conservation of the Galapagos Islands are the Galapagos National Park Directorate (GNPD), created by the Ecuadorian government, and the Charles Darwin Foundation, both founded in 1959 (see Box 15.1). Meanwhile, marine conservation in Peru started in 1958, with measures to maintain guano exploitation (i.e., bird excrement from coastal capes, exported as fertilizer). The state prohibited fishing nearby the capes because the activity—in combination with El Niño events, (see Cushman 2003)—was reducing the birds’ source of food, anchoveta *Engraulis ringens*. Currently, the National Reserve of Guano Islands, Islets and Capes System allows ecosystem-based management and resource use around these highly productive areas.

The 1950s saw the rise of industrial fisheries in Ecuador and Peru. In Ecuador, the shrimp trawl fishery began in this decade and eventually entered in conflict with coastal communities for the use of ancestral fishing grounds and high rates of bycatch. In 2012, the shrimp-trawl fishery was officially closed (MAE 2012). In Peru, the industrial fishing of anchoveta started in 1952 (Mendo and Claudia 2016). For a long time, this was the most important economic activity associated to the sea. Anchoveta stocks collapsed in the early 1970s but measures were taken and the fishery is today one of the largest single-species and best-managed fisheries in the world (Chavez et al. 2008; Tarazona and Arntz 2001).

During the 1970s, mangrove deforestation for shrimp farming prevailed in Ecuador and Northern Peru. The process started in Ecuador early in the decade and affected the traditional fishing communities depending on crustaceans, molluscs, and fish (Terán et al. 2007). The mangrove forest ecological reserve Manglares Churute was created in Ecuador in 1979 to counter this process. During the 1990s, the Ecuadorian government adopted the strategy of managing mangrove forests through concessions assigned to legally constituted fishing associations. Similarly, the Peruvian State initiated a series of experiments in shrimp aquaculture in 1970, and by 1978 it allowed the private sector to take part. For Peru, shrimp aquaculture was an alternative to the recently collapsed anchoveta fishery, but it was also motivated by a shift toward a liberal economy. Shrimp production in Peru has increased ever since, despite disastrous El Niño events in 1982–1983 and 1997–1998, which destroyed ponds, channels, and facilities (Mialhe et al. 2013). In 1988 the Sanctuary “Los Manglares de Tumbes” was created as an important natural reserve to protect the mangrove forests of northern Peru in response to the growth of unregulated shrimp farming in the area (INRENA 2002). However, its management is still challenging due to contamination, deforestation, aquaculture, agriculture and urban expansion, added to information gaps that deter decision-making (Flores et al. 2013). Ecuador is currently the second largest exporter of frozen shrimp after India, while Peru occupies the 13th place (Workman 2019).

During the 1980s the artisanal fishing fleet of Ecuador experienced a significant development of its capacity to reach fishing areas outside the continental platform. In

1989, the National Fisheries Institute (INP) of Ecuador started monitoring the main artisanal fishing ports along the coast, collecting information about landings, fishing effort and biological data about the main target species (Peralta 2009).

The signing of the Convention on Biological Diversity (CBD) in Rio 1992 had a positive effect on conservation efforts in Ecuador, although not immediately. In 2000, stakeholders from the coastal region engaged with the Ministry of Environment, exerting pressure for the declaration of a series of coastal marine protected areas. However, a study of biodiversity conservation gaps and priorities in continental Ecuador concluded that the existing protected areas failed to cover and represent the different ecosystem types, particularly, the marine ecosystems (Terán et al. 2007). A portfolio of potential conservation areas resulting from the study was included in the National Strategy for Biodiversity 2015–2030 to guide the development and expansion of the National System of Protected Areas (MAE 2016).

In Peru, the creation of the Peruvian Ministry of Environment in 2008 constituted a turning point from fisheries-oriented coastal zone management, toward ecosystem-based management. The current policy for integrated coastal zone management (Ministerio del Ambiente 2016) was assessed by Barragan and Lazo in 2018. The authors explain that the State has recently included coastal zone management in the political agenda, but only as a bottom-up process. They consider that this is an incomplete approach, lacking a clear description of the role of the State in supporting coastal communities in policy implementation, and in facilitating the advance of regions and districts. Therefore, Peru is considered to be in a transition toward a more integrated model but still with a long way to go. For instance, it has been suggested that the marine nature of the Guano Islands and Capes system should be complemented with a protected terrestrial coast strip that would act as a coastal ecological corridor, but this is not yet included in official plans (Barragán and Lazo 2018).

In summary, Ecuador and Peru have had similar, parallel processes of natural resource exploitation in marine and coastal ecosystems. Both have significant environmental sustainability challenges and therefore national policies are now turning toward ecosystem-based management.

Box 15.1 Fisheries Management in Galapagos, Ecuador

The importance of Galapagos for global marine biodiversity has been widely recognized: UNESCO World Heritage Site (1978), Biosphere Reserve and Whale Sanctuary (1985), and Shark Sanctuary (2016). However, multiple drivers of environmental degradation are still acting, including biological invasions and extinctions, overfishing, massive tourism, and contamination (see Wolff and Gardener 2012).

The Galapagos Marine Reserve (GMR) is a multi-use oceanic protected area of ~138,000 km^2 from a 40 nm buffer measured from the baseline around of the archipelago and its inland waters. Industrial fishing was prohibited in

(continued)

Box 15.1 (continued)
1998 by the Special Law for Galapagos, and its special regulation for fishing activity. However, industrial fishing has been displaced outside the boundaries of the GMR. The local artisanal fishery is the only permitted and managed by GNPD and takes place in 99% of the GMR (Moity et al. 2018). Measures to reduce the fishing effort and pressure on coastal and demersal fish include the use of anchored fish aggregation devices (FADs). These are being evaluated as sustainable alternatives for the fishing sector. Evidence shows that the GMR had a positive effect on industrial fisheries targeting yellowfin and skipjack tuna during the first decade of operation (Wolff et al. 2012), whereas the sustainability of industrial fisheries operating outside the GMR is threatened by the overuse of FADs (Bucaram et al. 2017).

Despite management efforts and the existence of a muti-stakeholder management board ("Junta de manejo participativo"), the threat of illegal fishing is still real for Galapagos. In 2017, a Chinese-flag fishing vessel was caught inside the GMR containing 300 tons of protected species, including hammerhead sharks (EFE 2017). More recently, the Ecuadorian Navy caught four fishing vessels manned by Peruvian crews inside the Galapagos EEZ, once again, targeting protected shark species (El Comercio 2019). The illegal entry of industrial vessels is evident, especially long-liners (Carr et al. 2013; Jacquet et al. 2008). Long-line fishing is not a sustainable option for Galapagos, where marine-based tourism is related to megafauna sighting (Cerutti-Pereyra et al. 2019; Moity and Izurieta 2017). In addition, marine-based tourism represents the biggest economic revenue (58%) (Lynham et al. 2015) in the GMR. Other illegal activities such as fishing inside no-take zones, targeting species in closed seasons and using banned fishing gear are daily local challenges.

Although small-scale fishing practices and management are different between Ecuador mainland and the Galapagos Archipelago, governance problems persist in both sub-regions due to incongruent jurisdictional and legal frameworks, and a lack of attention to the social and cultural dimensions of fisheries governance (Barragán Paladines 2015).

3 A Continuous Environment Across Political Borders

Marine ecology around the political border between Ecuador and Peru is highly dynamic due to the proximity of three biogeochemical provinces: the Central American Coastal Province, which extends from Baja California to the Gulf of Guayaquil, in Ecuador; the Humboldt Current Coastal Province which covers the coastal waters off Chile and Peru from 40–45 to 5°S; and the Pacific Equatorial Divergence Province, dominated by the South Equatorial Current west of the Galapagos Archipelago (Longhurst 1998). The exact latitudinal extent of these provinces is subject to variations associated with the El Niño Southern Oscillation

(ENSO). Additionally, this political border is located inside the Tropical East Pacific—Guayaquil biogeographic ecoregion (Spalding Mark et al. 2007), dominated by the Gulf of Guayaquil, the largest estuary in the Pacific coast of South America (Fig. 15.1).

The predominant feature throughout this region is the presence of the Humboldt Current (HC)—the most productive eastern boundary current system in terms of fish production (Mendo and Claudia 2016; Miloslavich et al. 2011). The northern coast of Peru is particularly productive in this sense. For example, the Region of Piura represents only 10% of the Peruvian coastline but hosts ~30% of all fishers and ~35% of all artisanal boats and small-scale vessels (Guevara-Carrasco and Bertrand 2017). In the HC system, upwelling of cold water sustains a highly productive plankton community, which in turn supports a high biomass of small pelagic fish (mainly anchovies and sardines) and top predators feeding on them. However, during ENSO's warm phases, the upwelling current brings warm, nutrient-poor but oxygen-enriched water from offshore and from equatorial latitudes (Taylor et al. 2008). This generates a disruption of the food chain that cascades all the way from the phytoplankton through herbivores and leads to the drastic reduction of pelagic fish stocks (Longhurst 1998).

The environmental oscillation between ENSO's warm and cold phases also causes changes in the composition of the marine communities for a given latitude (IOC 1989). For instance, warm phases have been associated with a decrease in catches of *Engraulis ringens, Merluccius gayi peruanus, Aulacomya ater*, and increases of *Trachurus picturatus murphyi, Octopus* spp., and *Penaeus* spp.; additionally, the fisheries have shown a trend from mono- to multi-specific catches (Badjeck 2008) during these times. In the case of the highly valued scallop *Argopecten purpuratus*, warmer waters have increased catches almost 50-fold in the Ica Region, central Peru, which lies under typical upwelling conditions (~14°S). On the other hand, scallop stocks collapse around 4°S, due to increased rainfall that leads to decreased salinity and higher discharge of particulate matter (Mendo et al. 2008; Taylor et al. 2008; Wolff 1987). Similarly, Ecuadorian waters are also heavily affected by ENSO and the HC's upwelling system, as documented in studies of periodic modifications of ocean biogeochemistry (Borbor-Cordova et al. 2019; Wolff 2010).

4 Fishing Target Species Common to Ecuador and Peru

This section presents the biodiversity of fishery resources that have been documented both in Ecuador and Peru. It is supported by a list of species (see Appendix) compiled using public information in English and Spanish. Species were included in this list based on their latitudinal distribution across the political border and after confirmation of their presence in both countries from the literature. Taxonomic synonymy was checked using online databases (Maddison et al. 2007) and conservation status was retrieved from IUCN (2019). The compiled list consists

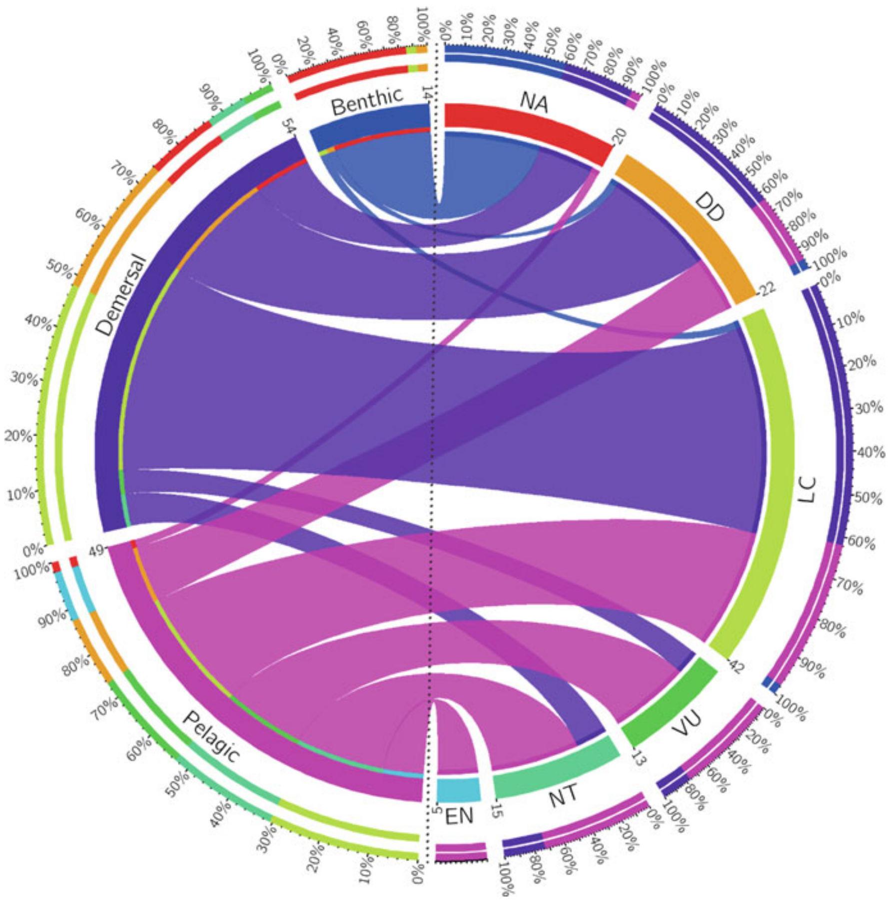


Fig. 15.2 Two-variable circular diagram built with information from 117 fishing-target species reported both in Ecuador and Peru. The first variable is ecological distribution (benthic, demersal, pelagic)—represented on the left hemisphere. The right hemisphere contains the second variable: threat categories from least to most (NA not assessed, DD data deficient, LC least concern, VU vulnerable, NT near threatened, EN endangered IUCN 2019). Bands connecting both sides represent the proportion of species in each combination. Number of species in each category is written next to the category's name. Percentages of species in each subcategory are colored on peripheral scales (e.g., demersal and LC: 62%). Diagram generated with Circos Table Viewer (Krzywinski et al. 2009)

of 117 species, including fishes (95 spp.), crustaceans (16 spp.), and molluscs (6 spp.).

There is a considerable gap of knowledge in terms of IUCN categories as 35.8% of the list corresponds to species not assessed, or data deficient (Fig. 15.2). The largest gap is among benthic species. Demersal species are mostly under the least concern category, but also include the majority of data deficiency cases. More than half the pelagic species are in threatened categories.

4.1 Threatened Species by Large-Scale Distribution

Coastal Species The coastal zone contains the largest proportion of species in the total list (66.7%). Almost half of coastal species are in the low-concern category, but the population trends are unknown for the majority (78.2%). Two rays (*Rhinobatos leucorhynchus, Myliobatis longirostris)*, and two sharks (*Squatina californica*, *Mustelus mento)* are near threatened, while three other shark species (*Galeorhinus galeus, Mustelus whitneyi, Triakis maculata)* are considered vulnerable.

Oceanic Species Oceanic waters are occupied by 21.4% of the species in the list. Population trends are known for 76.0% and decreasing for 64.0% of oceanic species. Eleven species of rays (genus *Mobula*), sharks (genera *Carcharhinus, Rhincodon, Isurus, Sphyrna, Alopias*) and tuna (*Thunnus orientalis, T. obsesus*), and billfishes (*Makaira mazara, Istiompax indica, Kajikia audax, Xiphias gladius*) are either vulnerable or endangered.

Semi-oceanic Species The semi-oceanic species account for 11.9% of our list, including one ray *(Mobula tarapacana*) and 13 sharks. The near threatened species are *Carcharhinus galapagensis*, *C. limbatus, C. brachyurus, C. leucas* and *Galeocerdo cuvier,* the vulnerable species are *M. tarapacana* and *Carcharhinus falciformis*, and the endangered species are *Sphyrna mokarran* and *S. lewini.* The population trends are unknown for 71.4% of the semi-oceanic species reported.

4.2 Major Fishing Targets and Shared Stocks

Ten species from our list—nine fishes and one squid—were found among the major targets for marine fisheries between 1950 and 2010 (Table 15.1), according to catch reconstructions for Ecuador (Alava et al. 2016; Schiller et al. 2016) and Peru (Mendo and Claudia 2016). In five of these cases, Ecuador and Peru exploited the same stocks. Nowadays, Jumbo flying squid and Pacific sardine are marginal fisheries in Ecuador, while Chilean jack mackerel is developing (Pablo Guerrero, personal communication).

The most important shared stocks are currently those of tropical tunas (*Thunnus obesus*, *T. albacares,* and *Katsuwonus pelamis*), Chilean jack mackerel (*Trachurus murphiyi*), and dolphinfish (*Coryphaena hippurus*; Pablo Guerrero, personal communication). Ecuador and Peru seek to coordinate research and management measures for these stocks through different mechanisms. Tropical tunas and dolphinfish are managed through the Inter-American Tropical Tuna Commission (IATTC), while Chilean Jack mackerel is managed through the South Pacific Regional Fisheries Management Organization (SP-RFMO).

Table 15.1 Major species in catch reconstructions from 1950 to 2010, present in Ecuador and Peru

Species	EEZs where the species was a main target[a]			IUCN category[b]	Shared stocks[c]
	Peru	Continental Ecuador	Galapagos		
1. Jumbo flying squid *Dosidicus gigas*	x		x	DD	x
2. Blue shark *Prionace glauca*			x	NT	
3. Anchoveta *Engraulis ringens*	x			LC	
4. Pacific sardine *Sardinops sagax*	x	x		LC	
5. Peruvian hake *Merluccius gayi* peruanusi	x			DD	x
6. Chilean jack mackerel *Trachurus murphyi*	x			DD	x
7. Pacific thread herring *Opisthonema libertate*		x		LC	
8. Chub mackerel *Scomber japonicas*		x		LC	
9. Skipjack tuna *Katsuwonus pelamis*				LC	x
10. Bigeye tuna *Thunnus obesus*			x	VU	x

[a]Pauly and Zeller (2016)
[b]IUCN (2019): *DD* data deficient, *LC* least concern, *VU* vulnerable, *NT* near threatened
[c]El Telégrafo (2019); Pablo Guerrero, personal communication)

5 Economic and Societal Value of Fishery in Ecuador and Peru

Ecuador and Peru are among the top 25 nations in the world for landed value of fish and fisheries products (FAO 2016b). They are located in the FAO major fishing area 87 (Pacific, SE) where the percentage of overfished stocks is estimated at 41%, and the rate of IUU fishing at 19% (Cawthorn et al. 2018). During 2014, Ecuador contributed with 0.8% of the total global marine captures, while Peru represented 4.4% in total, and 1.5% excluding anchoveta. Peru is around three times larger than Ecuador in area, coastline length and population size, and marine fishing catches in Peru are around one order of magnitude higher to those of Ecuador (Table 15.2). Fishing has been an essential subsistence activity for local coastal populations in this region since pre-Columbian times (see Béarez et al. 2012).

Industrial fisheries are key economic sectors in Ecuador and Peru. Ecuador is the highest tuna producer in the Eastern Pacific Ocean (EPO). The port of Manta takes the largest amount of tuna landed by the industrial purse seine fleet in the EPO (Martínez-Ortiz et al. 2015). Ecuador exports 80% of its industrial fisheries products, mainly to Europe, the United States, China, Japan, Colombia, and Mexico (Ecuador Pesquero 2017). Likewise, Peru has the world's biggest single-species industrial

Table 15.2 Comparative summary of marine fisheries statistics from Ecuador and Peru

Characteristics of marine fisheries	Ecuador	Peru
Coastal geography		
Latitudinal range	01° 24′ N–03° 25′ S[a]	03° 25′ S–18° 21′ S
Coastline length	>1200 km (exc. Galapagos)[b]	3080 km[i]
Oceanic surface	270,670 km^2 [b]	1,100,000 km^2 [i]
Inshore Fishing Area (IFA)	27,202 km^2 [o]	71,057 km^2 [o]
National population	17,317,049 in 2019 [c]	31,237,385 in 2017 [j]
Proportion of the population living in the coast	52% in 2010 [c]	43% in 2007 [k]
Economic value of fisheries		
Marine capture production in 2016 (tones)	715,357 [e]	3,774,887 (total) 919,847 (excluding anchoveta) [e]
Variation from 2015 to 2016 (tones)	72,181 [e]	–1,011,664 (total) –96,784 (excluding anchoveta) [e]
Fleet size *Industrial fisheries*		
Number of designated ports for implementation of FAO Agreement on IUU	2 (Manta, Guayaquil)[f]	7 (Piura, Chimbote, Trujillo, Ica, Moquegua, Arequipa, Lima)[f]
Number of vessels	698[g]	1071[m]
Number of direct jobs	24,000[d]	232,357[k]
Artisanal/small-scale fisheries		
Number of landing sites	243[h]	116[m]
Number of fishing boats (plus >10 000 units not registered in each country)	45,793 in 2013[a]	17,920 in 2015[i]
Number of fishermen	ca. 80,000[h]	ca. 70,000[i]
Fishmeal production		
Number of plants	31[d]	>8000[n]
Number of jobs	950 formal 121 informal[d]	>12,000[k]
Domestic consumption		
Apparent fish consumption per capita 2013–2015	5–10 kg $year^{-1}$ [e]	10–20 kg [e]

[a]Martínez-Ortiz et al. (2015)
[b]Inocar (2012)
[c]INEC (2010)
[d]SCI (2020)
[e]FAO (2018)
[f]SPRFMO (2018)
[g]Ayala Villa (2017)
[h]Alava et al. (2015)
[i]Guevara-Carrasco and Bertrand (2017)
[j]INEI (2019)
[k]Christensen et al. 2014
[l]INEI (2014)
[m]INEI-PRODUCE (2013)
[n]Grillo et al. (2018)
[o]Zeller et al. (2015)

fishery of anchoveta *Engraulis ringens* for the production of fishmeal (Christensen et al. 2014). Industrial purse seine fisheries targeting anchoveta contribute to up to 30% of the GDP generated by the fishery sector in Peru.

Fishmeal production is another activity the two nations have in common. Peru is the largest fishmeal producer in the world (FAO 2014; Grillo et al. 2018) and Ecuador is currently ranked 13th for this commodity (Index Mundi 2019). Fishmeal production is principally related with industrial fishing as most fishmeal comes from small-pelagic species and fish residues from the industrial sector. Yet there are reports of fishmeal-processing facilities lacking official registry and buying prime materials from IUU fishing activities to cover market demands. This way, illegal fishmeal infiltrates processing and trade chains of balanced meal in Peru and Ecuador (Grillo et al. 2018). Furthermore, some of it is then transported from Peru to Ecuador to satisfy shrimp farms' high demand for preparing animal feed. Poor traceability of fishmeal represents a competitive disadvantage for both countries in international markets (Cawthorn et al. 2018; Trujillo 2017).

Artisanal and small-scale fisheries represent the main source of fish for local and national markets in Ecuador and Peru, but have long been overlooked in national policies (Arellano and Swartzman 2010; MAE 2010).

In Peru, fish represents 26% of the animal protein in domestic human consumption (Béné 2006)—among the highest in the world—and small-scale fisheries provide four times more employment than the industrial sector (Alvarez 2003). Additionally, artisanal purse seine, squid boats (and other artisanal subsectors including mariculture) contribute with more than 60% of the fisheries' GDP, and generate more than 75% of the total employment (Christensen et al. 2014). Such statistics are unclear in Ecuador because the artisanal fishing sector has been poorly monitored and managed, particularly in continental waters (Alava et al. 2016; Barragán and Lazo 2018).

Management measures for artisanal fisheries are different in each country. In Ecuador, artisanal fishing has an exclusive zone of up to 8 nm from the coastline, while in Peru this is up to 5 nm. Artisanal fishing often occurs beyond that limit and even outside the EEZ's boundaries, either to target oceanic species (e.g., dolphinfish, tuna, billfish, sharks), or because other target species are becoming more scarce in near shore areas (Guevara-Carrasco and Bertrand 2017; Martínez-Ortiz et al. 2015). The multi-gear, multi-species nature of these fisheries further complicates their monitoring and regulation. Moreover, artisanal fishers tend to rotate efforts among fishing grounds and chase migrating fish (i.e., ontogenetically, seasonally, or on the search for food), resulting in longitudinal and latitudinal displacements. This becomes particularly problematic for communities located close to the bi-national frontier, because fishers become illegal as soon as they cross the invisible political boundary. This has created conflicts between local authorities and communities in both countries, yet fishers have organized bi-national meetings on either side of the border to address this situation.

6 Antecedents of Bi-national Cooperation Between Ecuador and Peru

As noted in Sect. 1, Ecuador and Peru have a common history of cooperation in marine affairs, despite the territorial conflicts that occurred during the twentieth century. They are partners alongside Colombia and Chile in the Permanent Commission of the Southeast Pacific (CPPS), established in 1952 (Barragán and Lazo 2018). In 1989, scientists from the CPPS countries participated in a workshop to analyze the biological effects of ENSO in the region and identified an "alarming" lack of knowledge exchange among fisheries researchers (IOC 1989). In 2010, the CPPS developed the Regional Action Plan for the conservation of sharks, rays, and chimeras, which allowed these countries to aim for common goals. As it is common with other regional plans, adequate operationalization has been one of the main issues to tackle.

International organizations for fisheries management (e.g. SP-RFMO, IATTC) have allowed a better coordination of actions and policies between Ecuador and Peru. Despite these regional organizations involving several parties, Ecuador and Peru have worked more closely to establish common strategies for the most important shared stocks. The clearest example is that of dolphinfish fisheries management which has been addressed within the IATTC since proposed by Ecuador in 2012. Dolphinfish is highly relevant for Ecuador and Peru because together they produce around 90% of the catches from the Eastern Pacific (Pablo Guerrero, personal communication). Similarly, Ecuador posed another request in the 2019 SP-RFMO meeting, asking Peru to approve an increase in the fishing quota over the Chilean jack mackerel stock. This request was supported by other parties in the organization (El Telégrafo 2019).

In 2014, Ecuador and Peru signed an agreement toward bi-national management of protected areas, followed by meetings, projects, and a common fund (Plan Binacional Peru-Ecuador 2018). Then the National Institute of Fisheries in Ecuador (INP, renamed in 2020 as the Public Institute of Fisheries and Aquaculture Research IPIAP) and the Institute of the Sea of Peru (IMARPE) started working on a joint model of stock assessment for dolphinfish. The same year, hundreds of fishers from both countries gathered for the I Binational Congress for Responsible Artisanal Fisheries, in Lobitos (Piura, Peru). A second congress took place in Huaquillas (El Oro, Ecuador) in 2015. Since then, further initiatives have been working toward a bi-national strategy for responsible fisheries—although this is still unofficial. The growing number of cooperation initiatives between both countries, and the fact that they are coming from "top-down" and from "bottom-up," makes this a particularly important time for developing and formalizing this strategy between the two countries. More bi-national agreements have been recently signed in the same direction (El Universo 2019).

A very relevant and important agreement has to do with the launch in 2017 of a 5-year project led by the UN's Development Fund (UNDP), in collaboration with the NGOs Conservation International (CI) and the Worldwide Fund for Nature (WWF).

The project is part of FAO's Coastal Fisheries Initiative Latin America (CFI-LA), which is funded by the Global Environment Facility (GEF) as "a global effort to preserve marine resources and ensure that coastal fisheries can continue to play their crucial role in society, contributing to food security, as well as economic and social development." It focuses on the following main areas: (1) ecosystem-based, collaborative fisheries management and governance of the following fisheries: mahi-mahi, hake, shrimps, mangrove crabs and cockles, and pole and line tuna; (2) marine spatial planning in the Bay of Sechura in Peru and the Gulf of Guayaquil in Ecuador; and (3) sharing knowledge to develop more holistic processes and integrated approaches to coastal fisheries management. It is worth noting that even when this CFI project includes both countries, each working group is independently managing and developing their tasks toward their particular targets, which might break the whole meaning of bi-national collaboration. At present, the project is yet to produce its final result, so it is not clear if an internal collaboration between countries will arise in the end.

7 Challenges and Needs for Trans-boundary Collaboration Towards Sustainable Fisheries Management

In this chapter, different aspects common to Ecuador and Peru in relation to their coastal and marine resources have been described. Special focus has been given to fishery resources due to their essential role in economic and social development, at the local and national levels. The fishing sectors of both countries demand attention and support from different segments of society in order to enhance their transformation into sustainable systems, capable of adapting to global change and thriving over crisis.

Sustainability is a continuous process that allows the use of a resource without compromising its availability for future generations (Hilborn et al. 2015). In particular, seafood sustainability requires understanding how people affect and respond to ecosystem processes—in other words, understanding fisheries as social-ecological systems that emerge from resource use. The basic elements for sustainable management are: (a) specific objectives and targets for fishing pressure and abundance, (b) monitoring of fishing pressure and abundance, (c) assessments to determine if targets are being met, (d) feedback management systems that adjust regulations in response to the assessments and in particular restrict fishing pressure when it is too high, and (e) enforcement systems to assure compliance with regulations (Hilborn et al. 2015). According to our review, regional organizations (e.g., CIAT) offer a platform for the application of those elements to trans-boundary fisheries management between Ecuador and Peru (Sect. 6)—but equivalent spaces are still needed to address the transformation of small-scale fisheries.

Transformation of fisheries' socio-ecosystems toward sustainability requires action in three equally relevant dimensions: environmental protection, social development, and economic growth (Hilborn et al. 2015). The main challenges faced by Ecuador and Peru in these areas are also those of many developing countries: prevent overfishing, preserve mangrove ecosystems, combat IUU fishing, increase seafood traceability, strengthen fishing associations, visualize women's participation, protect environmental services, among others. In addition, climate change is a transversal component because it is fundamental to know the impact of this global threat on fishing target species, ecosystems and coastal communities. Given the similarities between Ecuador and Peru and the resources they have in common, we argue that some challenges could be better addressed by means of official bi-national cooperation, while others could benefit from academic cooperation and knowledge exchange among stakeholders from both countries. A detailed classification and association of challenges, needs, and prospective collaborators is presented in Fig. 15.3.

Challenges around economic growth in the fishing sector (Fig. 15.3) involve the transformation of value chains into more inclusive and competitive ones. Progress in this aspect can be reached through reduced bycatch rates and increased seafood traceability, which in turn, allow access to markets with strict sustainability standards. Such a goal can be supported by the application of emergent methods and technologies like molecular tools for assessing fishery activity and fish traceability along the value chain. On the other hand, inclusiveness implies recognizing the importance of women and their role within the value chain of marine resources, which can be promoted through bi-national studies and workshops similar to those conducted by fishing associations in recent years (Sect. 6). The situation around illegal fishmeal production and its commercialization (Sect. 5) represents a clear opportunity for both countries to join efforts in solving a common problem.

In terms of social development (Fig. 15.3), there are challenges related with social organization and equal access to basic rights, and challenges related with effective stocks management. Empowering women and fishing associations is necessary to support the rights of local communities and their participation during decision-making processes. Governments can foster such processes by facilitating the exchange of experiences among organizations from the region in the context of bi-national workshops and assist organizations with capacity building in governance. Moreover, bi-national cooperation is essential for the definition of science-based management measures for shared stocks of migratory species, which currently differ from country to country (e.g., dolphinfish ban periods, minimum and maximum catch size, regulations on elasmobranchs and sailfishes). This implies collaboration in fisheries research, agreement on common management measures, and coordination of enforcement procedures.

General challenges in the environmental protection component are related to the prevention of habitat degradation and regulation of resource use. Habitat degradation through direct (e.g., mangrove deforestation) and indirect (e.g., upstream contamination) impacts affects seafood quality and safety. Indeed, water quality assessments are urgent in the border zone as reported concentrations of heavy metals in seafood samples have been above safety levels for human consumption across the Gulf of Guayaquil in Ecuador (Navarrete-Forero et al. 2019). Similar situations potentially

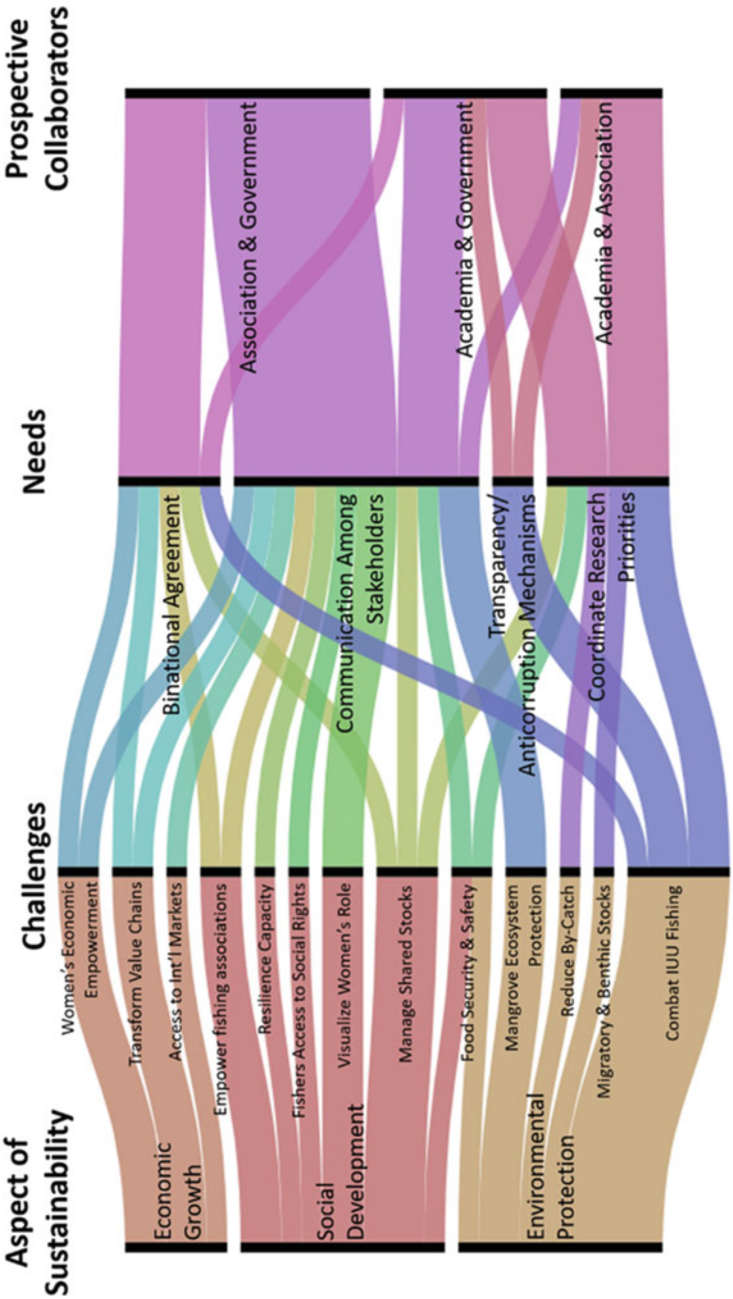


Fig. 15.3 Multi-category alluvial diagram illustrating three primary Aspects of Sustainability and the associated challenges and needs to reach a more sustainable fisheries sector. Prospective collaborators are indicated to meet the challenges and needs for sustainability. Diagram generated in RAWGraphs (Mauri et al. 2017)

occur on the Peruvian side due to widespread gold mining activities in the Andean region. In addition, our analysis of IUCN threat categories (Sect. 4) shows significant knowledge gaps for certain ecological groups, particularly among benthic species that are the basis for livelihoods in mangrove ecosystems. In this context, scientific cooperation is needed in order to assess populations in their natural distribution and not as separate entities based on a political boundary.

Another field for scientific collaboration included in the environmental protection component is the fight against IUU fishing. The multiple effects of IUU fishing on the ecosystem, society and economy justify its consideration as a target for bi-national cooperation. This requires basic scientific research about population genetics, but also applied research to develop tools for enforcement procedures and increase transparency in their application.

Perhaps the greatest challenge in this context is to develop governability across scales in the fishery sector, which would allow the effective implementation of sustainable management strategies. Bi-national agreements are valuable for addressing the biggest challenges such as the fight against IUU fishing, which need coordination among multiple institutions and stakeholders. However, no strategy can be effectively applied without local governance and resource users' compliance. Therefore, different sectors of society should join the task and support small-scale fishing associations in their empowerment processes. We consider that while a legal framework for bi-national cooperation at the national government level is necessary (Nikanorova and Egorov 2019), it is also possible to establish cooperation through interdisciplinary research networks between both countries, and even from countries where the fishery products are consumed. This sort of bottom-up pressure can encourage further collaboration at higher levels of governance or at regional platforms, and its influence in the transformation of fisheries socio-ecosystems should not be underestimated.

Acknowledgments We thank participants and co-organizers of the Fulbright-sponsored workshop "Leveraging actionable science to aid policy decisions to combat illegal, unreported and unregulated fishing across the Pacific" held in Guayaquil in July 2017, where this contribution was conceived. In particular, Luis Domínguez Granda (*Centro del Agua y Desarrollo Sustentable CADS-ESPOL*), Giovanna Sotil Caycho and Deivis Cueva (IMARPE), Angie Mera and Julio Bonilla (ESPOL), Jose Luis Pacheco (INP) and Boris Ayala (*Secretaria de Recursos Pesqueros*). DAW thanks M. Joaquin for logistical support during the workshop, as well as U.S. Fulbright Global Scholar Program and LMU's Seaver College of Science and Engineering for their supporting grants. Thanks to Mireya Pozo-Cajas (*Universidad de Guayaquil*) for commenting on the historical development section, and Pablo Guerrero (WWF Ecuador) for providing context information about shared stocks. AdSE thanks the Peruvian association REDES-SP, Wilmer Huamán and Mariano Valverde for information and discussion on bi-national collaboration initiatives.

Appendix

List of fisheries target species distributed across the maritime border between Ecuador and Peru

N	Family	Species	Marine zone	Habitat	Latitudinal range	Threat category[a]	Population trend[a]	Reference
Mollusca								
1	Arcidae	*Anadara tuberculosa*	Coastal	Benthic	32°N–04°S	NA	Unknown	(IMARPE 2009; INP 2010b; Palomares and Pauly 2019)
2	Pteriidae	*Pteria sterna*	Coastal	Benthic	32°N–05°S	NA	Unknown	(INP 2010b; Ordinola et al. 2010; Palomares and Pauly 2019).
3	Ostreidae	*Striostrea prismatica*	Coastal	Benthic	32°N–04°30′S	NA	Unknown	(IMARPE 2009; Palomares and Pauly 2019; Roskov et al. 2019)
4	Ommastrephidae	*Dosidicus gigas*	Oceanic	Pelagic	50°N–30°S	DD	Unknown	(INP 2010b)
5	Octopodinae	*Octopus mimus*	Coastal	Benthic	02°S–33°S	NA	Unknown	(INP 2010b; Palomares and Pauly 2019)
6	Octopodinae	*Octopus oculifer*	Coastal	Benthic	Galapagos	NA	Unknown	(Palomares and Pauly 2019)
Crustacea								
7	Penaeidae	*Farfantepenaeus brevirostris*	Coastal	Demersal	32°N–06°S	NA	Unknown	(IMARPE 2009; INP 2010a)
8	Penaeidae	*Farfantepenaeus californiensis*	Coastal	Demersal	32°N–06°S	NA	Unknown	(IMARPE 2009; INP 2010a)
9	Penaeidae	*Litopenaeus occidentalis*	Coastal	Demersal	32°N–06°S	NA	Unknown	(IMARPE 2009; INP 2010a)
10	Penaeidae	*Litopenaeus stylirostris*	Coastal	Demersal	32°N–06°S	NA	Unknown	(Herrera et al. 2013; IMARPE 2009)
11	Penaeidae	*Litopenaeus vannamei*	Coastal	Demersal	32°N–06°S	NA	Unknown	(Herrera et al. 2013; IMARPE 2009)
12	Palinuridae	*Panulirus gracilis*	Coastal	Benthic	32°N–06°S	DD	Unknown	(Chirichigno 1970; IMARPE 2009; INP 2010a)
13	Penaeidae	*Protrachypene precipua*	Coastal	Benthic	15°N–04°S	NA	Unknown	(INP 2010a; Palomares and Pauly 2019)

14	Penaeidae	*Trachypenaeus byrdi*	Coastal	Demersal	26°N–06°S	NA	Unknown	(Herrera et al. 2013; Palomares and Pauly 2019)
15	Penaeidae	*Xiphopenaeus riveti*	Coastal	Benthic	32°N–18°S	NA	Unknown	(Herrera et al. 2013; Palomares and Pauly 2019)
16	Calappidae	*Calappa convexa*	Coastal	Benthic	32°N–18°S	NA	Unknown	(INP 2010a; Palomares and Pauly 2019)
17	Portunidae	*Callinectes arcuatus*	Coastal	Benthic	34°N–20°S	NA	Unknown	(Herrera et al. 2013; Palomares and Pauly 2019)
18	Portunidae	*Callinectes toxotes*	Coastal	Demersal	24°N–04°S	NA	Unknown	(Herrera et al. 2013; Palomares and Pauly 2019)
19	Portunidae	*Euphylax robustus*	Coastal	Benthic	32°N–18°S	NA	Unknown	(INP 2010a; Palomares and Pauly 2019)
20	Scyllaridae	*Evibacus princeps*	Coastal	Benthic	32°N–05°S	LC	Unknown	(INP 2010a; Palomares and Pauly 2019)
21	Menippidae	*Menippes frontalis*	Coastal	Benthic	32°N–18°S	NA	Unknown	(INP 2010a; Palomares and Pauly 2019)
22	Ocypodidae	*Ucides occidentalis*	Coastal	Benthic	32°N–04°S	NA	Unknown	(Herrera et al. 2013; IMARPE 2009)
Fishes (Chondrichthyes)								
23	Carcharhinidae	*Carcharhinus altimus*	Semi-oceanic	Pelagic	35°N–07°S	DD	Unknown	(Froese and Pauly 2019)
24	Carcharhinidae	*Carcharhinus brachyurus*	Semi-oceanic	Pelagic	35°N–09°S	NT	Unknown	(Froese and Pauly 2019)
25	Carcharhinidae	*Carcharhinus falciformis*	Semi-oceanic	Pelagic	40°N–40°S	VU	Decreasing	(Froese and Pauly 2019; Herrera et al. 2013)
26	Carcharhinidae	*Carcharhinus galapagensis*	Semi-oceanic	Pelagic	35°N–40°S	NT	Unknown	(Froese and Pauly 2019)
27	Carcharhinidae	*Carcharhinus leucas*	Semi-oceanic	Pelagic	40°N–40°S	NT	Unknown	(Froese and Pauly 2019; Herrera et al. 2013)
28	Carcharhinidae	*Carcharhinus limbatus*	Semi-oceanic	Pelagic	40°N–40°S	NT	Unknown	(Froese and Pauly 2019)
29	Carcharhinidae	*Carcharhinus longimanus*	Oceanic	Pelagic	46°N–43°S	VU	Decreasing	(Froese and Pauly 2019)

(continued)

N	Family	Species	Marine zone	Habitat	Latitudinal range	Threat category[a]	Population trend[a]	Reference
30	Carcharhinidae	*Carcharhinus porosus*	Semi-oceanic	Pelagic	35ºN–09ºS	DD	Unknown	(Froese and Pauly 2019)
31	Carcharhinidae	*Galeocerdo cuvier*	Semi-oceanic	Pelagic	40ºN–10ºS	NT	Unknown	(Froese and Pauly 2019; Herrera et al. 2013)
32	Carcharhinidae	*Nasolamia velox*	Semi-oceanic	Pelagic	35ºN–04ºS	DD	Unknown	(Froese and Pauly 2019; Herrera et al. 2013)
33	Carcharhinidae	*Prionace glauca*	Oceanic	Pelagic	71ºN–55ºS	NT	Unknown	(Froese and Pauly 2019; Herrera et al. 2013)
34	Carcharhinidae	*Rhizoprionodon longurio*	Semi-oceanic	Pelagic	36ºN–06ºS	DD	Unknown	(Froese and Pauly 2019; Herrera et al. 2013)
35	Rhincodontidae	*Rhincodon typus*	Oceanic	Pelagic	55ºN–48ºS	EN	Decreasing	(Froese and Pauly 2019)
36	Alopiidae	*Alopias pelagicus*	Oceanic	Pelagic	01ºN–13ºS	VU	Decreasing	(Froese and Pauly 2019; Herrera et al. 2013)
37	Alopiidae	*Alopias superciliosus*	Oceanic	Pelagic	35ºN–25ºS	VU	Decreasing	(Froese and Pauly 2019; Herrera et al. 2013)
38	Alopiidae	*Alopias vulpinus*	Oceanic	Pelagic	60ºN–50ºS	VU	Decreasing	(Froese and Pauly 2019; Herrera et al. 2013)
39	Lamnidae	*Isurus oxyrinchus*	Oceanic	Pelagic	61ºN–56ºS	EN	Decreasing	(Froese and Pauly 2019; Herrera et al. 2013)
40	Triakidae	*Galeorhinus galeus*	Coastal	Demersal	70ºN–58ºS	VU	Decreasing	(Froese and Pauly 2019)
41	Triakidae	*Mustelus dorsalis*	Coastal	Demersal	20ºS–04ºS	DD	Unknown	(Froese and Pauly 2019)
42	Triakidae	*Mustelus mento*	Coastal	Demersal	01ºN–55ºS	NT	Decreasing	(Froese and Pauly 2019)
43	Triakidae	*Mustelus whitneyi*	Coastal	Demersal	01ºN–45ºS	VU	Decreasing	(Froese and Pauly 2019)
44	Triakidae	*Triakis maculata*	Coastal	Demersal	01ºN–30ºS	VU	Decreasing	(Froese and Pauly 2019)
45	Sphyrnidae	*Sphyrna lewini*	Semi-oceanic	Pelagic	46ºN–31ºS	EN	Unknown	(Froese and Pauly 2019; Herrera et al. 2013)
46	Sphyrnidae	*Sphyrna mokarran*	Semi-oceanic	Pelagic	45ºN–37ºS	EN	Decreasing	(Froese and Pauly 2019)
47	Sphyrnidae	*Sphyrna tiburo*	Semi-oceanic	Pelagic	25ºN–05ºS	LC	Stable	(Froese and Pauly 2019; Herrera et al. 2013)

48	Sphyrnidae	*Sphyrna zygaena*	Oceanic	Pelagic	59ºN–55ºS	VU	Decreasing	(Froese and Pauly 2019; Herrera et al. 2013)
49	Squatinidae	*Squatina californica*	Coastal	Demersal	50ºN–50ºS	NT	Decreasing	(Froese and Pauly 2019; Herrera et al. 2013)
50	Rhinobatidae	*Rhinobatos glaucostigma*	Coastal	Demersal	28ºN–4ºS	DD	Unknown	(Froese and Pauly 2019)
51	Rhinobatidae	*Rhinobatos leucorhynchus*	Coastal	Demersal	22ºN–4ºS	NT	Unknown	(Froese and Pauly 2019; Herrera et al. 2013)
52	Rhinobatidae	*Rhinobatos planiceps*	Coastal	Demersal	16ºN–20ºS	DD	Unknown	(Froese and Pauly 2019; Herrera et al. 2013)
53	Rhinobatidae	*Zapteryx exasperata*	Coastal	Demersal	35ºN–18ºS	DD	Unknown	(Froese and Pauly 2019)
54	Rajidae	*Raja velezi*	Coastal	Demersal	32ºN–20ºS	DD	Unknown	(Froese and Pauly 2019; Herrera et al. 2013)
55	Urolophidae	*Urotrygon aspidura*	Coastal	Demersal	32ºN–18ºS	DD	Unknown	(Froese and Pauly 2019)
56	Dasyatidae	*Dasyatis brevis*	Coastal	Demersal	42ºN–19ºS	DD	Unknown	(Froese and Pauly 2019)
57	Dasyatidae	*Hypanus longus*	Coastal	Demersal	26ºN–3ºS	DD	Unknown	(Froese and Pauly 2019)
58	Dasyatidae	*Hypanus dipterurus*	Coastal	Demersal	42ºN–25ºS	DD	Unknown	(Froese and Pauly 2019)
59	Mobulidae	*Manta birostris*	Oceanic	Pelagic	32ºN–09ºS	VU	Decreasing	(Froese and Pauly 2019)
60	Mobulidae	*Mobula mobular*	Oceanic	Pelagic	40ºN–30ºS	EN	Decreasing	(Froese and Pauly 2019)
61	Mobulidae	*Mobula munkiana*	Oceanic	Pelagic	30ºN–23ºS	NT	Unknown	(Froese and Pauly 2019)
62	Mobulidae	*Mobula tarapacana*	Semi-oceanic	Pelagic	32ºN–23ºS	VU	Decreasing	(Froese and Pauly 2019)
63	Mobulidae	*Mobula thurstoni*	Oceanic	Pelagic	38ºN–34ºS	NT	Decreasing	(Froese and Pauly 2019)
64	Myliobatidae	*Myliobatis longirostris*	Coastal	Demersal	32ºN–6ºS	NT	Unknown	(Froese and Pauly 2019; Herrera et al. 2013)
65	Myliobatidae	*Myliobatis peruvianus*	Coastal	Demersal	0º–35ºS	DD	Unknown	(Froese and Pauly 2019)

(continued)

N	Family	Species	Marine zone	Habitat	Latitudinal range	Threat category[a]	Population trend[a]	Reference
Fishes (Actinopterygii)								
66	Ophichthidae	*Ophichthus remiger*	Coastal	Demersal	13°N–30°S	LC	Unknown	(Froese and Pauly 2019)
67	Engraulidae	*Anchoa nasus*	Coastal	Pelagic	31°N–14°S	LC	Unknown	(Chirichigno and Cornejo 2001; Froese and Pauly 2019; IMARPE 2009; STRI 2016)
68	Engraulidae	*Cetengraulis mysticetus*	Coastal	Pelagic	32°N–06°S	LC	Stable	(Chirichigno and Cornejo 2001; Froese and Pauly 2019; IMARPE 2009; STRI 2016)
69	Engraulidae	*Engraulis ringens*	Coastal	Pelagic	00°–37°S	LC	Unknown	(Chirichigno and Cornejo 2001; Froese and Pauly 2019; IMARPE 2009; STRI 2016)
70	Clupeidae	*Opisthonema bulleri*	Coastal	Pelagic	25°N–05°S	LC	Stable	(Froese and Pauly 2019)
71	Clupeidae	*Opisthonema libertate*	Coastal	Pelagic	32°N–04°S	LC	stable	(Chirichigno and Cornejo 2001; Froese and Pauly 2019; IMARPE 2009; STRI 2016)
72	Merlucciidae	*Merluccius gayi peruanus*	Coastal	Demersal	01°N–14°S	DD	Unknown	(Froese and Pauly 2019)
73	Ophidiidae	*Lepophidium negropinna*	Coastal	Demersal	32°N–07°S	LC	Unknown	(Froese and Pauly 2019)
74	Mugilidae	*Mugil cephalus*	Coastal	Demersal	62°N–57°S	LC	Stable	(Froese and Pauly 2019)
75	Scorpaenidae	*Pontinus sierra*	Coastal	Demersal	25°N–06°S	LC	Unknown	(Chirichigno and Cornejo 2001; Froese and Pauly 2019; IMARPE 2009; STRI 2016)
76	Triglidae	*Prionotus stephanophrys*	Coastal	Demersal	32°N–20°S	LC	Unknown	(Froese and Pauly 2019; IMARPE 2009)
77	Centropomidae	*Centropomus nigrescens*	Coastal	Demersal	33°N–20°S	LC	Unknown	(Froese and Pauly 2019),
78	Serranidae	*Acanthistius pictus*	Coastal	Demersal	20°N–26°S	LC	Unknown	(Chirichigno and Cornejo 2001; Froese and Pauly 2019; IMARPE 2009; STRI 2016)

79	Serranidae	*Diplectrum conceptione*	Coastal	Demersal	01°N–37°S	LC	Unknown	(Chirichigno and Cornejo 2001; Froese and Pauly 2019; IMARPE 2009; STRI 2016)
80	Serranidae	*Diplectrum euryplectrum*	Coastal	Demersal	32°N–06°S	LC	Unknown	(Chirichigno and Cornejo 2001; Froese and Pauly 2019; IMARPE 2009; STRI 2016)
81	Serranidae	*Diplectrum maximum*	Coastal	Demersal	35°N–06°S	LC	Unknown	(Chirichigno and Cornejo 2001; Froese and Pauly 2019; IMARPE 2009; STRI 2016)
82	Serranidae	*Epinephelus analogus*	Coastal	Demersal	32°N–10°S	LC	Stable	(Froese and Pauly 2019)
83	Serranidae	*Epinephelus cifuentesi*	Coastal	Demersal	10°N–4°S	LC	Unknown	(Froese and Pauly 2019)
84	Serranidae	*Epinephelus labriformis*	Coastal	Demersal	31°N–10°S	LC	Stable	(Froese and Pauly 2019)
85	Serranidae	*Epinephelus quinquefasciatus*	Coastal	Demersal	32°N–18°S	DD	decreasing	(Froese and Pauly 2019)
86	Serranidae	*Hemilutjanus macrophthalmos*	Coastal	Demersal	02°N–54°S	DD	Unknown	(Froese and Pauly 2019)
87	Serranidae	*Hyporthodus acanthistius*	Coastal	Demersal	33°N–10°S	LC	Unknown	(Froese and Pauly 2019)
88	Serranidae	*Hyporthodus niphobles*	Coastal	Demersal	33°N–9°S	LC	Unknown	(Froese and Pauly 2019)
89	Serranidae	*Mycteroperca xenarcha*	Coastal	Demersal	32°N–9°S	LC	Unknown	(FaPe-UNALM 2018)
90	Serranidae	*Paralabrax humeralis*	Coastal	Demersal	06°N–30°S	DD	Unknown	(Chirichigno and Cornejo 2001; Froese and Pauly 2019; IMARPE 2009; STRI 2016)
91	Malacanthidae	*Caulolatilus affinis*	Coastal	Demersal	33°N–18°S	LC	Stable	(Froese and Pauly 2019; IMARPE 2009)
92	Malacanthidae	*Caulolatilus princeps*	Coastal	Demersal	50°N–18°S	LC	Unknown	(Froese and Pauly 2019; IMARPE 2009)
93	Coryphaenidae	*Coryphaena hippurus*	Oceanic	Pelagic	47°N–38°S	LC	Stable	(Froese and Pauly 2019)

(continued)

N	Family	Species	Marine zone	Habitat	Latitudinal range	Threat category[a]	Population trend[a]	Reference
94	Carangidae	*Chloroscombrus orqueta*	Coastal	Demersal	33°N–18°S	LC	Unknown	(Chirichigno and Cornejo 2001; Froese and Pauly 2019; IMARPE 2009; STRI 2016)
95	Carangidae	*Decapterus macrosoma*	Coastal	Demersal	39°N–34°S	LC	Unknown	(Chirichigno and Cornejo 2001; Froese and Pauly 2019; IMARPE 2009; STRI 2016)
96	Carangidae	*Selene peruviana*	Coastal	Demersal	32°N–14°S	LC	Unknown	(Chirichigno and Cornejo 2001; Froese and Pauly 2019; IMARPE 2009; STRI 2016)
97	Carangidae	*Trachinotus paitensis*	Coastal	Demersal	32°N–18°S	LC	Unknown	(Froese and Pauly 2019)
98	Carangidae	*Trachurus murphyi*	Oceanic	Pelagic	02°N–52°S	DD	Unknown	(Chirichigno and Cornejo 2001; Froese and Pauly 2019; IMARPE 2009; STRI 2016)
99	Sciaenidae	*Cynoscion analis*	Coastal	Demersal	2.5°N–30°S	LC	Unknown	(IMARPE 2009)
100	Sciaenidae	*Paralonchurus peruanus*	Coastal	Demersal	09°N–20°S	LC	Unknown	(Froese and Pauly 2019; IMARPE 2009)
101	Sphyraenidae	*Sphyraena ensis*	Coastal	Pelagic	31°N–09°20′S	LC	Unknown	(Chirichigno and Cornejo 2001; IMARPE 2009)
102	Scombridae	*Acanthocybium solandri*	Oceanic	Pelagic	46°N–37°S	LC	Stable	(Froese and Pauly 2019)
103	Scombridae	*Auxis rochei*	Coastal	Pelagic	61°N–51°S	LC	Stable	(Froese and Pauly 2019)
104	Scombridae	*Katsuwonus pelamis*	Oceanic	Pelagic	63°N–47°S	LC	Stable	(Froese and Pauly 2019)
105	Scombridae	*Sarda chilensis*	Coastal	Pelagic	40°N–40°S	LC	Decreasing	(Froese and Pauly 2019)
106	Scombridae	*Scomber japonicus*	Coastal	Pelagic	60°N–48°S	LC	Stable	(Froese and Pauly 2019)
107	Scombridae	*Scomberomorus sierra*	Coastal	Pelagic	33°N–27°S	LC	Stable	(Froese and Pauly 2019)
108	Scombridae	*Thunnus alalunga*	Oceanic	Pelagic	59°N–46°S	NT	Decreasing	(Froese and Pauly 2019)

109	Scombridae	*Thunnus albacares*	Oceanic	Pelagic	59ºN–48ºS	NT	Decreasing	(Froese and Pauly 2019)
110	Scombridae	*Thunnus obesus*	Oceanic	Pelagic	45ºN–43ºS	VU	Decreasing	(Froese and Pauly 2019)
111	Scombridae	*Thunnus orientalis*	Oceanic	Pelagic	52ºN–50ºS	VU	Decreasing	(Froese and Pauly 2019)
112	Paralichthyidae	*Etropus ectenes*	Coastal	Demersal	08ºN–06ºS	LC	Unknown	(Froese and Pauly 2019)
113	Xiphiidae	*Xiphias gladius*	Oceanic	Pelagic	69ºN–50ºS	LC	Decreasing	(Froese and Pauly 2019)
114	Istiophoridae	*Istiompax indica*	Oceanic	Pelagic	44ºN–47ºS	DD	Unknown	(Froese and Pauly 2019)
115	Istiophoridae	*Kajikia audax*	Oceanic	Pelagic	46ºN–50ºS	NT	decreasing	(Froese and Pauly 2019)
116	Istiophoridae	*Makaira mazara*	Oceanic	Pelagic	44ºN–40ºS	NA	Unknown	(Froese and Pauly 2019)
117	Stromateidae	*Peprilus medius*	Coastal	Demersal	32ºN–13ºS	LC	Unknown	(Chirichigno and Cornejo 2001; Froese and Pauly 2019; IMARPE 2009; STRI 2016)

[a]IUCN (2019)

References

Agnew DJ, Pearce J, Pramod G, Peatman T, Watson R, Beddington JR, Pitcher TJ (2009) Estimating the worldwide extent of illegal fishing. PLoS One 4(2). https://doi.org/10.1371/journal.pone.0004570

Alava JJ, Lindop A, Jacquet J (2015) Marine Fisheries Catch Reconstructions for Continental Ecuador: 1950–2010. Fisheries Centre Working Paper #2015-34, p 25

Alava JJ, Alasdair L, Jennifer J (2016) In: Pauly D, Zeller D (eds) Ecuador. In Global atlas of marine fisheries. A critical appraisal of catches and ecosystem impacts. Island Press, Washington, p 241

Alvarez J (2003) Estudio sobre el impacto socioeconomico de la pesca artesanal en los Estados Miembros de la Comisión Permanente del Pacífico Sur. Reporte preparado para la Secretaria General-Dirección de Asuntos Económicos de la CPPS, 27

Arellano CE, Swartzman G (2010) The Peruvian artisanal fishery: Changes in patterns and distribution over time. Fish Res 101(3):133–145. https://doi.org/10.1016/j.fishres.2009.08.007

Argüelles J, Tafur R, Taipe A, Villegas P, Keyl F, Dominguez N, Salazar M (2008) Size increment of jumbo flying squid Dosidicus gigas mature females in Peruvian waters, 1989–2004. Prog Oceanogr 79(2-4):308–312

Ayala Villa B (2017) Pesca Ilegal, No Declara, No Reglamentada - Subsecretaría de Recursos Pesqueros. En El Seminario: Biotecnología Aplicada a La Lucha Contra La Pesca Ilegal, No Declarada y No Reglamentada En Los Países Del Océano Pacífico

Badjeck M-C (2008) Vulnerability of coastal fishing communities to climate variability and change: implications for fisheries livelihoods and management in Peru Universität Bremen

Barragán JM, Lazo Ó (2018) Policy progress on ICZM in Peru. Ocean Coast Manag 157:203–216

Barragán Paladines MJ (2015) Two rules for the same fish: Small-scale fisheries governance in mainland Ecuador and Galapagos Islands. In: Interactive governance for small-scale fisheries. Springer, pp 157–178

Béarez P, Gay P, Lunniss R (2012) Sea fishing at Salango (Manabí province, Ecuador) during the middle formative Machalilla phase. Latin Am Antiq 23(2):195–214

Béné C (2006) Small-scale fisheries: assessing their contribution to rural livelihoods in developing countries, vol 1008. Food and Agriculture Organization of the United Nations Rome, Italy

Borbor-Cordova MJ, Torres G, Mantilla-Saltos G, Casierra-Tomala A, Bermúdez JR, Renteria W, Bayot B (2019) Oceanography of harmful algal blooms on the ecuadorian coast (1997–2017): integrating remote sensing and biological data. Front Mar Sci 13

Bucaram S, Hearn A, Trujillo A, Rentería W, Bustamante R, Morán G, Reck G, García J (2017) Assessing fishing effects inside and outside an MPA: The impact of the Galapagos Marine Reserve on the Industrial pelagic tuna fisheries during the first decade of operation. Mar Policy 87. https://doi.org/10.1016/j.marpol.2017.10.002

Carr LA, Stier AC, Fietz K, Montero I, Gallagher AJ, Bruno JF (2013) Illegal shark fishing in the Galapagos Marine Reserve. Mar Policy 39:317–321. https://doi.org/10.1016/j.marpol.2012.12.005

Cawthorn DM, Baillie C, Mariani S (2018) Generic names and mislabeling conceal high species diversity in global fisheries markets. Conserv Lett 11(5). https://doi.org/10.1111/conl.12573

Cerutti-Pereyra F, Moity N, Dureuil M, Ramírez-González J, Reyes H, Budd K, Jarrín JM, Salinas-de-León P (2019) Artisanal longline fishing the Galapagos Islands–effects on vulnerable megafauna in a UNESCO World Heritage site. Ocean Coast Manag 183:104995

Chavez FP, Bertrand A, Guevara-Carrasco R, Soler P, Csirke J (2008) The northern Humboldt Current System: Brief history, present status and a view towards the future. Prog Oceanogr 79(2–4):95–105. https://doi.org/10.1016/j.pocean.2008.10.012

Chile Ecuador and Peru (1976) Joint declaration concerning fishing problems in the South Pacific. Signed at Santiago on 18 August 1952

Chirichigno N (1970) Lista de Crustáceos del Perú. Boletín IMARPE, Lima

Chirichigno N, Cornejo UR (2001) Catálogo comentado de los peces marinos del Perú. Publicación Especial, Callao
Christensen V, de la Puente S, Sueiro JC, Steenbeek J, Majluf P (2014) Valuing seafood: The Peruvian fisheries sector. Mar Policy 44:302–311. https://doi.org/10.1016/j.marpol.2013.09.022
Cushman GT (2003) The Lords of Guano: science and the management of Peru's marine environment, 1800-1973. The University of Texas at Austin
Defeo O, Castrejón M, Ortega L, Kuhn AM, Gutiérrez NL, Castilla JC (2013) Impacts of climate variability on Latin American small-scale fisheries. Ecol Soc 18(4)
Del Solar EA, Jorge GN, Gozzer R, Correa M (2017) Traceability of the Peruvian Mahi Mahi fishery: assessment and proposal
Dueri S, Bopp L, Maury O (2014) Projecting the impacts of climate change on skipjack tuna abundance and spatial distribution. Glob Chang Biol 20(3):742–753. https://doi.org/10.1111/gcb.12460
Ecuador Pesquero (2017) "Estadísticas." Ecuador Pesquero 83 / Noviembre-Enero. https://issuu.com/cnpecuador/docs/ecuador_pesquero_83_web
EFE (2017) Detienen En Galápagos a Un Barco Chino Con 300 Toneladas de Especies Protegidas. ABC Sociedad. https://www.abc.es/sociedad/abci-detienen-galapagos-barco-chino-300-toneladas-especies-protegidas-201708150209_noticia.html
El Comercio (2019) La Armada Del Ecuador Captura 4 Barcos Pesqueros Extranjeros Dentro de La Zona Económica Exclusiva Insular. El Comercio—Actualidad Ecuador. Retrieved 30 Aug 2019. https://www.elcomercio.com/actualidad/armada-captura-embarcaciones-pesqueras-galapagos.html
El Telégrafo (2019) Ecuador Tiene Apoyo Para Aumentar Pesca Del Jurel. February 14
El Universo (2019) Ecuador y Perú Firman Nueve Acuerdos Nuevos En El XIII Gabinete Binacional. Política, November 7
FAO (2009) Implementation of port state measures. Swan J (ed) Food and Agriculture Organization of the United Nations, Rome
FAO (2014) The state of world fisheries and aquaculture 2014—Opportunities and challenges. Food and Agriculture Organization of the United Nations
FAO (2016a) Report of the FAO workshop on implementing the agreement on port state measures to prevent, deter and eliminate illegal, unreported and unregulated fishing. Montevideo, Uruguay, 29 Sept–3 Oct 2014
FAO (2016b) The state of world fisheries and aquaculture. contributing to food security and nutrition for all
FAO (2018) The State of the World Fisheries and Aquaculture 2018 – Meeting the Sustainable Development Goals. Food and Agriculture Organization of the United Nations, Rome
FaPe-UNALM (2018) Infopes. http://tumi.lamolina.edu.pe/infopes/?page_id=101. Accessed 3 Oct 2019
Flores D, Céspedes Reyes L, Martínez Grimaldo A (2013) Identificación de servicios ecosistémicos en el Santuario Nacional Los Manglares de Tumbes. Informe técnico especial
Froese R, Pauly D (2019) FishBase. In: Froese R, Pauly D (eds) World Wide Web electronic publication. www.fishbase.org, version (12/2019). https://www.fishbase.se/search.php
Grillo J, Gozzer R, Sueiro JC, Riveros JC (2018) Producción ilegal de harina de pescado en Perú a partir de anchoveta extraída por la flota artesanal y de menor escala. Oceana Perú, Lima
Guevara-Carrasco R, Bertrand A (2017) Atlas de La Pesca Artesanal Del Mar Del Perú. IMARPE-IDR. Lima, Perú
Herrera M, Castro R, Coello D, Saa I, Elías E (2013) Puertos, caletas y asentamientos pesqueros artesanales del Ecuador. Boletín Especial del Instituto Nacional de Pesca del Ecuador (Vol. Año 04)
Hilborn R, Fulton EA, Green BS, Hartmann K, Tracey SR, Watson RA (2015) When is a fishery sustainable? Can J Fish Aquat Sci 72(9):1433–1441. https://doi.org/10.1139/cjfas-2015-0062

Index Mundi (2019) Fish meal production by country in 1000 MT—country rankings 2018. Retrieved 28 Mar 2019. https://www.indexmundi.com/agriculture/?commodity=fish-meal
IMARPE (2009) Instituto del Mar del Perú. http://www.imarpe.gob.pe/imarpe/. Accessed 3 Oct 2019
INEC (2010) Población y Demografía. Ecuador. Instituto Nacional de Estadísticas y Censos. http://www.ecuadorencifras.gob.ec/censo-de-poblacion-y-vivienda/. Accessed 21 Feb 2019
INEI (2014) Datos Sobre El Valor Agregado Bruto Por Sectores Económicos y PBI Sectorial. Instituto Nacional de Estadística e Informática. https://www1.inei.gob.pe/. Accessed 6 Mar 2019
INEI (2019) PERU Instituto Nacional de Estadística e Informática INEI. https://www.inei.gob.pe/estadisticas/indice-tematico/population/. Accessed 10 Oct 2019
INEI-PRODUCE (2013) Perú - I Censo Nacional de La Pesca Artesanal Del Ámbito Marítimo 2012. Instituto Nacional de Estadística e Informática. https://webinei.inei.gob.pe/anda_inei/index.php/catalog/223. Accessed 6 Mar 2019
Inocar, Ecuador (2012) CAPÍTULO I: Información General de La República Del Ecuador INOCAR 2012 1.1. Instituto Oceanografico de La Fuerzas Armadas, Capitulo 1:13–24
INP (2010a) Lámina de crustáceos de mayor importancia comercial. Instituto Nacional de Pesca del Ecuador. http://institutopesca.gob.ec/wp-content/uploads/2017/07/Lamina-de-Crustaceos.pdf
INP (2010b) Lámina de moluscos de mayor importancia comercial. Instituto Nacional de Pesca del Ecuador. http://institutopesca.gob.ec/wp-content/uploads/2017/07/Lamina-de-Moluscos.pdf. Accessed 13 July 2020
INRENA (2002) Reserva Nacional de Paracas. Plan Maestro 2003-2007
IOC (1989) Workshop on biological effects of the El Niño phenomenon in coastal ecosystems of the Southeast Pacific Region. Intergovernmental Oceanographic Commission
IUCN (2019) The IUCN red list of threatened species. Version 2019-2. http://www.iucnredlist.org
Jacquet J, Alava JJ, Pramod G, Henderson S, Zeller D (2008) In hot soup: sharks captured in Ecuador's waters. Environ Sci 5(4):269–283
Krzywinski M, Schein J, Birol I, Connors J, Gascoyne R, Horsman D, Jones SJ, Marra MA (2009) Circos: An information aesthetic for comparative genomics. Genome Res 19(9):1639–1645. https://doi.org/10.1101/gr.092759.109
Longhurst A (1998) Ecological geography of the sea. Academic, San Diego. 398 p
Lynham J, Costello C, Gaines S, Sala E (2015) Economic valuation of marine- and shark-based tourisms in the Galápagos Islands. Natl Geogr Pristine Seas 44
Maddison DR, Schulz K-S, Maddison WP (2007) The tree of life web project. Zootaxa 1668(1): 19–40
MAE (2010) Proyecto: Conservación de La Biodiversidad Marina y Costera de Ecuador. Guayaquil, Ecuador
MAE (2012) La Pesquería de Arrastre Camaronero En Ecuador, Guayaquil
MAE (2016) Estrategia Nacional de Biodiversidad 2015–2030. Primera (ed) Ministerio de Ambiente del Ecuador, Quito
Martínez-Ortiz J, Aires-da-Silva AM, Lennert-Cody CE, Maunder MN (2015) The Ecuadorian artisanal fishery for large pelagics: species composition and spatio-temporal dynamics. PLoS One 10(8):e0135136
Mauri M, Elli T, Caviglia G, Uboldi G, Azzi M (2017) RAWGraphs: a visualisation platform to create open outputs. In: Proceedings of the 12th biannual conference on Italian SIGCHI chapter
Mendo J, Claudia W-M (2016) Peru. In: Pauly D, Zeller D (eds) Global atlas of marine fisheries. A critical appraisal of catches and ecosystem impacts. Island Press, Washington, p 366
Mendo J, Wolff M, Carbajal W, Gonzáles I, Badjeck M (2008) Manejo y explotación de los principales bancos naturales de concha de abanico (Argopecten purpuratus) en la costa Peruana. Estado actual del cultivo y manejo de moluscos bivalvos y su proyección futura 101
Mialhe F, Gunnell Y, Mering C (2013) The impacts of shrimp farming on land use, employment and migration in Tumbes, northern Peru. Ocean Coast Manag 73:1–12. https://doi.org/10.1016/j.ocecoaman.2012.12.014

Miloslavich P, Klein E, Diaz JM, Hernandez CE, Bigatti G, Campos L, Artigas F, Castillo J, Penchaszadeh PE, Neill PE, Carranza A, Retana MV, de Astarloa JMD, Lewis M, Yorio P, Piriz ML, Rodriguez D, Yoneshigue-Valentin Y, Gamboa L, Martin A (2011) Marine biodiversity in the Atlantic and Pacific coasts of South America: Knowledge and gaps. PLoS One 6(1). https://doi.org/10.1371/journal.pone.0014631

Ministerio del Ambiente (2016) Lineamientos Para El Manejo Integrado de Las Zonas Marino Costeras. Resolución Ministerial n.o189-2015-MINAM, 28

Moity N, Izurieta J (2017) DiveStat Galapagos: indicadores del turismo de buceo en la Reserva Marina de Galá pagos. Indicadores de Perfil, Satisfacció n, Percepciones y Ciencia Ciudadana. Informe Té cnico (1):45

Moity N, Izurieta JC, Araujo E, Casafont M (2018) DiveStat: A new tool for managing dive tourism. Galapagos report 2017, pp 72–77

Navarrete-Forero G, Morales Baren L, Dominguez-Granda L, Pontón Cevallos J, Marín Jarrín JR (2019) Heavy metals contamination in the Gulf of Guayaquil: even limited data reflects environmental impacts from anthropogenic activity. Revista internacional de contaminación ambiental 35(3):731–755

Nikanorova A, Egorov S (2019) Development of principles and legal rules regulating the use of transboundary water resources by states. Water Resour 46(1):138–142

Ordinola E, Montero P, Alemán S, Argüelles J, Beltrán L, Llanos J (2010) The pearl oyster, Pteria sterna (Gould), in Talara, Peru. April 2007. Informe IMARPE, vol 37. Instituto del Mar del Peru, Callao. http://biblioimarpe.imarpe.gob.pe/handle/123456789/2014

Palomares MLD, Pauly D (2019) SeaLifeBase, version (08/2019). www.sealifebase.org. Accessed 3 Oct 2019

Pauly D, Zeller D (2016) Global atlas of marine fisheries: a critical appraisal of catches and ecosystem impacts. Island Press, Washington, DC

Peralta M (2009) Desembarques de la pesca artesanal de peces pelágicos grandes y tiburones en la costa ecuatoriana durante el 2008

Plan Binacional Peru-Ecuador (2018) Plan Binacional de Desarrollo de La Región Fronteriza Capítulo Perú. https://planbinacional.org.pe/

Roskov Y, Ower G, Orrell T, Nicolson D, Bailly N, Kirk PM et al (2019) Species 2000 & ITIS Catalogue of Life, 2019 Annual Checklist. www.catalogueoflife.org/annual-checklist/2019. Accessed 3 Oct 2019

Schiller L, Alava JJ, Grove J, Reck G, Pauly D (2016) Ecuador (Galápagos). In: Pauly D, Zeller D (eds) Global atlas of marine fisheries. A critical appraisal of catches and ecosystem impacts. Island Press, Washington, DC, p 242

SCI (2020) Plantas Harineras Registradas y Aprobadas. Actualización 17 de Marzo Del 2020. Subsecretaría de Calidad e Inocuidad. Ministerio de Producción Comercio Exterior, Inversiones y Pesca Del Ecuador. Manta, Ecuador

Spalding Mark D, Fox Helen E, Allen Gerald R, Davidson Nick FZA, Finlayson Max HBS, Jorge Miguel A, Lombana A, Lourie Sara A, Martin KD, McManus E, Molnar J, Recchia CA, Robertson J (2007) Marine ecoregions of the world: A bioregionalization of coastal and shelf areas. BioScience 57(7):573–583

SPRFMO (2018) Conservation and management measures. South Pacific Regional Fisheries Management Organisation. https://www.sprfmo.int/measures/. Accessed 31 Jan 2019

STRI (2016) Peces: Pacífico oriental en app store. Smithsonian Tropical Research Institute. https://apps.apple.com/gt/app/peces-pacífico-oriental/id494644648. Accessed 3 Oct 2019

Tarazona J, Arntz W (2001) The Peruvian coastal upwelling system. In: Coastal marine ecosystems of Latin America. Springer, pp 229–244

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(2–4):336–351

Terán MC, Clark K, Suárez C, Luna S, Yánez FC, Denkinger J, Ruiz D, Jiménez P (2007) Identificación de Vacíos y Prioridades de Conservación de La Biodiversidad de La Plataforma Marina Del Ecuador Continental. In: Prioridades para la conservación de la biodiversidad en el

Ecuador continental. Instituto Nazca de Investigaciones Marinas, EcoCiencia, Ministerio de Ambiente, The Nature Conservancy, Conservación Internacional, Quito, Ecuador, pp 41–62
Thorpe A, Bennett E (2001) Globalisation and the sustainability of world fisheries: a view from Latin America. Mar Resour Econ 16(2):143–164
Trujillo R (2017) 2017, Buen Año Para El Sector. Editorial. Ecuador Pesquero 83, January, 4–5
UN (2019) United Nations Convention on the Law of the Sea. Montego Bay, 10 December 1982. United Nations Audiovisual Library of International Law. http://legal.un.org/avl/ha/uncls/uncls.html. Accessed 30 Sept 2019
Varea A (2004) Iniciativas para conservar la biodiversidad. Universitas (4):7–44
Willette DA, Cheng SH (2018) Delivering on seafood traceability under the new US import monitoring program. Ambio 47(1):25–30
Wolff M (1987) Population dynamics of the Peruvian scallop Argopecten purpuratus during the El Niño phenomenon of 1983. Can J Fish Aquat Sci 44(10):1684–1691
Wolff M (2010) Galapagos does not show recent warming but increased seasonality
Wolff M, Gardener M (2012) The role of science for conservation, vol 34. Routledge, Abingdon, England
Wolff M, Penaherrera-Palma C, Krutwa A (2012) Food web structure of the Galapagos Marine Reserve after a decade of protection: insights from trophic modeling. In: The role of science for conservation. Routledge
Workman D (2019) Big Export Sales for Frozen Shrimps. World's Top Exports. http://www.worldstopexports.com/big-export-sales-for-frozen-shrimps/. Accessed 25 Oct 2019
Zeller D, Pauly D, Kitchingman A, Lai S, Kleisner K, Hoornaert C (2015) Sea around us area parameters

Chapter 16
Thailand Case Study

Artificial Reefs as a Fishery Management Tool: A Social-Ecological Assessment in the Gulf of Thailand

Naomi R. Bauer, Isabell J. Kittel, Eike Schoenig, Sebastian C. A. Ferse, and Christian Wild

Abstract Thailand's coral reefs not only attract a wealth of tourists, contributing to the national economy but also provide a significant revenue through the fisheries sector, as well as playing an important social, economic and nutritional role for local coastal communities. However, as with most coral reefs around the world, these are being severely degraded due to overfishing, destructive fishing practices, eutrophication, coastal development, and pollution. This has affected Thailand's fishing sector, with both commercial and small-scale fishing showing a declining trend since 2002. Since 1978, Thailand has been deploying artificial reefs to compensate for these losses and as a tool to strengthen coastal habitats and small-scale fisheries, in both the Gulf of Thailand and the Andaman Sea.

Author "Eike Schoenig" has died before the publication of this book.

N. R. Bauer (✉)
Marine Ecology Department, Faculty of Chemistry and Biology, University of Bremen, Bremen, Germany

COREsea, Koh Phangan, Surat Thani, Thailand

I. J. Kittel
Marine Ecology Department, Faculty of Chemistry and Biology, University of Bremen, Bremen, Germany

COREsea, Koh Phangan, Surat Thani, Thailand

Leibniz Centre for Tropical Marine Research (ZMT), Bremen GmbH, Bremen, Germany

S. C. A. Ferse
Marine Ecology Department, Faculty of Chemistry and Biology, University of Bremen, Bremen, Germany

Leibniz Centre for Tropical Marine Research (ZMT), Bremen GmbH, Bremen, Germany

C. Wild
Marine Ecology Department, Faculty of Chemistry and Biology, University of Bremen, Bremen, Germany

M. Wolff et al. (eds.), *Challenges in Tropical Coastal Zone Management*,
https://doi.org/10.1007/978-3-031-17879-5_16

Keywords Artificial reefs · Fisheries management · Coastal habitats · Tourism · Thailand

1 Introduction

This case study investigated artificial reef prototypes—metal structures, deployed in 2013 in the bay of Chaloklum, Koh Phangan, Gulf of Thailand. The concepts behind their deployment were to (a) create new fishing grounds, (b) protect the bay from commercial vessels, and (c) enhance recreational activities. Aims of this study were to assess the prototypes ecological effectiveness in regard to fish communities, abundance and biomass, as well as their success regarding the acceptance, usefulness, and benefit for the local key communities. Using an interdisciplinary approach, combining underwater fish surveys with stakeholder interviews and observations, we evaluated whether the structures provide ecosystem services such as biodiversity maintenance, food provision and recreation, to support local livelihoods and/or maintain a typical reef fish assemblage in comparison to the surrounding natural reefs.

Artisanal fishers were the primary users of the prototypes, catching valuable target species belonging mainly to the families Carangidae, Lutjanidae, and Serranidae, occasionally selling them to local restaurants and/or markets. The metal structures had a higher total abundance of fishes, including valuable target families, contributing to a higher biomass and economic value than local coral reefs. Although many common species were found between the natural reefs and artificial prototype; fish community composition was very dissimilar. For example, the metal structures missed important functional groups such as corallivores and herbivores. This contributed to a lower species richness (species number and diversity).

As the artificial structures harbour many important target species for subsistence fisheries, we conclude they have the potential to play an important role in the local economy. Size classes for these target species populations consisted more of juveniles and maturing individuals than adults, indicating that either larger individuals move away from the structures or, alternately, a tendency of recruitment and (over)-fishing. Thus, despite the findings suggesting species-specific attraction and production, further analysis should focus on catch effort and fishing pressure to ensure sustainable use for the long-term support of the fishing community.

The prototypes' ability to maintain a biologically diverse natural reef fish assemblage is questionable, and thus measures should be taken to increase their attractiveness to missing functional groups. These findings add to the current literature that artificial habitats can never fully replicate a natural habitat. However, how one derives the success of such a project will depend on the objectives for deployment. In our case, the artificial structures can be considered a short-term win, providing valuable economic services, such as food provision, recreation via fishing trips, and habitat protection.

1.1 Historical Development of Coastal Use, Coastal Resource Management and Conservation in the Gulf of Thailand

1.1.1 Reef Degradation in the Gulf of Thailand: Drivers and Trends

The Gulf of Thailand is no exception to local and global anthropogenic disturbances such as overfishing, destructive fishing practices (Wattayakorn 2006; Wilkinson 2008), eutrophication, coastal development and pollution (Wattayakorn 2006), its situation aggravated due to its geological nature of a semi-enclosed basin (Choowong 2002). Coral reefs cover approximately 75 km^2 with prominent conditions such as low salinity and high turbidity (Sudara and Yeemin 1997; Yeemin et al. 2009). This is partly due to the Gulf forming a discharge area for numerous rivers. Relatively static conditions of circulation and mixing of water masses are generally weak and variable allowing contaminants to accumulate (Wattayakorn 2006). Municipal and industrial wastewater enters the Gulf untreated causing eutrophication, ultimately affecting shrimp, shellfish and green mussel production (Cheevaporn and Menasveta 2003).

Thailand's reefs are currently a major attraction for international visitors (Worachananant et al. 2008), with the ability to generate a large consumer surplus (Seenprachawong 2016). However, intensive coastal development produces excessive sediment run-off and erosion associated with the conversion of mangrove forest (McManus 1988; Wilkinson 2008; Wong 1998; Yeemin et al. 2006); leading to sedimentation and degradation of near-shore reefs (Phongsuwan et al. 2013). Furthermore, reef degradation has been progressively attributed to tourism through activities such as reef walking, snorkelling and SCUBA diving, as well as anchor damage by powerboats (Wong 1998; Worachananant et al. 2008; Yeemin et al. 2006). Reef-based tourism is an essential contributor to the national economy, but long-term sustainability of the industry and well-being of local communities are undermined through unplanned development, causing environmental degradation and socio-cultural conflicts (Wongthong and Harvey 2014). Constant disturbance and pollution classified over 50% of coral reefs in the Gulf of Thailand in very poor to fair condition, with risk of continued degradation (World Bank 2006).

1.1.2 Coastal Management and Fishery Trends in the Gulf of Thailand

For the 70 million people of the Kingdom of Thailand, fisheries and aquaculture play an important social, economic and nutritional role, with fish as one of the most significant sources of animal protein for most Thai people (FAO 2020). Until recently, Thailand's seas have been highly productive, forming the base of Thailand's fisheries industry (Kheawwongjan and Kim 2012). Due to the development of fisheries technology and gear, fisheries production increased since the 1960s (Kheawwongjan and Kim 2012), peaking around the beginning of the millennium and decreasing ever since (FAO 2020). Reconstructed fisheries total catch, within

Thailand's Exclusive Economic Zone (EEZ), between 1950 and 2014 was estimated to increase from 400,000 t·year^{-1} in 1950 to a peak of 2.6 million t·year^{-1} in 1987, before declining to around 1.7 million t·year^{-1} in 2014. Catch by Thailand's fleet in neighbouring countries' EEZs increased from 52,000 t·year^{-1} in 1965 to a peak of 7.6 million t·year^{-1} in 1996, before declining to around 3.7 million t·year^{-1} by 2014 (Derrick et al. 2017). In 2017, Thailand's total marine catch was estimated at 1.3 million tonnes and inland waters, i.e., aquaculture production at 0.2 million tonnes, with only 60% of the total marine catch caught in Thai waters and the rest from waters outside the Thai EEZ (FAO 2020). Thai trawlers have expanded to farther fishing grounds and into the now exclusive economic zones of neighbouring countries, whether through official and private agreements and/or illegally (Butcher 2004). Conflicts amongst stakeholders have also arisen, worsened by the cost of fishing, increasing labour costs and low price of certain fish species (FAO 2020). It is no surprise that assessments of fish stocks under the UNEP/GEF South China Sea Project indicate that most stocks are now under high fishing effort, with most target species considered fully fished or over-fished (Wilkinson 2008). Further, with the destruction of the marine ecosystem and high socio-economic pressure, forced, bonded, slave labour and piracy increased (Environmental Justice Foundation 2015).

1.1.3 Artificial Reefs as a Fishery Management Tool in the Gulf of Thailand

In order to compensate for the decrease in fisheries catch and strengthen coastal habitats, Thailand's Artificial Reef Program was initiated in 1978 under the jurisdiction of the Department of Fisheries (Kheawwongjan and Kim 2012; Supongpan 2006). Its goal is to enhance and restock fish resources in both the Gulf of Thailand and the Andaman Sea (Kheawwongjan and Kim 2012; Supongpan 2006). Until 1986, this was mainly experimental, with a focus on material, structure and duration. Since 1988, artificial reef development policies have been included in Thailand's national socio-economic development plans. Between 1988 and 2003, the Thai Department of Fisheries implemented a Small-Scale Fisheries Development Project, comprising of three aspects: coastal small-scale fisheries development, artificial reef installation and fishery resource rehabilitation (Supongpan 2006). The project's objective was to conserve areas for marine coastal resources, with 50 km^2 of designated small-scale fishing ground in both the Gulf of Thailand and Andaman Sea to help reduce conflicts and poverty (Supongpan 2006).

From 1978 to 2006, nine types of artificial reef structures were deployed in both provinces (Kheawwongjan and Kim 2012). Concrete, modelled into simple patches, rings, tubes and blocks were the dominant structure type but were criticised for their short duration, broken easily by environmental and/or fishing gear impact. Recycled materials made of iron, such as war ships, trains and oil rigs and even fiberglass were deployed since 2002 (Kheawwongjan and Kim 2012). A total artificial reef area of 2026 m^{-2} is dispersed in both seas, of which most structures are deployed in nearshore shallow waters from 1 to 20 m depth (Kheawwongjan and Kim 2012).

With the background to create fishing grounds for subsistence fisheries, higher densities of artificial reefs were created in areas with less natural reefs and vice versa (Kheawwongjan and Kim 2012). In the Surat Thani province (which encloses the case study described here), the Department of Fisheries deployed 2805 concrete cylinders within 5–10 m water depths over a threadfin fishing ground used by commercial and artisanal fishers. After the artificial reef installation, the fish catch increased from 4.7 to 8.3 kg per trip for artisanal fishers, as trawler boats could no longer access the area (Polovina 1991).

1.2 *Case Study: Social-Ecological Assessment of Artificial Reefs in the Gulf of Thailand*

1.2.1 Background

In late 2013 four metal structures were placed on the seabed floor (~18 m bottom depth) in the Bay of Chaloklum, Koh Phangan (Fig. 16.1). Originally placed on the demarcation line (which is up to 3 nautical miles) between artisanal fisheries zone and industrial fisheries zone (DOF 2015), the metal structures were deployed as a collaborative project between local fishers, the Department of Marine Coastal Resources (DMCR), and the Petroleum Institute of Thailand (PTIT). The project, instigated by the local fishing community, was a response to severe fish catch declines and aggravated fishing efforts. As part of a 3-year trial period, these structures were deployed to simulate the effects of using decommissioned oil rigs as artificial reefs. Their objectives being to (a) create new fishing grounds, (b) protect the bay from commercial vessels, and (c) enhance recreational activities. The project, initially funded by the PTIT, would be monitored throughout, by the governmental body DMCR and the international marine research and conservation institute COREsea. However, since their deployment, the structures were not fully studied with respect to their deployment objectives and stakeholder usage, as well as their

Fig. 16.1 Metal structures with the DMCR team before deployment in Chaloklum Bay. Photograph courtesy of Lotus Diving, Chaloklum, Koh Phangan

associated fish community in relation to the surrounding natural reefs. The following study set out to monitor these aspects.

1.2.2 Approach

From October 2015 to April 2016, a study combining the use of social and ecological assessments investigated three of the four metal structure's (hereon referred to as artificial reefs) ecological effectiveness in regards to fish communities, abundance and biomass, as well as their success in regards to the acceptance, usefulness and benefit for the local key communities. Using an interdisciplinary approach, combining underwater fish surveys with stakeholder interviews and observations, the aims were to evaluate whether the structures could provide ecosystem services such as biodiversity maintenance, food provision and recreation, to support local livelihoods and/or maintain a typical reef fish assemblage in comparison to the surrounding natural reefs.

The final analysis describes positive and negative socio-economic impacts of artificial reefs, as well as their influence on ecological functions, identifying local specific challenges and problems encountered and further describing the needed actions for management, environmental monitoring, biodiversity conservation and policy.

2 Methodology

2.1 Study Area

The Bay of Chaloklum, on the north coast of Koh Phangan, stretches approximately 4.7 km. The 2.7 km long beach strip hosts mainly small restaurants, dive operators and some resorts. A small river on the eastern side of the bay discharges into the sea and usually hosts the Thai longtail boats, which are used for fishing and as taxi boats for tourists. Fishing occurs in the area, and gleaning of snails and mussels on the beach strip was frequently observed. For the social assessment reef users were defined as any person or group using the natural and/or artificial reefs, whose activities affect these reefs, or even those who have an interest in these activities either directly or indirectly. For the ecological assessment, underwater fish surveys were conducted at three natural reef locations and three artificial reef locations within the Bay of Chaloklum (Table 16.1; Fig. 16.4).

All natural reef study sites were chosen in terms of comparable current regime, water depth, vertical relief, distance to shoreline, reef health and accessibility. Coral Bay Point on the eastern side of Chaloklum bay is a shallow sloping fringing reef. Rocky Boulders and sandy patches are common here. However, massive, plate-like and occasional branching corals can be found. Koh Maa is a peninsula, on the North East of Koh Phangan. It is further away from the rest of the sampled locations and

Table 16.1 GPS-Data of reef locations in decimal degree

Reef type	Name	X coordinate	Y coordinate
Artificial	East Out	100.01214478	9.80224605
	West In	99.9982567	9.80259270
	West Out	99.99819512	9.80303250
Natural	Coral Bay Point	100.01212603	9.79783036
	Koh Maa	99.97726727	9.80083911
	Kong Ork	100.01511928	9.80338171

offers a relatively intact sloping reef along a rocky wall. Massive and plate-like corals are dominant with occasional branching corals. Kong Ork is a rocky reef consisting of submerged granite boulders on the far east of Chaloklum Bay, containing massive and plate-like corals, as well as wire corals found in the deeper regions.

The artificial reefs are located in the outer part of Chaloklum Bay (Fig. 16.4). The East Outer reef is approximately 300–400 m away from the nearest coral reefs, Coral Bay Point and Kong Ork. The West Inner and West Outer reef is approximately 600 m away from Hin Ngam. All metal structures are situated on a silty sand seafloor bed. The structures are cube-shaped, made from hollow steel rods, sized 9 × 9 × 9 m and coated with anti-rust. Their benthic flora and fauna consisted of turf algae, sponges, crustaceans, especially barnacles, echinoderms and mollusks. Corals were absent.

2.2 *Field Methods*

The sociological assessment combined the use of consultations with key representatives within the Chaloklum community, semi-structured interviews with local fishermen, restaurant owners and dive operators, and targeted surveys with dive instructors and their customers. Throughout the project, observations were collected and recorded through written reports and photography. Maps and fish ID cards were used to aid interviews, along with a translator when available (Jones et al. 2010). Reef users were asked to identify locations used on the map, whether for diving or fishing. Fish ID cards consisted of all fish species commonly observed in the surrounding vicinity and those spotted on the fish surveys at Coral Bay Point, Koh Ma, Kong Ork and the artificial reefs. Fishers were asked to value all fish species identified on the cards in Thai Baht.

For the ecological assessment, study sites were reached by long tail boat from the village of Chaloklum. As Thailand was experiencing a severe El Nino during this period (UN ESCAP 2015) the seasonal and daily environmental conditions widely varied over the period of the study. Consequently, surveys were collected irregularly with a minimum of six sub-replicates at each site, as and when weather permitted.

Sub-replicates served to establish a baseline of the fish assemblage and to control the short-term variability of the individual inspections.

Fish population and assemblage data was collected through underwater visual census techniques by COREsea volunteers previously trained in fish identification and sizing. Methods were adapted from the traditional Belt Transect Method (Brock 1954) where species sight identification, abundance and size estimates (Bortone et al. 2000) were recorded on underwater slates for all diurnally active fishes—excluding cryptic species of the families Blenniidae and Gobiidae—over a timed dive of 60 min (Cinner et al. 2009). Each survey was taken between 10:00 and 14:00 h in order to maximise visual conditions (Bortone et al. 2000) and the same starting point was used, as well as the direction of transect using a compass.

Sizes of fish were sorted into eleven different size classes (Table 16.2). Size classes range in a 2.5 cm step from 0 to 10 cm, in 5 cm steps from 10 to 30 cm, and 10 cm steps from 30 to 50 cm, and everything above

Transect dimensions for the natural reef fish surveys consisted of three 50 m × 5 m (250 m^2), laid parallel to the shoreline, totaling an area of 750 m^2 (Fig. 16.2). The technician laid the transect tape out at the specified depth range (varying between 5 and 15 m depending on site and tide) with the surveyors following to conduct the survey (Fig. 16.2). At the end of the third transect all divers waited five minutes. The survey was then conducted backwards counting all remaining fish in the transect. The time of count and swimming speed was standardised by dividing the average dive time of 60–10 min per transect.

For the artificial reef fish surveys, methods were adapted to the reef size, structure, environmental conditions and maximum diving depth of the voluntary divers. This could not exceed 15 m due to constrains of no decompression diving limits. Transect dimensions consisted of four 9 m × 4 m (36 m^2), totaling an area of 144 m^2 (Fig. 16.3). The water depth range for the artificial surveys varied between 11 and 15 m depending on tide. Only the upper level of the metal cube structure was analysed (a) to minimise biases in depth and (b) due to logistical and safety

Table 16.2 Size classes using total length (tip of snout to end of caudal fin) as used in the underwater visual census. Size classes A–G were drawn onto the A4 slate for reference. For larger fish volunteers were encouraged to use elbow to fingertip length as reference

A	B	C	D	E	F	G	H	I	J	K
0–2.5	2.5–5	5–7.5	7.5–10	10–15	15–20	20–25	25–35	35–45	45–55	>55

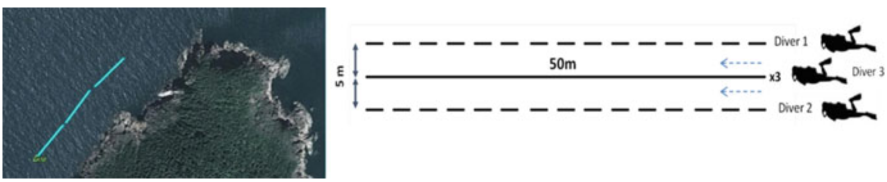


Fig. 16.2 Example of belt transect method for the natural reef site at Koh Ma

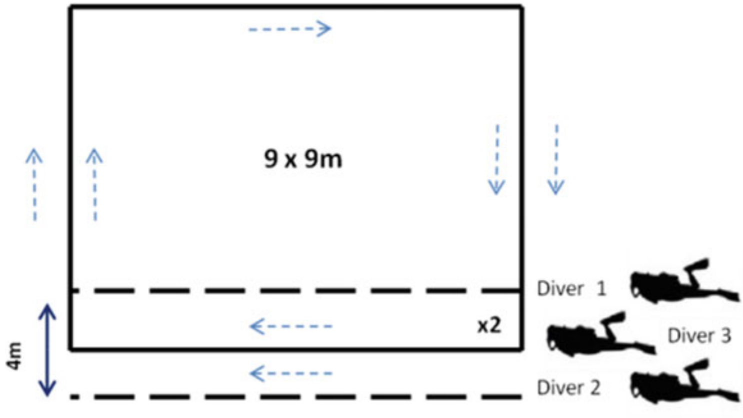


Fig. 16.3 Belt transect method for the artificial reef sites

constraints. The team consisted of one safety diver and two surveyors (Fig. 16.3). Divers descended slowly along the mooring rope towards the artificial reef. If good visibility was available, divers stopped three to four meters above the structure and assessed the fish assemblage for mobile and schooling fish species. Then, divers descended down to the structure and to one of the edges of the artificial reef to conduct the survey. One swim around the structure corresponded to one transect. Low visibility, higher depth and strong currents constrained the divers to two transects per dive. The time of count and swimming speed was standardised by dividing the average dive time of 60–7 min 30 s per 9 m.

2.3 *Data Analysis*

Semi-structured interviews were qualitatively analysed across stakeholders to look for common themes. Using the data from fisher and dive operator interviews, fishing and dive locations were mapped. Data from the targeted surveys was analysed quantitatively using proportional data to compare dive preferences and whether the artificial reefs in Koh Phangan could meet these preferences. Using information from Fisher interviews, fish species were categorised as target or non-target species. Fish prices from the Fisher interviews were then pooled to create a list of target species and value.

All underwater fish survey data was compiled and taxonomically categorised using the Linnaeus system to species, genus and family (Jones et al. 2010) and further into functional subgroups (Pratchett et al. 2011). Please see (Kittel 2016) for information on functional subgroups. A total of 120 species were identified during the underwater visual census. As the sampling area differed between reef types, 144 m^2 for the artificial reefs and 750 m^2 for the natural reefs, reef area was standardised to 100 m^2. Abundance was calculated as number of fish per 100 m^2. Biomass was calculated as kilogram of fish per 100-m^2.

Abundances of individuals in each size class were converted into biomass applying the following equation

$$W = a \times Lb$$

where

W = weight of the fish in grams
L = observed total length in cm
a = regression intercept
b = regression slope

The L value was calculated as the mid-value of the size classes (Table 16.2), and the (a) and (b) values for total length were obtained from the online database FishBase (Froese and Pauly 2016). Biomass values were combined with the value of target species given by fishers to create an overall economic value for both reef types. Restaurant values were also analysed in order to explore the local economic value of each target species.

To compare fish assemblage between reef types, natural and artificial, and to evaluate whether artificial reefs harboured fish of ecological importance, multivariate techniques were applied using indirect gradient analysis with DCA ordination. Sites were arranged along axes on the basis of data on species composition represented by presence/absence data. This preference was used over abundance data due to the large variation in data points affected by schooling species.

Statistical analysis was conducted in RStudio (R Core Team, 2014) and Microsoft Excel (2007). Significant levels were set to 0.05. Using nonlinear mixed effects model with the nlme library in R; reef type, depth and visibility were compared to explain species richness (total number of species) and abundance (total number of individuals), as well as the abundance of target families Lutjanidae, Carangidae, and Serranidae. For the family abundances, a value of 0.01 was added to all data points to account for 0 abundances.

All mixed models (glmm) used location as a random effect to account for non-independence of samples within location (Cinner et al. 2009), and date to account for day effects i.e. some samples were taken at different locations within the same day and other such samples were taken at other dates. In case of glmm, models used appropriate generalised linear models (glm) to test for fit of data and were inspected using Residuals vs Fitted, Normal Q-Q plot, Scale Location, and Residuals vs Leverage and any outliers were removed. A model comparison was used with backwards deletion of variables in order to find the minimum adequate model.

All fish family abundance models (Carangidae, Lutjanidae and Serranidae) used a Gamma (log) distribution to correct for overdispersion and the use of nonintegers. For the species richness model, a Poisson distribution was used for the count data in order to correct for overdispersion. For the total abundance model, a Gamma (log) distribution was used to correct for overdispersion and the use of non-integers.

3 Results

3.1 Reef User Community in Chaloklum

Findings indicate a small overlap between fishing and dive locations, where both fishers and divers used the site Koh Ma (KM) and Mae Haad (MH) (Fig. 16.4). Figure 16.4 visually displays the overlap in space between the reef users. Mae Haad, although not utilised for fish surveys in this study, is commonly used as a scientific research site and is highly touristic, attracting many swimmers and snorkelers.

The local governing body, DMCR and the international marine research and conservation institute, COREsea, indirectly use the local coral reefs and the metal structures for research. They work together with the local fishers to gain access to the sites in and around Chaloklum, as well as working together with local dive schools to promote education and stewardship.

Fishers were identified as the predominant users of the artificial reefs in Chaloklum. This study may represent 25–33% of the local fishing population, as locals reported only 15–20 fishers located in Chaloklum. A higher percentage could

Fig. 16.4 Map of natural and artificial reef locations used by fishers and divers. Map produced in QGIS 3.18

not be obtained due to the short time scale of the study, the lack of availability by the translator and a lack of available fishers. Due to squid season (15 February–15 May 2016), fishers were fishing at night time and sleeping in the day. Out of the five fishers interviewed, four were male and one female. Three of the fishers were aged >45 and two of the fishers were ≤30. All fishers fished for subsistence, selling their catch locally, to the market, community or restaurants, when and only if they caught an excessive amount (“over 200 kg” as claimed by one fisher). All fishers used traditional gear with handlines being the preferred type. This consists of a fishing line, a reel, hook and bait. Nets were occasionally used, as stated by one, “only in open spaces”. Two out of the five fishers, occasionally used fish traps in order to catch carnivorous fishes such as those from the Carangidae family. All five fishers attended the artificial reefs on a regular basis, weather permitting due to its “easy access”. One fisher visited every day, and four out of the five fishers visited four to five times a month.

Dive operators rarely used reef sites within and around Chaloklum, with the exceptions of Mae Haad and Koh Ma. Managers of the four local dive operators interviewed for this study gave three main reasons why the artificial reefs are not being used;

1. There is no demand as customers want to visit Sail Rock.
2. There is a limited appeal due to PADI marketing.
3. The site is not reliable when considering visibility and water current conditions.

Dive instructors commented on the need for new dive sites and better dive conditions, claiming the famous Sail Rock, a rocky outcrop approximately 17 km offshore from Chaloklum was overrun with divers and fishers alike. Surveys conducted with 21 dive instructors revealed that 69% had the opinion that local sites compared worse over the past 10 years. The manager of COREsea had a similar impression. He stated the sites have degraded over a 20-year interval and that “within the last five years there has been an increase in coral cover, but it’s still nowhere near the state of the 90s”.

To investigate whether artificial reefs have the potential to become a new dive site, dive instructors and customers were asked about their dive preferences. Seventy-six percent of 23 interviewed dive instructors expressed the opinion that species diversity (as described by the variety and quantity of species) is the most important factor when visiting a dive site. In comparison, only 40% of 30 interviewed dive customers reported this as the most important factor, equally with characteristic species (described by examples such as parrotfish or whale shark). 52% of 31 dive customers ranked interesting species as the most important factor when choosing a dive site. Next in line was topography (described by the underwater landscape) with 37% of 30 dive customers considering it the second most important factor, with good visibility falling shortly behind (30%). Most importantly dive customers showed a preference in visiting an artificial reef. Fifty-five percent out of 31 dive customers had already visited one and out of the 45% who had not, 86% expressed an interest in visiting one.

3.2 Target Fish and Their Associated Value

Interviews with the fishers identified a total of 12 families and 44 species as target catch. The highest numbers belonged to the families Carangidae, Lutjanidae and Serranidae. For these families, potential influences on abundance were evaluated using a backward stepwise analysis of covariance, initially containing reef type, depth and visibility as explanatory variables. Reef type was a significant explanatory variable when comparing all three families.

The artificial reefs had a significantly higher total number of Lutjanidae individuals per 100 m^2 (1320-fold) in comparison to the natural reefs with less than one individual per 100 m^2 ($\chi^2 = 14.90$, df $= 1$, $P = 1.14 \times 10^{-4}$). No significant effect of water depth ($\chi^2 = 0.05$, df $= 1$, $P = 0.82$) or visibility was observed ($\chi^2 = 0.57$, df $= 1$, $P = 0.45$). When comparing Serranidae abundance, the artificial reefs had a significantly larger (17-fold) total number of individuals per 100 m^2 in comparison to the natural reefs ($\chi^2 = 7.01$, df $= 1$, $P = 0.01$), with the total abundance for each reef type increasing with increasing visibility ($\chi^2 = 10.92$, df $= 1$, $P = 9.8 \times 10^{-4}$). Depth was analysed but not found to have a significant influence ($\chi^2 = 0.48$, df $= 1$, $P = 0.49$). The artificial reefs also had a significantly higher total number of individuals of Carangidae (900-fold) per 100 m^2 than the natural reefs ($\chi^2 = 8.76$, df $= 1$, $P = 3.08 \times 10^{-3}$), with abundances increasing for each reef type with both an increase in visibility ($\chi^2 = 10.92$, df $= 1$, $P = 4.4 \times 10^{-10}$) and depth ($\chi^2 = 11.67$, df $= 1$, $P = 6.36 \times 10^{-4}$).

Out of the 44 species identified as target catch, 38 species were given a value of Thai Baht (THB) per kilogram (Table 16.3). The highest number of target species came firstly from the Serranidae, with a price range of 30–210 THB/kg, then the Lutjanidae, with a price range of 80–160 THB/kg and then, Carangidae with a price range of 57–180 THB/kg. The highest values were given to species within the Serranidae: *Plectropomus maculatus, Epinephelus malabaricus* and *Epinephelus corallicola*. *Epinephelus fuscoguttatus* and *Plectropomus maculatus* were also given values of 1000 THB/kg and 500 THB/kg, respectively, if caught and kept alive.

The total biomass of all valued target fishes was greater on the artificial reefs with a mean value of 804.15 kg per 100 m^2, in comparison to natural reefs, with 62.12 kg per 100 m^2. This is approximately a 13-fold difference in biomass per 100 m^2. The overall economic value for all target species, based on fisher's estimates per 100 m^2 was greater for the metal structures than the natural reefs. The total value was calculated as 76,066 THB for all target fish per 100 m^2 on the artificial reefs, in comparison to 3560 THB on the natural reefs.

Fishers occasionally sold species, particularly from the families Lutjanidae and Serranidae, to the local restaurants in Chaloklum (Fig. 16.5). Consequently, the restaurants directly use the reef resources, but do not wholly rely on them.

Table 16.3 Target species and fishers value (THB/kg)

Family	Target species	Reef type	Value (THB/kg)
Caesionidae	*Caesio caerulaurea*	Common	20
Caesionidae	*Caesio teres*	Common	85
Caesionidae	*Pterocaesio chrysozona*	Common	20
Carangidae	*Atule mate*	Common	80
Carangidae	*Caranx sexfasciatus*	Common	115
Carangidae	*Gnathanodon speciosus*	Natural	180
Carangidae	*Megalaspis cordyla*	Common	57
Carangidae	*Selar boops*	Common	80
Ephippidae	*Platax teira*	Artificial	140
Haemulidae	*Plectorhinchus chaetodonoides*	Natural	120
Haemulidae	*Plectorhinchus picus*	Artificial	120
Haemulidae	*Diagramma pictum*	Natural	150
Lethrinidae	*Lethrinus lentjan*	Natural	60
Lutjanidae	*Lutjanus argentimaculatus*	Common	143
Lutjanidae	*Lutjanus carponotatus*	Natural	80
Lutjanidae	*Lutjanus decussatus*	Natural	80
Lutjanidae	*Lutjanus lutjanus*	Common	80
Lutjanidae	*Lutjanus russellii*	Common	128
Lutjanidae	*Lutjanus fulviflamma*	Common	160
Nemipteridae	*Scolopsis ciliata*	Common	40
Scaridae	*Scarus ghobban*	Natural	50
Scaridae	*Scarus rivulatus*	Natural	50
Scombridae	*Scomberomorus commerson*	Common	145
Serranidae	*Cephalopholis boenak*	Common	30
Serranidae	*Cephalopholis formosa*	Common	63
Serranidae	*Epinephelus bleekeri*	Artificial	90
Serranidae	*Epinephelus corallicola*	Common	175
Serranidae	*Epinephelus erythrurus*	Artificial	150
Serranidae	*Epinephelus fasciatus*	Natural	75
Serranidae	*Epinephelus fuscoguttatus*	Common	150
Serranidae	*Epinephelus malabaricus*	Common	200
Serranidae	*Epinephelus merra*	Common	80
Serranidae	*Plectropomus maculatus*	Natural	210
Siganidae	*Siganus canaliculatus*	Common	93
Siganidae	*Siganus guttatus*	Artificial	90
Siganidae	*Siganus javus*	Common	90
Sphyraenidae	*Sphyraena jello*	Natural[a]	163
Sphyraenidae	*Sphyraena qenie*	Natural[a]	107

[a]*Sphyraena jello* and *Sphyraena qenie* were only observed on fish surveys at the natural reefs, yet, were caught on the artificial reefs by local fishers. "Common" indicates species recorded on natural and artificial reefs

Fig. 16.5 Examples of fish for sale at six local restaurants in Chaloklum. A mix of fresh and saltwater species is displayed. Restaurant owners stated that all saltwater species were caught locally. Fish sizes were generally of larger-sized individuals and no juveniles were observed for sale. Please see Taylor (2016) for species and restaurant values

3.3 Fish Assemblage on the Metal Structures and Natural Reef Sites

A distinct fish assemblage between the natural and artificial reef types was observed, with species composition more similar within reef type than between reef locations, but more variable between the natural reef sites, than between the artificial reef sites (Fig. 16.6).

Taking into account all species observed on underwater fish surveys, the artificial reefs hosted only 12%. In comparison, the natural reef sites hosted 47% of the species observed, and a further 41% were shared. Although many common species were found between the two reef types; the metal structures missed important

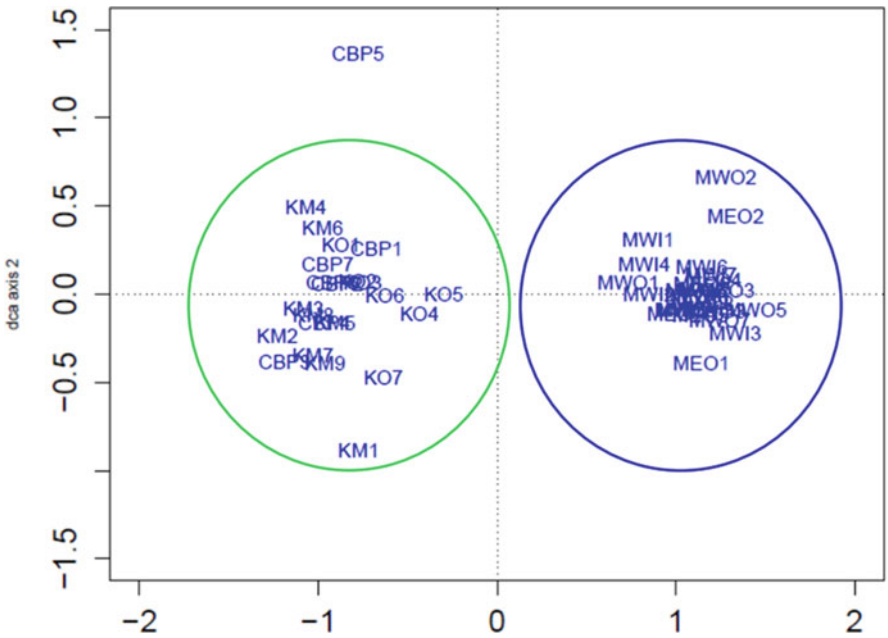


Fig. 16.6 DCA Ordination displaying similarities between and within reef type in regards to species composition. Note the distance between natural reef sites (left circle) and artificial reef sites (right)

functional groups such as Corallivores (*Chaetodon* sp.) and Herbivores/Scrapers (*Scarus* sp.) (Fig. 16.7). This contributed to a lower species richness. The natural reefs had a significantly higher number of species in comparison to the artificial reefs ($\chi^2 = 9.12$, df = 1, $P = 0.003$, $P < 0.05$), with no significant effect of visibility ($\chi^2 = 3.39$, df = 1, $P = 0.07$) or depth ($\chi^2 = 0.001$, df = 1, $P = 0.97$).

In contrast, the artificial reefs had a significantly higher total number of individuals per 100 m^2, with an approximately 17-fold difference in comparison to the natural reefs ($\chi^2 = 20.361$, df = 1, $P = 6.41 \times 10^{-6}$), the total abundance for each reef type increasing with increasing visibility ($\chi^2 = 31.06$, df = 1, $P = 2.5 \times 10^{-8}$), with no significant influence of water depth ($\chi^2 = 1.58$, df = 1, $P = 0.21$).

4 Discussion

While concrete blocks are the dominant form of artificial reef in Thailand, the metal structures in Chaloklum were described by an informant as the “first of their kind”. This fits with recent research, suggesting that the trend is now moving towards deploying recycled structures as these are more readily available at a lower cost

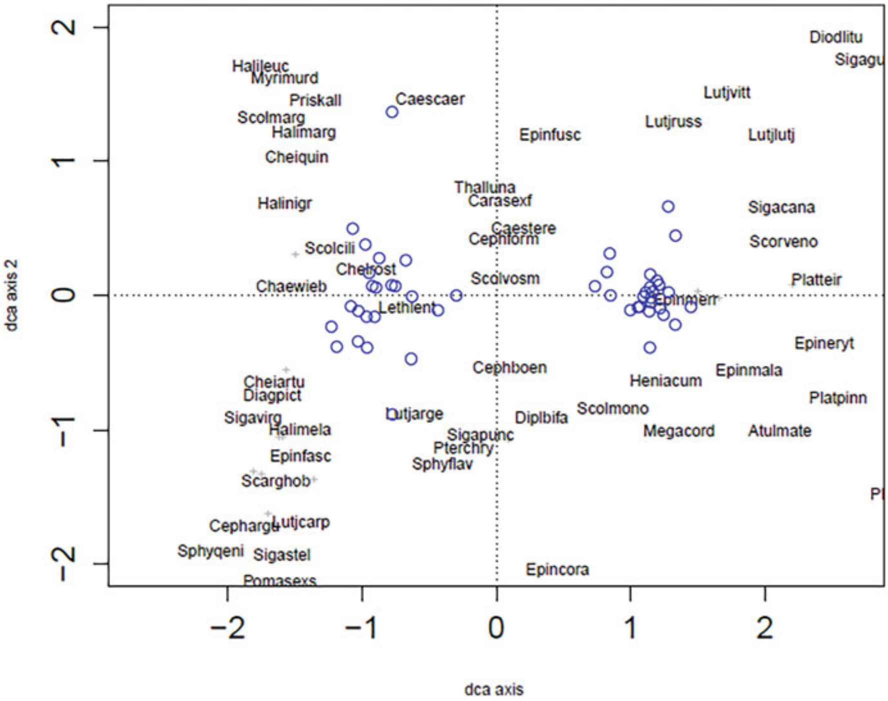


Fig. 16.7 DCA Ordination displaying species composition between reef types. Blue points represent natural and artificial locations as seen in Fig. 16.6. All species names shortened, displaying only most frequent species across plots. Species displayed on the right side of the ordination are more associated with the artificial reef sites while those on the left are more associated with the natural reef sites. Species associated with both reef types are located in the middle of the ordination diagram

(Kheawwongjan and Kim 2012). The ecological and economic performance of these structures is therefore important in addressing this trend.

Artificial reefs provide services and goods, such as habitat and coastal protection (Chou 1997; Moberg and Ronnback 2003; Pickering and Whitmarsh 1997; Rilov and Benayahu 2000), fishing and recreational enhancement (Chen et al. 2013; Leeworthy et al. 2006; Polovina 1991; Sutton and Bushnell 2007) and restoration and rehabilitation of natural reefs (Rilov and Benayahu 1998; Seaman 2000; Spieler et al. 2001). However, despite providing a variety of biological functions, they are primarily deployed for socio-economic reasons (Sutton and Bushnell 2007), to provide services deemed important for society, for example, by fishers' associations through private initiatives and funding (Chou 1997). In our case study, the objectives set out during deployment were to a certain extent met.

The metal structures were reported to effectively prevent trawlers from fishing within the demarcation line. In this case, the available structure, material and design had a positive outcome. However, it is important to note that trawl nets caught on reefs, whether natural and/or artificial can cause continuous problems for marine wildlife and divers alike. It is therefore important that GPS locations for the metal structures, as observed in this study, are regularly checked and included in navigation charts. Furthermore, the Buoys indicating their location must always be present and re-installed if lost due to stormy weather. The fourth metal structure, Metal East Inner, was specifically excluded from our case study for this reason. According to the DMCR, the location of this metal structure had been lost and was thought to be covered by a ghost net, labelling it unsafe for our divers. However, in April 2016 just before this study came to a close, DMCR and COREsea successfully found this structure on an exploration dive. A new Buoy was attached and DMCR were able to take an underwater visual census, including general habitat samples such as nutrients, salinity and oxygen. Unfortunately, no quantitative data exists in order to compare with the other three metal structures. As the two artificial reefs (Metal West Outer and Inner) are fairly close in our case study, survey data from the Metal East Inner could provide information over the possible synergistic effects or preference effects possibly leading to statistically non-independent artificial reef locations. This would be interesting for further studies, perhaps comparing the West and East locations along with the Outer and Inner structures.

Three of the five fishers suggested that over a 30-year time period there has been a large reduction in the number and diversity of fish on the natural reefs. Fishers' perceptions of the local reef sites over time suggested a decline in natural reef health, with bad fishing conditions in the last 5–10 years. Too many boats, especially larger ones that dwarfed the smaller fishers, and "too many fishermen coming from outside" of Koh Phangan were attributed as the main causes. This combined with "bad fishing weather" and unpredictable seasons saw a decline in fish catch. Declining fish catches have had a significant effect on fishers, pushing them to survive on marginal incomes (McManus et al. 2000). Nevertheless, a significant improvement was observed in the last 2–3 years. This was accredited to the introduction of new fishing laws, which stopped "outsiders" and larger boats from coming within 5.4 km of the rocks on either side of Chaloklum bay. This links with the introduction of the metal structures, which were deployed inside the boundary line between the small-scale and commercial fisheries zone (DOF 2008). This ensured usage only by artisanal fishers.

The metal structures were not currently used for recreational diving in our case study (Fig. 16.5). Dive managers reported the visibility and strong currents there were too unreliable and therefore, regarded as unsafe for newly certified divers. This unfortunately makes up a significant proportion of the dive customers in Koh Phangan. This is unfortunate as the redistribution of divers in a given area, through artificial reef deployment is important in reducing overcrowding and pressure on natural reefs (Leeworthy et al. 2006; Polak and Shashar 2012; Sutton and Bushnell 2007). Under optimal conditions, the artificial reefs could provide a unique new dive site, with opportunities to see a high abundance of fish, especially schooling and predatory species, as well as a distinct fish assemblage (Fig. 16.7) including large groupers (Serranidae spp.), batfish (Ephippidae spp.) and porcupine fish (Diodontidae spp.), in turn reducing dive pressure on the natural reef locations.

Dive managers and instructors interviewed in our case study openly expressed worries about the conditions of the local natural dive sites and an overuse of the main tourist site Sail Rock. Key themes were addressed including; reduction in coral cover and an increase in rubble, increase in coral damage, reduction in water quality and visibility, reduction in the variety and quantity of marine life (specifically, a lack of species such as nurse sharks, turtles, Christmas tree worms and nudibranchs). In addition, causal mechanisms for their above reasons were given including: negligence, increase in pollution and sediment runoff, higher volume of boats, divers and snorkelers, uncontrolled tourist development, an increase in hot summers and warmer waters, and overfishing. As a result, it seems the local dive community recognises the ongoing extent of natural reef degradation, to which they themselves contribute. Therefore, the addition of the metal structures in Koh Phangan, combined with the interest of dive customers to visit an artificial reef may have the potential to successfully divert diver's attention from natural sites in the future.

At the time of the study, the metal structures provided successful fishing grounds for artisanal fishers, who were the most prominent and direct users. Fishers stated, there are "lots of fish to catch" at the artificial reef, with 69% of identified target species being observed on fish surveys. Fishers showed a preference for marketable reef associated, pelagic, predators such as Carangidae, Lutjanidae, Scombridae and Sphyraenidae. These species are also valued on a regional scale contributing to the marine fisheries in Thailand (FAO 2020). Furthermore, reef-associated, non-pelagic, predators, such as the Serranidae family, were also highly valued by the fishers. These preferences support the general trend in fisheries for targeting higher trophic feeders (Jones et al. 2010). Nevertheless, target catch varied with each individual fisher. This was mainly due to differences in fishing location, depending on accessibility and boat size, plus, their dependability to sell. Fishing only for subsistence often meant all species caught were kept, despite value or size. Furthermore, fishers may withhold facts if they are not willing to reveal compromising information. In general, colourful reef-associated species such as Chaetodonidae, Labridae, and Pomacanthidae were not included in target lists. One fisher revealed that Pomacanthus annularis is occasionally caught in fish traps, but stated they are "beautiful to see, but aren't eaten". This may indicate the fishers' politeness to please the interviewer, knowing they are associated with the COREsea institute. On the other hand, it may suggest, fishers realise the aesthetic value of colourful fish for the tourism industry on Koh Phangan.

As seen with this project, artificial reefs do not necessarily mimic natural reefs but establish their own fish community (Figs. 16.6 and 16.7), which is influenced by spatial orientation, reef size, relief, surface area and structural complexity which influence the attractiveness of an artificial reef to target species (Rilov and Benayahu 2000; Simon et al. 2013). Age of deployment has also been suggested to play a role in species richness increasing over time (Bodilis et al. 2011; Simon et al. 2013; Yeemin et al. 2006). Furthermore, both rugosity (the measurement of surface roughness) and variety of growth forms are important predictors of observed species richness on artificial reefs, with vertical relief a strong predictor of total fish abundance (Gratwicke and Speight 2005).

The artificial reefs in this case study have a fairly monotonous topographic complexity with only two sizes of holes in the hollow steel tubes. These are covered by sponges and offer shelter for middle to large-sized fishes (20–80 cm) (Fig. 16.8). The outside of the steel tubes are covered by turf algae, sponges, crustaceans, echinoderms, molluscs and barnacles growing on top of each other, the latter offering hiding spaces for smaller fish species, such as damselfishes (up to 15 cm) (Fig. 16.8).

In comparison, the natural reefs in and around Chaloklum offer a much wider horizontal area of which 750 m^2 was surveyed. Furthermore, they offer a fairly complex topography with varying vertical relief due to the extensive range of growth forms, i.e., branching, massive and plate-like corals, thus providing shelter for fish of various sizes. This could explain why we see a significantly lower species richness on the artificial sites in comparison to the natural reef sites. Furthermore, the artificial reefs occupy a relatively small horizontal surface area, of which 144 m^2 was surveyed. This only accounted for the upper surface of the structure as lower parts of the structure could not be sampled due to logistical and safety reasons. Species thus associated with deeper vertical depths may not have been accounted for (Rilov and Benayahu 2000). It is important to note that abundances of Carangidae significantly increased at the artificial reefs, with increasing depth. Thus, for further studies, it is suggested that the vertical relief be taken into better consideration as seen in (Paxton et al. 2020), for they found that taller artificial reefs had higher densities of transient predators than the surrounding natural reefs, a pattern indicated in our case study.

Despite the relatively low complexity and short time since deployment, the artificial reefs offered 9 × 9 × 9 m of equally vertical and horizontal substrate, with sunny and shaded sides, in an otherwise structurally flat environment. Species in the families of Carangidae and Lutjanidae, as well as Scombridae and Sphyraenidae, had higher abundances on the artificial reefs in comparison to the natural reefs. These families were most probably drawn to the structures because of their transient behaviour—as fast-swimming, highly mobile, schooling species—and feeding traits (Folpp et al. 2013, Paxton et al. 2017, 2020). These species are likely to respond to the overall presence of an artificial reef as a feeding focal point, where vertically-extensive structures have been documented to host high abundances of schooling prey fish and thus, predators (Arena et al. 2007; Paxton et al. 2017; Simon et al. 2013). Furthermore, reef-associated, non-pelagic, predators, such as the Serranidae family also had a significantly higher abundance on the artificial reefs in comparison to the natural reefs in Chaloklum. Abundances surveyed increased with increasing visibility most probably due to the observed behaviour of hiding when divers approached (Fig. 16.8). Considering Serranidae as "resident" species, exhibiting high degrees of site fidelity and residence time (Paxton et al. 2020) and all sizes of *C. boenak*, *C. formosa* and *E. merra* observed at the artificial reefs, we suggest the structures not only provide food but additional habitat, including shelter and refuge area (Fig. 16.8), allowing for species-specific production.

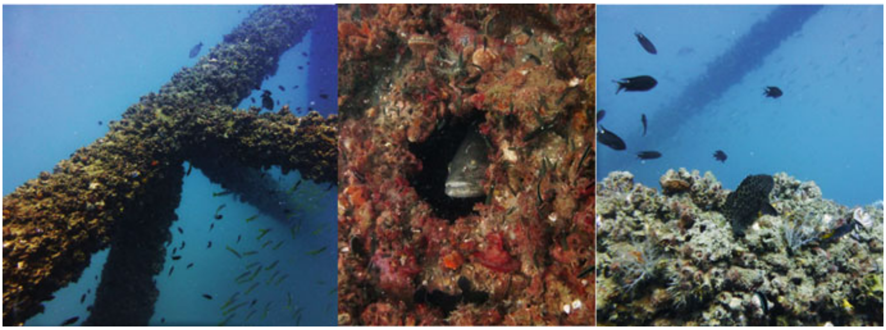


Fig. 16.8 East Outer Metal Reef: Two and a half years of succession provided small habitat and shelter to dwellers, such as Serranidae species. Hollow tubes and layering of barnacles and mussels supported larger and smaller fishes, indicating production, as well as providing a stop-over for pelagic fish on their migration routes

Fig. 16.9 Observational fishing trip with a local fishing and snorkel tour company at the metal west outer reef. Traditional fishing gear was used, handlines baited with sweet bread or squid, and a variety of species was caught

As 31% of target species specified by fishers were recorded only at the natural reefs, it seems the artificial reefs offered a reduced variety of seafood and cannot fully compensate for the ongoing reduction in fish stocks affecting local fishers. Adaptive measures were observed with local fishers participating in other economic sectors. Indeed, two of the younger fishers in our study had part-time work outside of fishing. On a national level, Thailand has seen a drop in the number of young fishers from 32.5 to 24.3 % within the last decade (DOF 2008). Jones et al. (2010) found similar results on the Andaman coast, with a noticeable decline in small-scale fishers being recruited into the industry. This was attributed to urbanisation and increasing opportunities within tourism. In this study, only two fishers wholly relied on fishing for their livelihoods. One purely fished for subsistence, whereas the other used his fishing boat to provide fishing and snorkelling tours (Fig. 16.9). Furthermore, one fisher owned a local beach bar and restaurant. Consequently, it demonstrates that tourism plays an increasing role in the fisher's livelihoods with the artificial reefs not only promoting target species and supporting subsistence fisheries but recreational fishing opportunities, thus meeting its' second and third deployment objectives.

Carangidae, Lutjanidae, Scombridae and Sphyraenidae were not only highly valued by the local fishers but by local restaurants too. Most saltwater species available for sale were also identified at the artificial reefs during underwater surveys. Despite the novel approach, using fishers' estimates rather than standard market prices to estimate the monetary value (Tuya et al. 2014), at a 21-fold difference in the total economic value between artificial and natural reefs, there is an indication that the establishment of these structures has direct local economic benefits. As the artificial reefs aggregated large amounts of economically important species, fishers' catch per unit effort was presumably increased. However, individual fishes observed during the visual census and caught by fishers were mostly juveniles. This could suggest that larger individuals move away from the structures or alternately a tendency of recruitment (over)fishing (Polovina 1989), which exacerbates the deterioration of populations, as the species' fecundity decreases. To have a more specific analysis of the structures' socio-economic benefits, more information including catch rates, catch size/weight and potential costs of fishing, such as gear prices, boat repairs, fuel etc., usually used in a cost-benefit analysis, need to be collected and taken into consideration (Supongpan 2006). Despite the artificial reefs' ability to produce and not just aggregate species, their sustainable management must be addressed, focussing on catch effort and fishing pressure to ensure sustainable use for the long-term support of the fishing community.

5 Conclusions, Lessons Learned and Changes in Policy

Despite the suggested benefits to small-scale fishers, artificial reef programs in Thailand have not managed to enhance and restock resources. In fact, the FAO (2020) states that the biomass of exploitable fish stocks has fallen within marine capture fisheries, mostly through the release of untreated sewage and illegal, unreported and unregulated (IUU) fishing. Both commercial fishing and small-scale fishing have shown a declining trend since 2002 (FAO 2020). However, the decline of fish stocks in Thailand's coral reefs has been attributed to commercial fishers rather than artisanal fishers (Jones et al. 2010).

Being the socio-economic backbone of coastal communities in Southeast Asia, small-scale fishers are heavily reliant upon local catch, often contributing more food fish for humans than industrial fisheries (Teh and Pauly 2018; Teh et al. 2013). In order to protect them, new reforms and policies have been implemented in recent years to improve fishing and coastal conditions in Thailand. The Royal Ordinance on Fisheries which came into force in 2015 as the new fisheries law, introduced robust financial sanctions for engaging in illegal fishing, new restrictions on destructive gear types, and basic protections for artisanal fisher rights through the introduction and enforcement of the Inshore Economic Zone—a zone currently set at 3 nautical miles (5.5 km) from shore, and reserved for artisanal/small-scale fishing vessels) (Environmental Justice Foundation 2019). Thailand has also fought to control IUU fishing by introducing new monitoring systems such as satellite tracking and unique vessel identifiers, enabling authorities to verify vessel identity and ownership, as well as collecting precise fishing locations, durations, and times, helping to detect unauthorised fishing activity (Environmental Justice Foundation 2019). Furthermore, Thailand has established a network of 30 "Port in Port out" (PIPO) centers across the country, which can liaise vessel information with at-sea patrols conducted by the Royal Thai Navy, DoF, Marine Department, and other relevant agencies (Environmental Justice Foundation 2019).

In 2019, the Thai fishing industry received approval from the European Commission through its compliance with international law, enforcement of its fisheries legal framework, and its curbing of IUU fishing (European Commission 2019). Over 75% of fishers interviewed by the Environmental Justice Foundation (2019) suggested that these recent reforms have minimised intrusions by commercial vessels into restricted areas, allowing fish stocks, especially the prevalence of juvenile economically important species, to recover. This trend is in line with our interviews conducted in Koh Phangan. By deploying the metal structures around the demarcation line, trawlers and big commercial vessels no longer had access to local natural reef sites around Chaloklum. Fishers and COREsea members alike suggested positive outcomes from these new regulations and the deployment of the artificial reefs. Fishers suggested an increased catch in the last 2–3 years and praised the artificial reefs, for their ability to promote and aggregate marketable species; supporting not only the fishers directly but local restaurants and markets too. Furthermore, the COREsea manager suggested an increase in coral cover on the natural reef sites, within the last 5 years. These results, despite being anecdotal, suggest that (a) the metal structures have succeeded in reducing fishing pressure at local natural reef sites, and (b) positive attitudes are displayed towards the artificial reefs, an important factor when considering the success of any conservation tool (Bennett and Dearden 2014).

To continue on this path and protect Thailand's traditional fishing communities, strict enforcement of the IEZ, diligent vessel monitoring and thorough vessel inspections should be made. Furthermore, local case studies throughout Southeast Asia have shown positive social and environmental changes, regarding integrated coastal management and resource use, by strengthening interagency and inter-sector cooperation, increasing policy-science integration, building local capacity and creating innovative financing for long-term investments (Chua et al. 2018). Such factors should be taken into consideration during artificial deployment and long-term monitoring, to ensure that the positive socio-economic and/or positive ecological impact is not short lived.

References

Arena PT, Jordan LKB, Spieler RE (2007) Fish assemblages on sunken vessels and natural reefs in southeast Florida, USA. Hydrobiologia 580:157–171. https://doi.org/10.1007/s10750-006-0456-x

Bennett NJ, Dearden P (2014) Why local people do not support conservation: Community perceptions of marine protected area livelihood impacts, governance and management in Thailand. Mar Policy 44:107–116

Bodilis P, Dombrowski E, Seytre C, Francour P (2011) Monitoring of the artificial reef fish assemblages of the marine protected areas along the alpes-maritimes coast (France, North-Western Meditteranean). In: Ceccaldi HJ, Dekeyser I, Girault M, Stora G (eds) Global change: mankind-marine environment interactions. Springer

Bortone SA, Samoilys MA, Francour P (2000) Fish and macroinvertebrate evaluation methods. In: Artificial reef evaluation with application to natural marine habitats. CRC, Boca Ratón, Florida, EEUU, pp 127–164

Brock VE (1954) A preliminary report on a method of estimating reef fish populations. J Wildlife Manag 18(3):297–308. https://doi.org/10.2307/3797016

Butcher JG (2004) The closing of the frontier: a history of the marine fisheries of Southeast Asia c. 1850-2000. Institute of Southeast Asian Studies (ISEAS) - Yusof Ishak Institute, Singapore

Cheevaporn V, Menasveta P (2003) Water pollution and habitat degradation in the Gulf of Thailand. Mar Pollut Bull 47(1–6):43–51. https://doi.org/10.1016/S0025-326x(03)00101-2

Chen JL, Chuang CT, Jan RQ, Liu LC, Jan MS (2013) Recreational benefits of ecosystem services on and around artificial reefs: a case study in Penghu, Taiwan. Ocean Coast Manag 85:58–64. https://doi.org/10.1016/j.ocecoaman.2013.09.005

Choowong M (2002) The geomorphology and assessment of indicators of sea-level changes to study coastal evolution from the Gulf of Thailand. In: Proceedings of international symposium on “Geology of Thailand”, Department of Mineral Resources, Thailand

Chou LM (1997) Artificial reefs of Southeast Asia—do they enhance or degrade the marine environment? Environ Monit Assess 44(1–3):45–52. https://doi.org/10.1023/A:1005759818050

Chua TE, Chou LM, Jacinto G, Ross SA, Bonga D (2018) Local contributions to global sustainable agenda: case studies in integrated coastal management in the East Asian Seas Region. Partnerships in environmental management for the seas of East Asia (PEMSEA), Coastal Management Center (CMC), Quezon City, Philippines

Cinner JE, McClanahan TR, Daw TM, Graham NAJ, Maina J, Wilson SK, Hughes TP (2009) Linking social and ecological systems to sustain coral reef fisheries. Curr Biol 19(3):206–212. https://doi.org/10.1016/j.cub.2008.11.055

Department of Fisheries (DOF) (2008) Ministry of Agriculture and Cooperative, 2008. The Master Plan: Marine Fisheries Management of Thailand

Department of Fisheries (DOF) (2015) Ministry of Agriculture and Cooperatives, Thailand, 2015. Marine Fisheries Management Plan of Thailand—A National Policy for Marine Fisheries Management. https://www.iotc.org/documents/marine-fisheries-management-plan-thailand-national-policy-marine-fisheries-management-2015

Derrick B, Noranarttragoon P, Zeller D, Teh LCL, Pauly D (2017) Thailand’s missing marine fisheries catch (1950-2014). Front Mar Sci 4. https://doi.org/10.3389/fmars.2017.00402

Environmental Justice Foundation (2015) Pirates and slaves: how overfishing in Thailand fuels human trafficking and the plundering of our oceans. https://ejfoundation.org/resources/downloads/EJF_Pirates_and_Slaves_2015_0.pdf

Environmental Justice Foundation (2019) Thailand’s road to reform: securing a sustainable, legal and ethical fishery https://ejfoundation.org/resources/downloads/ThailandRoadToReform.pdf

European Commission (2019) January 8th. Commission lifts “yellow card” from Thailand for its actions against illegal fishing [Press release]. https://ec.europa.eu/commission/presscorner/detail/en/IP_19_61

FAO (2020) Fishery and aquaculture country profiles: The Kingdom of Thailand. http://www.fao.org/fishery/facp/THA/en#CountrySector-StatusTrends

Folpp H, Lowry M, Gregson M, Suthers IM (2013) Fish assemblages on estuarine artificial reefs: natural rocky-reef mimics or discrete assemblages? PLoS One 8(6). https://doi.org/10.1371/journal.pone.0063505

Froese R, Pauly D (2016) FishBase. Fisheries Centre, University of British Columbia

Gratwicke B, Speight MR (2005) The relationship between fish species richness, abundance and habitat complexity in a range of shallow tropical marine habitats. J Fish Biol 66(3):650–667. https://doi.org/10.1111/j.0022-1112.2005.00629.x

Jones EV, Gray TS, Umponstira C (2010) Small-scale fishing: perceptions and threats to conserving a livelihood in the province of Phang-Nga, Thailand. Environ Asia 3(1):1–7

Kheawwongjan A, Kim DS (2012) Present status and prospects of artificial reefs in Thailand. Ocean Coast Manag 57:21–33. https://doi.org/10.1016/j.ocecoaman.2011.11.001

Kittel I (2016) Ecosystem services provided by artificial reefs in the Gulf of Thailand—Associated Fish Communities, their Diversity, Abundance and Biomass University of Bremen, Bremen

Leeworthy VR, Maher T, Stone EA (2006) Can artificial reefs alter user pressure on adjacent natural reefs? Bull Mar Sci 78(1):29–38

McManus JW (1988) Coral reefs of the ASEAN region: status and management. Ambio 17(3): 189–193

McManus JW, Menez LAB, Kesner-Reyes KN, Vergara SG, Ablan MC (2000) Coral reef fishing and coral-algal phase shifts: implications for global reef status. Ices J Mar Sci 57(3):572–578. https://doi.org/10.1006/jmsc.2000.0720

Moberg F, Ronnback P (2003) Ecosystem services of the tropical seascape: interactions, substitutions and restoration. Ocean Coast Manag 46(1-2):27–46. https://doi.org/10.1016/S0964-5691(02)00119-9

Paxton AB, Pickering EA, Adler AM, Taylor JC, Peterson CH (2017) Flat and complex temperate reefs provide similar support for fish: Evidence for a unimodal species-habitat relationship. PLoS One 12(9). https://doi.org/10.1371/journal.pone.0183906

Paxton AB, Newton EA, Adler AM, Van Hoeck RV, Iversen ES, Taylor JC, Peterson CH, Silliman BR (2020) Artificial habitats host elevated densities of large reef-associated predators. PLoS One 15(9). https://doi.org/10.1371/journal.pone.0237374

Phongsuwan N, Chankong A, Yamarunpatthana C, Chansang H, Boonprakob R, Petchkumnerd P, Thongtham N, Paokantha S, Chanmethakul T, Panchaiyapoom P, Bundit OA (2013) Status and changing patterns on coral reefs in Thailand during the last two decades. Deep Sea Res Part II Topical Stud Oceanogr 96:19–24. https://doi.org/10.1016/j.dsr2.2013.02.015

Pickering H, Whitmarsh D (1997) Artificial reefs and fisheries exploitation: A review of the 'attraction versus production' debate, the influence of design and its significance for policy. Fish Res 31(1-2):39–59. https://doi.org/10.1016/S0165-7836(97)00019-2

Polak O, Shashar N (2012) Can a small artificial reef reduce diving pressure from a natural coral reef? Lessons learned from Eilat, Red Sea. Ocean Coast Manag 55:94–100. https://doi.org/10.1016/j.ocecoaman.2011.10.006

Polovina JJ (1989) Artificial reefs—nothing more than benthic fish aggregators. Calif Cooper Ocean Fish Investig Rep 30:37–39

Polovina J (1991) Fisheries applications and biological impacts of artificial habitats. In: Artificial habitats for marine and freshwater fisheries. Academic, New York

Pratchett MS, Hoey AS, Wilson SK, Messmer V, Graham NA (2011) Changes in biodiversity and functioning of reef fish assemblages following coral bleaching and coral loss. Diversity 3(3): 424–452

Rilov G, Benayahu Y (1998) Vertical artificial structures as an alternative habitat for coral reef fishes in disturbed environments. Mar Environ Res 45(4–5):431–451. https://doi.org/10.1016/S0141-1136(98)00106-8

Rilov G, Benayahu Y (2000) Fish assemblage on natural versus vertical artificial reefs: the rehabilitation perspective. Mar Biol 136(5):931–942. https://doi.org/10.1007/s002279900250

Seaman W (2000) Artificial reef evaluation: with application to natural marine habitats. CRC, Boca Raton, FL

Seenprachawong U (2016) An economic analysis of coral reefs in the Andaman Sea of Thailand. In: Marine and coastal ecosystem valuation, institutions, and policy in Southeast Asia. Springer, pp 31–45

Simon T, Joyeux JC, Pinheiro HT (2013) Fish assemblages on shipwrecks and natural rocky reefs strongly differ in trophic structure. Mar Environ Res 90:55–65. https://doi.org/10.1016/j.marenvres.2013.05.012

Spieler RE, Gilliam DS, Sherman RL (2001) Artificial substrate and coral reef restoration: What do we need to know to know what we need. Bull Mar Sci 69(2):1013–1030

Sudara S., Yeemin T (1997) Status of coral reefs in Thailand. In: Grigg RW, Birkeland C (eds) Status of coral reefs in the Pacific. Sea Grant College Program, School of Ocean and Earth Science and Technology, University of Hawaii, CP-98-01, pp 135–144

Supongpan S (2006) Artificial reefs in Thailand. Training Department, Southeast Asian Fisheries Development Center

Sutton SG, Bushnell SL (2007) Socio-economic aspects of artificial reefs: Considerations for the great barrier reef marine park. Ocean Coast Manag 50(10):829–846. https://doi.org/10.1016/j.ocecoaman.2007.01.003

Taylor N (2016) Socio-ecological assessment of artificial reef use in the Gulf of Thailand. MSc. Thesis. University of Bremen, Bremen, Germany

Teh LC, Pauly D (2018) Who brings in the fish? The relative contribution of small-scale and industrial fisheries to food security in Southeast Asia. Front Mar Sci 44

Teh LSL, Teh LCL, Sumaila UR (2013) A global estimate of the number of coral reef fishers. PLoS One 8(6). https://doi.org/10.1371/journal.pone.0065397

Tuya F, Haroun R, Espino F (2014) Economic assessment of ecosystem services: Monetary value of seagrass meadows for coastal fisheries. Ocean Coast Manag 96:181–187. https://doi.org/10.1016/j.ocecoaman.2014.04.032

UN ESCAP (2015) The State of Asian and Pacific Cities 2015: Urban transformations Shifting from quantity to quality

Wattayakorn G (2006) Environmental issues in the Gulf of Thailand. In: Wolandski E (ed) The environment in Asia Pacific harbours. Springer, Dordrecht, pp 249–259

Wilkinson C (2008) Status of coral reefs of the world: 2008. Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre, Townsville

Wong PP (1998) Coastal tourism development in Southeast Asia: relevance and lessons for coastal zone management. Ocean Coast Manag 38(2):89–109. https://doi.org/10.1016/S0964-5691(97)00066-5

Wongthong P, Harvey N (2014) Integrated coastal management and sustainable tourism: A case study of the reef-based SCUBA dive industry from Thailand. Ocean Coast Manag 95:138–146. https://doi.org/10.1016/j.ocecoaman.2014.04.004

Worachananant S, Carter RW, Hockings M, Reopanichkul P (2008) Managing the impacts of SCUBA divers on Thailand's coral reefs. J Sustain Tour 16(6):645–663. https://doi.org/10.2167/jost771.0

World Bank (2006) Thailand—environment monitor 2006. World Bank

Yeemin T, Sutthacheep M, Pettongma R (2006) Coral reef restoration projects in Thailand. Ocean Coast Manag 49(9–10):562–575. https://doi.org/10.1016/j.ocecoaman.2006.06.002

Yeemin T, Saenghaisuk C, Sutthacheep M, Pengsakun S, Klinthong W, Saengmanee K (2009) Conditions of coral communities in the Gulf of Thailand: a decade after the 1998 severe bleaching event. Galaxea J Coral Reef Stud 11(2):207–217

Chapter 17
Peru Case Study

Big Challenges for Small Islands: Management and Governance of "Lobos de Afuera" Islands in the Peruvian Upwelling Ecosystem

Alonso Del Solar, Eliana Alfaro-Cordova, Tania Mendo, Kelly Ortega-Cisneros, Milena Arias Schreiber, Jorge Grillo-Núñez, and Joanna Alfaro-Shigueto

Abstract The management of coastal marine ecosystems requires a multi-sectorial, multidisciplinary approach, where both public and private sectors work together towards the conservation and sustainable use of the ecosystems. In an ideal scenario, the values and interests of all stakeholders should be considered in management strategies aligned with national and international norms and regulations. To this end, the establishment of Marine Protected Areas (MPAs) could provide a platform for stakeholders to collaborate and achieve common management and conservation goals. In Peru, the "Guano Islands, Isles and Capes National Reserve System" was

A. Del Solar (✉)
Resource Management Working Group, Leibniz Centre for Tropical Marine Research, Bremen, Germany

E. Alfaro-Cordova
ProDelphinus, Lima, Peru

Carrera de Biología Marina, Universidad Científica del Sur, Lima, Peru

T. Mendo
Scottish Oceans Institute, University of St Andrews, East Sands, UK

K. Ortega-Cisneros
Department of Biological Sciences, University of Cape Town, Cape Town, South Africa

M. Arias Schreiber
School of Global Studies, University of Gothenburg, Gothenburg, Sweden

J. Grillo-Núñez
REDES – Sostenibilidad Pesquera, Lima, Peru

J. Alfaro-Shigueto
ProDelphinus, Lima, Peru

Carrera de Biología Marina, Universidad Científica del Sur, Lima, Peru

School of Biosciences, University of Exeter, Exeter, UK

M. Wolff et al. (eds.), *Challenges in Tropical Coastal Zone Management*,
https://doi.org/10.1007/978-3-031-17879-5_17

established in 2009 to conserve the biodiversity of the Northern Humboldt Current System. This MPA consists of 22 islands and isles, 11 capes, and their adjacent sea, divided into 25 polygons that cover 140,000 ha, representing a big challenge in terms of management. In this chapter, we draw upon the case study of the octopus fishery in the polygon named Lobos de Afuera Islands (ILA) at the northern part of the MPA, to analyse the advances and setbacks, as well as the challenges associated with stakeholders participation, in relation to the accomplishment of the sustainability goals defined for this polygon. We assess institutional and knowledge challenges for ILA and describe how the deficient acknowledgment of users, the ecological knowledge gaps and a complex administrative system, which involves many institutions, have hindered the understanding of the social-ecological system and the islands management and governance desired outcomes. The neglect to acknowledge the octopus fishers as longtime users of ILA, due to the current illegal status of their fishery in northern Peru, and therefore as formal stakeholders in the polygon's management, decreases the possibility of applying appropriate co-management strategies. However, a group of octopus divers has recently been formalised into a fishers association and aim at being accepted as formal stakeholders of ILA, through ongoing capacity building related to data collection and organisational skills. The problems of the rigid, inefficient, and limited institutional setup at ILA are also opportunities for identifying bottlenecks and blackboxes, from where research priorities towards an integrated management strategy can be outlined. The increased knowledge of this social-ecological system can also be extended to the whole Guano Islands MPA, where additional flexibility and operational capacities will be needed due to the connectivity among many polygons. Potential pathways towards useful ecosystem-based management may include the emergence of transversal government bodies that can respond faster to the MPA's inner dynamic and to external pressures, allowing for a less bureaucratic and more integrated approach to management. Moreover, MPA authorities could promote signing general and specific agreements with public and private institutions, prioritising lines of research beyond sporadic projects, towards long-term sustainable management in ILA. The lessons and challenges here presented could also serve to improve the design and implementation of future MPAs in Peru to meet its international commitments.

Keywords Peruvian coast · Lobos de Afuera Islands · MPA · Governance · Marine conservation · Resource management · Small-scale fisheries

1 Introduction

The rapid growth of human populations inhabiting coastal areas, along with advances in technology and the soaring worldwide demand for seafood products, are impacting marine ecosystems and the goods and services they provide. Global, regional, and local social-ecological dynamics, including high-impact anthropogenic stressors, such as resource overexploitation and pollution, are becoming particularly complex issues to address, evermore in the face of climate change. Maintaining the health and fostering resilience of marine ecosystems is not only important for their own sake and beauty, but crucial for the livelihoods of coastal communities directly benefiting from them (i.e. through fisheries, tourism, or other ecosystem services), as well as for sustaining seafood production industries worldwide. Thus, governments and other institutions dealing with resource management have the responsibility to present strategies that secure ecosystems services, while guaranteeing sustainable livelihoods.

Addressing this complex situation can often lead to conflicting ideas regarding the conservation, exploitation, management, and sustainability of marine ecosystems. Even with the advances made over the past few decades on implementing ecosystem-based management (Pikitch et al. 2004), efforts towards adequate governance and management measures remain one of the key environmental and development challenges of the present century. Evidently, not all social-ecological systems behave alike, thus not one single approach is sufficient to ensure the sustainable use of marine resources and to safeguard the oceans for human wellbeing and intergenerational equity. To this end, there is much debate among scientific, stakeholder, and political circles on effective regulatory instruments and social innovations that would facilitate an integrated sustainable development of coastal social-ecological systems.

Among regulatory instruments, Marine Protected Areas (MPAs) have been designed and implemented with varying results for many decades (Edgar et al. 2014). MPAs allow managers and stakeholders to protect certain fragile or functionally important ecosystems, while controlling the impacts of economic activities such as fisheries. Ideally, an MPA will allow for more public awareness, improved academic work, and adequate enforcement of relevant regulations through collaboratively established plans and goals; backed up by both public and private stakeholders. However, not all MPAs are based on the best scientific evidence and are sometimes used as legitimised exclusion zones. Wolff (2015) argues that MPAs should not be created simply to prevent specific activities (e.g. fishing), but rather should lead the way to share the ocean via the appropriate assessment and management tools. Nevertheless, evidence has highlighted the conservation benefits of MPAs, which include positive effects on species and functional diversity, the rebuilding of depleted fish stocks, and the preservation of ecosystems and their services (Halpern 2003; Lester et al. 2009; Martins et al. 2012; Worm et al. 2006).

In the Peruvian Upwelling System, one of the most productive systems in the world in terms of fisheries (Carr 2001; Chavez et al. 2008), there are currently only four out of eleven protected coastal areas that include marine ecosystems. This corresponds to approximately 0.6% of Peru's exclusive economic zone (EEZ). In contrast, terrestrial protected areas cover ~21% of the total land area of Peru. The current MPA coverage in Peru lags behind the international commitments of protecting at least 10% of coastal and marine areas by 2020 and 30% by 2030,[1] though this last commitment is not binding and it is even disputed if participants

[1] WCC-2016-Res-050-EN

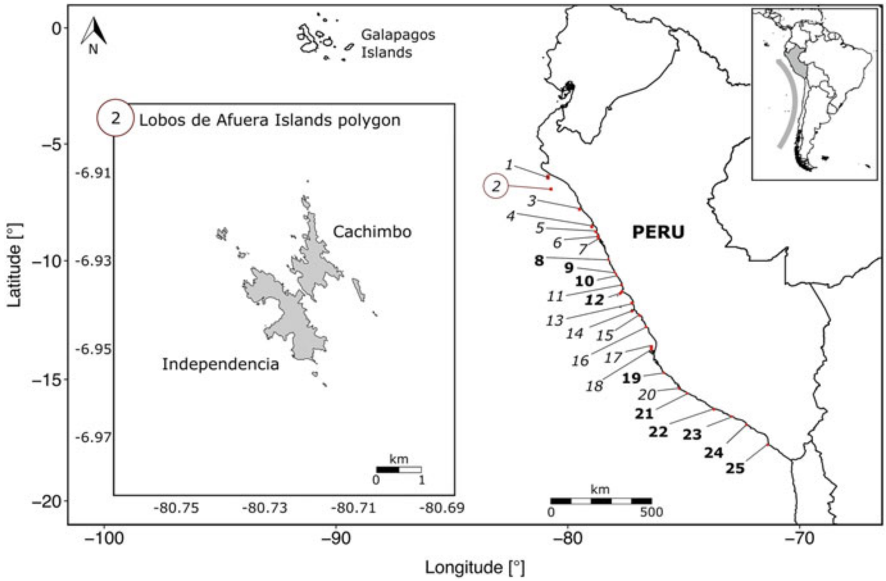


Fig. 17.1 Location of the twenty-five polygons comprising the Guano Islands MPA, and a close-up of our study site, in Peru, western coast of South America. Numbers along the coast represent the polygons; in *italics*, the islands and isles, and in **bold**, the capes. From north to south: (1) Lobos de Tierra, (2) Lobos de Afuera, (3) Macabi, (4) Guanyape, (5) Chao, (6) Corcovado, (7) Santa, (8) Culebras, (9) Colorado, (10) La Litera, (11) Don Martín, (12) Mazorca, Huampanu & Salinas, (13) Grupo de Pescadores, (14) Cavinzas & Palomino, (15) Pachacamac, (16) Asia, (17) Chincha, (18) Ballesta, (19) Lomitas, (20) San Juan, (21) Lomas, (22) Atico, (23) La Chira, (24) Hornillos, (25) Coles

agreed on such an arbitrary number (Charles et al. 2016). The aim should be to achieve MPAs that are managed effectively, not just established in paper.

The Peruvian coastline contains several capes, tips and bays, as well as a series of islands and islets that run parallel to the coast along the continental shelf. They span almost twelve degrees of latitude (~6–18° S) and are located within the first 32 nm (60 km) offshore (Fig. 17.1). These islands and capes, in conjunction with the nutrient-filled upwelling waters, provide the conditions for highly diverse and abundant ecosystems with a very rich trophic structure. They serve as habitat for many species of fish and shellfish, birds, reptiles, and mammals, which use them as reproduction sites, nurseries, and feeding grounds, or as a temporal resting place or refuge. Seabirds have historically taken possession of the islands and high capes to use them as nesting or resting grounds. They feed mostly on small pelagic fish such as sardines *(Sardinops sagax)* or the Peruvian anchovy (*Engraulis ringens*) (Jordan 1967; Vogt and Duffy 2018; Zavalaga and Paredes 1999) and tend to migrate long distances (Weimerskirch et al. 2012; Zavalaga et al. 2011). Due to the large amount of excreta produced by these seabirds—mainly cormorants, pelicans, and boobies, which not only form huge piles on land but also fertilise the surface of the ocean—this system is commonly known as the *guano islands, isles, and capes.* The fact that they are categorised as continental islands suggests a strong geological and ecological connectivity between them and mainland, which is key for understanding the functionality of the system. In 2009, the guano islands, isles, and capes system was given the status of National Marine Reserve named as "The Guano Islands, Isles and Capes National Reserve System" (hereafter, Guano Islands MPA).

In the present chapter, we develop a case study within this MPA, at "Lobos de Afuera" Islands (hereafter, ILA) in northern Peru and its artisanal octopus fishery (*Octopus mimus*). We describe the ecosystem, characterise its octopus fishery and assess the progress made in relation to ILA's MPA objectives, aiming at identifying institutional limitations, knowledge gaps and challenges to its management and governance. The bulk of this chapter was written in 2019. However, we have updated some information on the main status of the MPA, to the best of our knowledge.

2 Resource Use Within the Guano Islands MPA: Octopus Fishery in Lobos de Afuera Islands

2.1 Guano Islands MPA

The management of Natural Protected Areas in Peru is led by the National Parks Service (SERNANP, Ministry of Environment), through the National System of Natural Protected Areas (SINANPE). The Guano Islands MPA is a National Reserve and, as such, SERNANP can establish different conservation levels for each area, following the framework used for terrestrial protected areas: (1) Strict protection, (2) Wild zone, (3) Tourism and recreation, (4) Direct use, (5) Special use, (6) Recovery, and (7) Historical-Cultural. Each polygon in the Guano Islands MPA is classified based on scientific information and the approval of the main stakeholders. Furthermore, because this MPA includes marine areas with fisheries as the main economic activities, part of the responsibility in the MCS activities has to be shared with the Ministry of Production and the Navy (Ministry of Defence). The Ministry of Agriculture is also involved through AGRO RURAL, which safeguards the island guano and by extension the guano birds.

The Guano Islands MPA consists of 22 islands and 11 capes divided into 25 geographical areas named "polygons" for management purposes adding up to a total area of 140,833.47 ha (Fig. 17.1, Valverde et al. 2016). Each polygon comprises an area of at least one insular or continental landmass surrounded by water extending roughly two nautical miles offshore. The MPA was established to "conserve a representative sample of the marine biodiversity from the Northern Humboldt Current Upwelling System, ensuring the continuation of natural processes as well as the sustainable and fair use of its resources".[2] It currently has a so-called

[2] Supreme Decree N° 024-2009-MINAM

management committee that groups all stakeholders along the MPA (users, government, civil society, others). Considering the extent of the Guano Islands MPA, this committee was divided into 25 sub-committees, one per polygon. These committees are not decision-making bodies but provide a space for discussion and knowledge exchange among actors, which can serve as guidelines for managers.

In 2016, the Guano Islands MPA master plan for the period 2016–2020 was published. This master plan is the roadmap to implementing any project in the MPA and assigns general and specific objectives under three main categories: (1) environmental: to conserve terrestrial and marine ecosystems, (2) economical: to develop sustainable activities, and (3) sociocultural: to promote the participation of local stakeholders in management (Valverde et al. 2016). Since the establishment of this MPA, the Ministry of Environment's National Parks Service (SERNANP) has received external international financial and technical support to help implement its master plan and strengthen the capabilities of stakeholders, with emphasis on ecosystem-based management and appropriate monitoring, control and surveillance (MCS) tools and policies. This was the case of the project "Strengthening Sustainable Management of the Guano Islands MPA", through which SERNANP called for proposals to carry out subprojects and address the objectives posed in the master plan for the different polygons within the MPA. One of these subprojects was developed for the polygon ILA, which spanned from October 2017 to February 2019 and was implemented by a multidisciplinary team led by the Peruvian NGO *Pro Delphinus* (under SERNANP's supervision). A summary of some of the results and challenges of this project (hereafter, ILA-subproject) is included in this chapter.

Lobos de Afuera Islands (ILA) are located at the northern part of the Guano Islands MPA, close to the ecotone between the NHCUS and the warmer Tropical East Pacific (TEP) waters (De La Cruz et al. 2017). Of the 22 islands in the MPA, these are the farthest offshore, close to the edge of the continental shelf, 45 nm (~84 km) from the nearest mainland port. ILA consists of two main islands that are separated by a narrow 30-m long channel surrounded by a handful of smaller islets (Fig. 17.2). ILA has a total area of 8265 ha, 97% of which is water, representing about a 2–3 nm radius around the islands.

Because ILA's rocky shores are exposed to high wave impact, the intertidal community has only a few species of crustaceans and mollusks. Among them, the barnacle *Pollicipes elegans* was a highly demanded crustacean used in local gastronomy but no longer abundant around these islands. In the sub-tidal region, biodiversity and abundance are larger. A survey reported by De La Cruz et al. (2017) found 47 species of fish within two miles around the islands and down to thirty metres depth.

Commercially important molluscs are mostly found on the protected east side of the islands. Towards deeper waters, several demersal and pelagic resources either pass through or approach the islands for feeding and/or mating (De La Cruz et al. 2017). Besides marine mammals identified by Figueroa et al. (2017) (i.e. *Otaria byronia*, *Megaptera novaeangliae*, *Tursiops truncatus*, and *Delphinus capensis*), blue whale (*Balaenoptera musculus*) have been recently observed in the surroundings (Alfaro-Cordova pers. comm.). On land, ILA provides reproductive and resting

Fig. 17.2 Views of Lobos de Afuera Islands. Source: ILA-subproject. Lobos de Afuera Islands MPA (top: Lyanne Ampuero, bottom: ProDelphinus)

grounds for several species feeding on fish close-by or using these areas as a stop on their long migration routes. Figueroa et al. (2017) identified the South American sea lion and 43 species of seabirds, all of which fit into some category or status of conservation under Peruvian legislation. The introduction of the common rat, one of the permanent residents on the islands, represents a particular threat to eggs and youngsters of nesting birds and reptiles (Ampuero et al. 2018).

Table 17.1 Summary of the artisanal fisheries characteristics identified during the ILA-subproject

Operating distance from shore (nm)	Fishers organisations			Main species targeted
	Number	Main gear used		
0–2	8	75.0%	Air-assisted diving	Octopus “pulpo” *Octopus mimus*
		12.5%	Hand-line	Peruvian rock seabass “cabrilla” *Paralabrax humeralis*
		12.5%	Purse-seine net	
2–5	10	41.7%	Hand-line	Eastern pacific bonito “bonito” *Sarda chiliensis* Chub mackerel “caballa” *Scomber japonicus*Peruvian rock seabass “cabrilla” *Paralabrax humeralis* Sharks and rays
		33.3%	Drift and bottom nets	
		25.0%	Purse-seine net	
5–15	4	75.0%	Purse-seine net	Eastern pacific bonito “bonito” *Sarda chiliensis*
		25.0%	Hand-line-P[a]	Giant squid “pota” *Dosidicus gigas*

Note: 18 fishers organisations were identified, but 4 of them fish both in the first 2 nm and from 2 to 5 nm, so the table adds up to 22 organisations
Source: Grillo et al. (2018)
[a]Refers to the special multi-hook sample hand-line used for catching giant squid

2.2 Small-Scale Fisheries in ILA

Fisheries at ILA have been restricted since 2001 through two main National Decrees[3]: a Presidential ban on motorised fishing vessels within 2 nm of any guano island, and a prohibition enacted by the Defence Ministry on all fishing activities up to 200 m from the shore. Nevertheless, different small-scale and industrial fishing fleets have since been reported within the first 5 nm (9.3 km) surrounding the islands, targeting demersal and pelagic species of fish and shellfish and using mainly drift, bottom, purse-seine nets and air-assisted diving (De La Cruz et al. 2017; Table 17.1). A recent characterisation of the small-scale fisheries operating around ILA estimated 118 small vessels (6–9 m length) organised in 18 fishing organisations, from which 3 were identified as “not formally established” (Grillo et al. 2018). It is worth noting that members of 4 further organisations were identified fishing in both the first 2 nm and within 2–5 nm, adding up to 22 organisations in Table 17.1.

To arrive at ILA, small-scale fishers usually travel between 8 and 17 h from different nearby ports. Some of the boats set sail together and the length of the duration of a fishing trip depends mainly on the season, environmental conditions,

[3]D.S. N°-014-2001-AG, 2001 ; D.S. N°-028-DE, 2001

and the size of the boat's hold. Fishing trips during the winter last approximately 15 days in total, compared to an average of 10 during the summer, when environmental conditions are favourable for the availability of most of the targeted resources. This means that fishers not only get higher yields during the summer but engage in more trips to ILA, thus increasing their effort considerably.

Outside the limits of the ILA MPA, fishers catch mainly bonito, mackerel, rock seabass, sharks, rays, and giant squid. The fishery inside the reserve is usually multi-specific but targets principally octopus (*Octopus mimus*) and Peruvian rock seabass (*Paralabrax humeralis*) (Table 17.1). Seabass are usually caught with hand-lines but fishers have been observed setting small purse-seine nets to target this fish and other small fish when catches are low. Both octopus and seabass are present all year round, though it is during the summer that catches per vessel increase considerably. Furthermore, vessels that target elasmobranchs with drift nets and giant squid with mechanical hand-line have also been reported fishing illegally inside the reserve (within ~2 nm), on the outer limits of the polygon area (De La Cruz et al. 2017). Although juveniles of giant squid and elasmobranchs are also caught by smaller hand-line boats fishing close to ILA, most catches are reported outside the polygon boundaries by larger vessels.

Nearly 30 nm north of ILA is the island "Lobos de Tierra" (ILT), which belongs to the northernmost polygon of the Guano Islands MPA and is a very productive area as well. Halfway between ILA and ILT runs a deep marine canyon that is well known among fishers for its good quality as a fishing ground. ILT is also conspicuous for its large stocks of the Peruvian scallop *Argopecten purpuratus,* which is a highly economic profitable resource. It has been reported that fishers who tend to fish at ILA also fish at ILT, and vice-versa, motivated by environmental and economic conditions.

2.3 *Octopus Fishery in ILA*

The octopus fishery takes place all year round and is one of the most important fisheries at ILA in terms of catches and value. During summer, the number of vessels can rise up to almost 30, but there are usually 8 boats that are permanently and exclusively fishing octopus. These are small wooden boats equipped with off-board engines and with crews of about 3–6. Divers use a hose attached to a petrol fuelled on-board air compressor (Fig. 17.3). They usually dive for a total of 8 h each day (Eliana Alfaro-Cordova, personal observation). Octopus landings from ILA takes place at several ports along the northern coast of Peru and are estimated between 800 and 2000 kg/year in winter and summer, respectively (Grillo et al. 2018). Even though this fishery has been operating at ILA since decades, it is an illegal fishery and was not included in the 2016 MPA's master plan.

Fig. 17.3 Typical octopus divers boat at ILA. Source: ILA-subproject (Eduardo Valverde)

In 2001, the Ministry of Fisheries set a minimum-weight limit of 1 kg for octopuses catches, which corresponds to ~13 cm of mantle length, above the average length of maturity reported for the species in northern Peru (Ramírez et al. 2016). Furthermore, since 2002, the extraction and commercialisation of octopus in the adjacent regions of Piura and Lambayeque (including ILA and ILT) have been prohibited via three ministerial resolutions.[4] These regulations were based on studies from the Peruvian Marine Institute (IMARPE), indicating that the majority of octopuses at ILA did not reach the minimum extraction weight of 1 kg (Carbajal et al. 2001, 2003; Ramírez et al. 2008, 2016). The octopus population in ILA during 2017 was estimated at 32,943 individuals with a biomass of 31,963 kg (surveyed area: 15,861.25 m^2, up to the 20 m isobath) (De La Cruz et al. 2017).

[4] *Weight limit*: Ministerial Resolution (MR) N°-209-2001-PE; *Prohibition*: MRs N°-292-2001-PE, N°-069-2003-PRODUCE and N°-063-2009-PRODUCE.

Table 17.2 Successes and challenges identified with regards to the ILA MPA objectives according to the three main goals established in the master plan (environmental, economic and sociocultural), and an institutional category added as a transversal component

Component	Challenges	Successes
Environmental (to conserve the terrestrial and marine ecosystems)	No clear and well-articulated research plan Remote nature of islands requiring interinstitutional cooperation Interconnectivity with ILT needs to be considered	More biological and fisheries data were collected Increased monitoring (fisheries data)
Economic (to develop sustainable activities)	Illegality of octopus fishery hindering access to funds Interinstitutional cooperation needed to address illegality of Octopus fishery	Formalisation of octopus fishers Access to funds by different fisher organisations
Sociocultural (to promote the participation of local actors in MPA management)	Identification of relevant stakeholders in participatory process	Establishment of stakeholder committee
Institutional—transversal	Historic lack of collaboration among isntitutions Length of bureaucratic proceedings (i.e. to address illegality issue)	Cooperation agreement between SERNANP, AGRORURAL, and IMARPE

3 Towards the Sustainable Management of ILA

3.1 Challenges and Successes in Achieving the ILA MPA Objectives

Using the example of the octopus artisanal fishery we evaluated some of the challenges and successes in achieving the ILA MPA objectives posed for the ILA-subproject, i.e. to formalise fishers associations, to achieve increased economic revenue for fishers, to increase stakeholder participation, and to maintain the presence and distribution of several conservation target species. We divided our analysis into four categories: (1) environmental, (2) economic and (3) sociocultural (based on the main goals established in the master plan), and (4) institutional (transversal component). A summary of these is shown in Table 17.2.

3.1.1 Environmental

The remoteness of ILA and associated low operational capacity of the regional offices for monitoring the area are important factors constraining the achievement of the environmental goals. SERNANP can obtain information on marine biota through interinstitutional agreements with IMARPE, AGRORURAL, and private institutions. Within the marine realm of the polygon, IMARPE has conducted a baseline study of the intertidal and subaquatic marine biota (De La Cruz et al. 2017) and is also responsible for the annual assessment of important resources, such as *O. mimus*. Currently, IMARPE carries out a yearly assessment of the octopus population, being the main source of information supporting the octopus fishery ban in Piura and Lambayeque regions. Two main issues with the ban are: it assumes one single octopus stock for ILA, ILT, and other localities along the Piura and Lambayeque shoreline, and it does not incorporate data from catches. These limitations add uncertainty to the analysis and hinder the decision-making process.

Through the ILA-subproject, biological and fisheries information on octopus was obtained by working directly with a group of artisanal divers. This collaboration represented a first step forward towards filling knowledge gaps, improving the monitoring of ILA's octopus fishery and designing strategies for its management. This data collection also supported an ongoing genetic connectivity study of different stocks of *O. mimus* along the Peruvian coast, providing an interesting contribution to the study of their population structures; something important to consider for further management regulations (Ortiz-Alvarez, pers. comm.).

To be able to design and set up adequate management strategies, it is essential that the ecosystem dynamics are understood, incorporating novel methods of analysis and allowing long-term budget for research and monitoring. Through the ILA-subproject, SERNANP has contributed with important information about octopus in ILA, while the biology, population and social-ecological dynamics of many other species are still poorly understood. Without this basic knowledge, there would be issues with the identification of conservation goals and the implementation of management strategies.

3.1.2 Economic

The development of sustainable economic activities in ILA is mainly focused on small-scale fisheries. Guano extraction and tourism are not feasible economic activities in ILA, because guano is typically scarce and tourism activities are limited by the long distances from shore. Considering the formalisation of fisheries as the first step towards sustainability, SERNANP promoted it through the signing of so-called "conservation agreements" with the users (i.e. fishers). These agreements were proposed as a way to engage formal parties in the co-management of ILA. Additionally, the agreements allowed fishers gain access to funds (from the ILA-subproject) to make their activities more sustainable (e.g. by investing in improving gear and equipment to achieve best practices of extraction and conservation of their target resources).

The identification of the octopus diving fishery as one of the main activities was very important for addressing ILA's economic objective. This group of fishers has been operating in a semi-organised manner at ILA since 1998, mainly diving for benthic and demersal species and particularly targeting *O. mimus*. Through the

ILA-subproject, SERNANP initiated a dialogue with the divers and prompted the formal establishment of the fishers' association "Asociación de Pescadores Artesanales y Extractores de Productos Hidrobiológicos "Lobos de Afuera" (APAEPHLA)". This organisation originally consisted of eleven artisanal wooden outboard motorboats, all equipped with air compressors for hookah diving.

Once formalised, the association could potentially sign the conservation agreement with SERNANP and access to specific funds. Furthermore, it was perceived that the increased monitoring of the octopus population by IMARPE, the divers' involvement in data collection, and their commitment to co-developing management strategies with SERNANP would allow them to continue fishing under controlled conditions towards a formal reopening of the fishery. Unfortunately, despite their successful formalisation, these divers could not sign the conservation agreement and access the funds because their activity remained illegal (since the ban on *O. mimus* continues). This put a stop to the collaboration between the divers and SERNANP, particularly because their activities were still perceived and recognised as illegal and they were not formally included in ILA's management sub-committee (which will be discussed in the next section). Nevertheless, conservation agreements were successfully signed with gill-net (drift) and hook-and-line fishers from Lambayeque and Piura, who occasionally target the islands.

3.1.3 Sociocultural

To promote the participation of local actors in MPA management, SERNANP had mapped the main users and stakeholders of each polygon in the Guano Islands MPA. The involvement of stakeholders was monitored through a tool labelled Participatory Management Radar (Valverde et al. 2016). These stakeholders' maps are basically a list of people and institutions that use the islands and capes system for an economic activity. It is an important tool to develop adequate baseline parameters of the social-ecological system under study.

A stakeholders committee was created to facilitate formal dialog and decision-making. Considering the extent of the Guano Islands MPA, this committee was divided into 25 sub-committees, one per polygon. For example one stakeholder (management) sub-committee for ILA and one for ILT. However, as pointed out by (Laínez del Pozo 2017), SERNANP used ILT's map of actors with minor modifications for ILA because they shared some actors and it was cost-effective given their limited budget. For example ILA does not have a stock of the scallop *A. pupuratus*, but the master plan included it as a conservation target, evidencing the use of ILT's information as a template for ILA. The assumption that ILT and ILA have the same actors was unfounded and hindered the participation of key stakeholders in this governance process from the very beginning (Laínez del Pozo and Jones 2020). Since the stakeholder maps listed the same actors for both polygons, the two sub-committees were later merged and split into two new ones, based on the location of their members. Presently each polygon has two sub-committees, corresponding to the regions of Lambayeque and Piura. Laínez del Pozo and Jones (2020) assessed the representativeness of these committees and showed that only ~10% of the 146 actors identified (mainly local governments, universities, corporations, NGOs and fisher associations) had a direct or indirect relationship with ILA, indicating that the current stakeholder map is flawed.

The current Guano Islands MPA master plan acknowledges 85 organisations of small-scale fishers who directly benefit from ILA. It does however not define or describe these organisations further, nor provide details about their activities and relations. Concerning the approach used in building the stakeholders map, Laínez del Pozo (2017) addresses this in detail, stating that SERNANP "prioritised bureaucratic procedures over the effectiveness of the participatory processes". Most actors were included because "they were formally registered and showed interest by attending the first meetings organised by SERNANP, but they do not have any activity there and many have never visited the islands" (Laínez del Pozo 2017). During the ILA-subproject, SERNANP updated and validated the map of actors to include new stakeholders in both of ILA's management sub-committees. However, due to conflicts of interest between the former mammbers of the management sub-committee and octopus fishers, the diver's association was not accepted to be included in the participatory management body of ILA.

Unfortunately, SERNANP rushed the establishment of ILA's zoning in late 2019, seeking quick approval from all the ILA fishers. This led to a misunderstanding that created tension and jeopardised the conservation agreement between octopus fishers and SERNANP. The fact that octopus fishing is banned in ILA complicates matters even more for the divers. In 2019, a joint law enforcement operation between SERNANP and the Navy took place in ILA and was inflicted upon octopus fishers, something that had never happened before. This action generated further mistrust and consequently, even though they are now a formal organisation, the octopus divers are still not included as formal actors in ILA's management sub-committee.

3.1.4 Institutional

The main decision-maker in all matters related to the Guano Islands MPA is SERNANP. However, the islands and capes are located in a marine environment, slightly different from those continental, landlocked ecosystems that SERNANP is used to deal with. This MPA has a special mix of economic activities and social-ecological values that demanded the inclusion of other sectors of society and government in its management. One of the main limitations in the current MPA management (through institutional silos, i.e. Ministries of Environment, Production and Defence) is a historic lack of collaboration between government institutions, resulting in an inability to communicate and collaborate effectively. Moreover, often the prospects of collaboration come from an external source; such as international pressure and the need to create marine protected areas for the achievement of global conservation goals. This was combined with a limited expertise and capacity on management of MPAs by the local institutions.

To illustrate this point, if, for example someone wants to sail to ILA for tourism or research, go fishing and stay overnight, this person should *in theory* ask the Navy for permission to sail, the Ministry of Production to extract fish and SERNANP to disembark, each through their own communication channels. The permit emitted by SERNANP would have to be validated upon arrival at ILA. However, SERNANP does not have permanent Park Rangers on any island and their regional monitoring offices do not have the capacity or the budget to take care of everyday (or even sporadic) activities related to MCS.[5] In remote islands such as ILA, only one or two patrolling rounds are done per year. Although the Navy has a camp at ILA, it is administrated exclusively by the hydrography direction, which is responsible for the maintenance of the lighthouse and data collection on marine abiotic factors, so they do not have a mandate in island-related permits. The Ministry of Production is responsible for fisheries policies, guiding their implementation and ensuring compliance and has a directorate of Control and Surveillance. However, their capabilities are really limited, in particular when dealing with protected areas. The only other institution with permanent presence in ILA is AGRO RURAL (Ministry of Agriculture), which must present an annual plan of guano extraction to SERNANP and cannot proceed without its consent.

SERNANP has made efforts to improve collaboration among institutions and signed agreements with AGRO RURAL and IMARPE to improve biological monitoring at the Guano Islands MPA and support biological monitoring of insular and marine zones, respectively. These agreements work to some extent but have failed when information needs to be readily available for analysis and discussion mainly due to bureaucratic delays in data sharing. The limited presence of SERNANP in ILA has resulted in a limited efficacy to achieve the objectives presented in the master plan. The problems of this rigid, inefficient and limited institutional setup at ILA can also be extended to the whole Guano Islands MPA, where additional flexibility and operational capacities will be needed due to the interconnection among many polygons.

3.2 *Pathways Towards a Sustainable Management of ILA*

We present the lessons and challenges taken from the octopus fishery in ILA that could serve as indicators of the management and governance of the Guano Islands MPA as a whole, though we try to avoid overgeneralisations. This MPA's current master plan expired in 2020, but we expect that the present work will provide some

[5] It is worth noting that in late 2018 the ILA management sub-committee of Lambayeque agreed on creating a MCS system, though it seems like they never met again to develop it further, nor did SERNANP follow through on that demand.

input for the next participatory process. We identify four main pathways towards a sustainable management of ILA, described in no particular order below.

3.2.1 Resume Relation and Dialogue with Octopus Divers Association

This dialogue (ideally led by SERNANP with the involvement of the civil society) should take into account interest of fishers in developing a formal and sustainable activity as well as adequate levels of organisation and management capacities. The development of management actions together with fishers is necessary to establish feasible options that can be implemented and increase ownership of the management process with the hope that will ultimately increase compliance. The group of "octopus divers" presents a great opportunity for accomplishing this perspective and keep developing a management strategy that includes them and their everyday data on the process. This will provide a very good opportunity to not only formalise and manage the octopus fishery in ILA, but to actually collect first-hand data from this organised group of divers, in favour of this fishery's management. In July 2021, the Ministry of Production published the Fisheries Management Regulation of Benthic Invertebrates,[6] which aims to regulate these resources through properly established extraction and monitoring plans designed and built through a bottom-up framework. This regulation is yet to be fully implemented but provides a great opportunity to involve the octopus divers of ILA in the design of their own management plans, though they need to be properly acknowledged as users first.

3.2.2 Updating the Master Plan

An important next step for the MPA is the elaboration of the updated master plan—led by SERNANP—focusing on all the difficulties and gaps identified during the first phase (2016–2020). For ILA, this would mean not only revising the map of stakeholders but also acknowledging that the illegal octopus fishery takes place and is in urgent need of adequate management, with all the caveats that fishing inside an MPA should have. This should be developed in a participatory manner. We also suggest that the ILA-ILT conundrum should be explicitly addressed in the discussions regarding the soon-to-be updated master plan, highlighting the need to improve coordination and cooperation among the different management sub-committees.

3.2.3 The Creation of a Transversal Committee

As mentioned above, the Guano Islands MPA has a management committee (divided into sub-committees for each polygon) that groups all stakeholders

[6]DS 018-2021-PRODUCE

(i.e. users, government institutions, and civil society) to discuss all issues concerning the MPA. These committees are however not making any management decisions, but only recommendations, so the institutions involved in the management (i.e. SERNANP, PRODUCE and DICAPI) are not necessarily making decisions in an integrated manner.

We propose the creation of an autonomous executive body that is led by these institutions and integrates all information and aspects relevant to the management of the MPA, reducing bureaucracy and facilitating participatory and decision-making processes. In broad terms, this body or committee would define the roles and responsibilities within and across institutions with views to reduce the overlap in activities, facilitate and coordinate communication and cooperation among institutions and stakeholders, facilitate capacity building of managers and users, among others. This committee would require a well-established transversal framework to allow for an adequate integrated (National) management strategy; at least for legislation and enforcement in their jurisdiction. As mentioned above, one of the main problems in this regard is the limitation in constant and sufficient funding, so there needs to be a strong political decision in this regard.

The control and surveillance activities could be boosted if the Navy, AGRO RURAL and SERNANP, all have clear functions and share conservation and management goals regarding this MPA. For this purpose further agreements could be signed between SERNANP and various institutions from the private sector and the civil society to facilitate the achievement of specific objectives, all within the proposed framework of the autonomous body for the management of ILA (or all MPAs for that matter).

3.2.4 Develop a Long-Term (10–20 Years) Interdisciplinary Research Plan

This plan should highlight basic research needs and gaps, for example in biology, ecology and associated socio-economic activities such as fisheries. In the specific case of the octopus fishery, as mentioned above, relevant studies were started based on the data collected during the ILA-subproject, such as the characterisation of the fisheries or the genetic variablity between stocks nationwide. However, there is an urgent need for updating the studies that sustain the octopus fishing ban in the north region of Peru. To this end, studies could focus on octopus physiology, stock assessment, population genetics, trophic ecology and fisheries, being useful for addressing management issues such as establishing an appropriate ban resolution.

The construction of ecological models, coupled with socio-economic inputs and drivers, could aid in the pursuit of an ecosystem-based management strategy, not only for ILA but also for the whole Guano Islands MPA. For example the connectivity between ILA and ILT could also be addressed in these terms. The most important aspect here is the ability to collect the appropriate data to understand these systems, including accurate fisheries information. This will allow for a better understanding of how the MPA will react to future environmental and anthropogenic stressors such as climate change, El Niño events, fisheries and policy implementation and enforcement. The ability of the MPA to meet its conservation goals could also be tested with ecological forecast simulation models. To this end, the transparency of the data generated must be guaranteed.

We want to reinforce the idea that a lack of basic knowledge leads to deficiencies in management and control measures further along the process, so basic science should not be understated. In the case of ILA, more biological-ecological information is needed and should be collected before attempting a co-management strategy. De La Cruz et al. (2017) provide a snapshot of the most important marine resources but fails to describe their ecological interactions (and associated socio-economic activities) any further.

Finally, in order to comply with international standards and goals, Peru is seeking to create more MPAs in the near future. Currently, the country is focusing on increasing the national coverage closer to the established MPA mark of 10%, and different social-ecological systems are relevant candidates for this purpose. In this sense, the "Dorsal de Nasca National Reserve" was established in June 2021,[7] being the first of its kind to include a fully submerged protected area. This brings the country closer to its MPA goals, which is very positive. However, it is imperative that the MPAs being developed have proper conservation goals and sound scientific research, and are not created only to fulfil international requirements. Most importantly, the capacities of the institutions involved have to be radically improved for the successful management of existing and future MPAs.

References

Ampuero ML, Alfaro-Cordova E, Alfaro-Shigueto J (2018) Primer reporte de depredación de roedores en piqueros y las implicancias para la conservación de aves marinas en las islas lobos de afuera. In: Ganoza F, Barreto J, Reyes F, Torres F (eds) Libro de Resúmenes: VI Congreso de Ciencias del Mar del Perú, Huacho, 22–26 de octubre 2018

Carbajal W, de la Cruz J, Ramirez P, Castro J, Galan J, Castañeda J (2001) Evaluacion del recurso pulpo Octopus mimus en las islas Lobos de Afuera, Lambayeque

Carbajal W, Ramírez P, de la Cruz J, Castro J (2003) Evaluación del recurso "pulpo" Octopus mimus en las islas Lobos de Tierra y de Afuera—Lambayeque, Mayo

Carr M-E (2001) Estimation of potential productivity in Eastern Boundary Currents using remote sensing. Deep-Sea Res II Top Stud Oceanogr 49(1–3):59–80

Charles A, Westlund L, Bartley DM, Fletcher WJ, Garcia S, Govan H, Sanders J (2016) Fishing livelihoods as key to marine protected areas: insights from the World Parks Congress. Aquat Conserv Mar Freshwater Ecosyst 26:165–184. https://doi.org/10.1002/aqc.2648

Chavez FP, Bertrand A, Guevara-Carrasco R, Soler P, Csirke J (2008) The northern Humboldt Current System: Brief history, present status and a view towards the future. Prog Oceanogr 79(2–4):95–105. https://doi.org/10.1016/j.pocean.2008.10.012

[7] DS 008-2021-MINAM

De La Cruz J, Ramírez P, Castro J, Galán J (2017) Estudio de línea base en las Islas Lobos de Afuera, Lambayeque (agosto 2016). Laboratorio Costero de Santa Rosa, Instituto del Mar del Perú (IMARPE). Technical report

Edgar GJ, Stuart-Smith RD, Willis TJ, Kininmonth S, Baker SC, Banks S, Barrett NS, Becerro MA, Bernard ATF, Berkhout J, Buxton CD, Campbell SJ, Cooper AT, Davey M, Edgar SC, Forsterra G, Galvan DE, Irigoyen AJ, Kushner DJ et al (2014) Global conservation outcomes depend on marine protected areas with five key features. Nature 506(7487):216+. https://doi.org/10.1038/nature13022

Figueroa J, Timaná L, Gutiérrez C, Roca M, Hernández W, Ramírez R (2017) Línea Base Biológica de la Reserva Nacional Sistema de Islas, Islotes y Puntas Guaneras: Islas Lobos de Afuera. Caracterización de la fauna Silvestre: aves, mamíferos y reptiles. Servicio Nacional de Áreas Naturales Protegidas por el Estado (SERNANP). 118pp

Grillo J, Del Solar A, Sánchez L, Pingo S, Gozzer R, Alfaro-Shigueto J (2018) Dinámica De Las Pesquerías Artesanales En El Área Natural Protegida Islas Lobos De Afuera, Perú. In: Ganoza F, Barreto J, Reyes F, Torres F (eds) Libro de Resúmenes: VI Congreso de Ciencias del Mar del Perú, Huacho, 22–26 de octubre 2018

Halpern BS (2003) The impact of marine reserves: Do reserves work and does reserve size matter? Ecol Appl 13(1):S117–S137

Jordan R (1967) The predation of guano birds on the Peruvian anchovy (*Engraulis ringens* Jenyns). CCOFI Rep 11:105–109

Laínez del Pozo D (2017) MPA Governance Analysis of Isla Lobos de Afuera, Peru. Unpublished manuscript chapter of PhD thesis. University College London, UK

Laínez del Pozo D, Jones PJS (2020) Governance analysis of two historical MPAs in northern Peru: Isla Lobos de Tierra and Isla Lobos de Afuera. Mar Policy 127. https://doi.org/10.1016/j.marpol.2020.104096

Lester SE, Halpern BS, Grorud-Colvert K, Lubchenco J, Ruttenberg BI, Gaines SD, Airame S, Warner RR (2009) Biological effects within no-take marine reserves: a global synthesis. Mar Ecol Prog Ser 384:33–46. https://doi.org/10.3354/meps08029

Martins GM, Arenas F, Neto AI, Jenkins SR (2012) Effects of fishing and regional species pool on the functional diversity of fish communities. PLoS One 7(8). https://doi.org/10.1371/journal.pone.0044297

Pikitch EK, Santora C, Babcock EA, Bakun A, Bonfil R, Conover DO, Dayton P, Doukakis P, Fluharty D, Heneman B, Houde ED, Link J, Livingston PA, Mangel M, McAllister MK, Pope J, Sainsbury KJ (2004) Ecosystem-based fishery management. Science 305(5682):346–347. https://doi.org/10.1126/science.1098222

Ramírez P, la Cruz J, Castaneda J, Galán J (2008) Prospección de los bancos naturales de pulpo Octopus mimus y evaluación de percebes Pollicipes elegans en las islas Lobos de Afuera, Lambayeque (11-16 Julio 2008). Informe Técnico Instituto del Mar del Perú 20

Ramírez P, De La Cruz J, Castro J (2016) Prospección Octopus mimus en las Islas Lobos de Afuera, 2015. Inf Progres Inst del Mar del Perú 43:326–338

Valverde M, Pradel J, Mamani R, Roca M (2016) Plan Maestro de la Reserva Nacional Sistema de Islas, Islotes y Puntas Guaneras 2016-2020. Servicio Nacional de Áreas Naturales Protegidas por el Estado (SERNANP)

Vogt W, Duffy DC (2018) A report on the guano-producing birds of Peru. Pacific Cooperative Studies Unit Technical Report 197. University of Hawai'i at Ma

Weimerskirch H, Bertrand S, Silva J, Bost C, Peraltilla S (2012) Foraging in Guanay cormorant and Peruvian booby, the major guano-producing seabirds in the Humboldt Current System. Mar Ecol Prog Ser 458:231–245. https://doi.org/10.3354/meps09752

Wolff M (2015) From sea sharing to sea sparing—Is there a paradigm shift in ocean management? Ocean Coast Manag 116:58–63. https://doi.org/10.1016/j.ocecoaman.2015.07.004

Worm B, Barbier EB, Beaumont N, Duffy JE, Folke C, Halpern BS, Jackson JBC, Lotze HK, Micheli F, Palumbi SR, Sala E, Selkoe KA, Stachowicz JJ, Watson R (2006) Impacts of biodiversity loss on ocean ecosystem services. Science 314(5800):787–790. https://doi.org/10.1126/science.1132294

Zavalaga CB, Paredes R (1999) Foraging behaviour and diet of the guanay cormorant. S Afr J Mar Sci Suid-Afrikaanse Tydskrif Vir Seewetenskap 21:251–258

Zavalaga CB, Dell'Omo G, Becciu P, Yoda K (2011) Patterns of GPS Tracks Suggest Nocturnal Foraging by Incubating Peruvian Pelicans (Pelecanus thagus). PLoS One 6(5). https://doi.org/10.1371/journal.pone.0019966

Part III
Evaluation and Synopsis

Chapter 18
Evaluation and Synopsis

Matthias Wolff, Sebastian C. A. Ferse, and Hugh Govan

1 Diagnosis of Important Issues of Tropical Coastal Zone Management and Conservation

While the countries covered in the presented cases differ in their political settings, state of socio-economic development, history, connectedness to the global market, and many other characteristics, they all have in common multiple stakeholder interests in the use of the coastal area and its resources, and most feature very high population densities in their coastal zones and/or a high dependency on marine resources., Moreover, all areas are exposed to and impacted by, the effects of climate change.

The various contributions cover the following broad themes: Living resource use (fishery and mariculture), Management and governance, Adaptations to climate change, pollution and coastal degradation, Non-extractive use (tourism and other activities), and Conservation (MPAs, LMMAs; see Table 18.1 for an overview).

The challenges to achieving successful tropical coastal zone management and conservation identified by the case studies fall into the following categories:

(a) Adequate regulatory frameworks and appropriate institutions
(b) Meaningful stakeholder participation and processes

M. Wolff (✉) · S. C. A. Ferse
Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany

Faculty of Biology and Chemistry, University of Bremen, Bremen, Germany
e-mail: matthias.wolff@leibniz-zmt.de; sebastian.ferse@leibniz-zmt.de

H. Govan
University of the South Pacific (USP), School of Law and Social Sciences (SoLaSS), Suva, Fiji Islands

Network Coordination Team, Locally Managed Marine Area (LMMA) Network International, Suva, Fiji Islands

M. Wolff et al. (eds.), *Challenges in Tropical Coastal Zone Management*,
https://doi.org/10.1007/978-3-031-17879-5_18

Table 18.1 Case studies with problems addressed, challenges, and broad themes covered

No	Country/ authors	Problems addressed	Broad themes covered: Living resource use	Management and governance	Climate change and coastal degradation/adaptations	Non-extractive use, tourism	Conservation, protected areas etc.
1	Kenya (Tuda et al.)	Overfishing	x				
2	Kenya (Benards & Murage)	Overfishing	x	X			x
3	Saudia Arabia (Robitzch et al.)	Overharvesting, multiple user conflicts		X	x	x	x
4	Ghana (Effah et al.)	Climate change		X	x		
5	Ghana (Abobi)	Overfishing, user conflicts	x	X			
6	Tanzania (Fabiani et al.)	Multitrophic aquaculture, sustainability, governance	x	X			
7	Cook Islands (Prinz & Letschert)	Degradation (unsustainable tourism)		X		x	x
8	Peru (del Solar et al.)	Overfishing, Challenge of MPA creation		X			x
9	Ecuador (Navarrete et al.)	Overfishing, hared stocks, bi-national cooperation	x	X			
10	Guatemala (Velasquez et al.)	Overharvesting, MPA creation	x	X			x

11	Panama (Seeman et al.)	User conflicts, overharvesting, MPA creation		X		x	x
12	Bangladesh (Neogi et al.)	Coastal pollution, climate change, waterborne disease		X	x		
13	Philippines (Bacalso et al.)	Overfishing, fishing closure	x	X			x
14	Philippines (Cordero-Bailey et al.)	Resource protection, MPA creation		X			x
15	Indonesia (Baitoningsih)	MPA management, legal framework		X			x
16	Thailand (Taylor et al.)	Stock rebuilding, artificial reefs for fisheries	x	X			x

(c) Adequate information/knowledge base and appropriate communication
(d) Sustainable implementation, enforcement, monitoring, capacity and funding

In the following, examples and lessons learned for these four main areas drawn from the case studies are presented and discussed.

2 Challenges for Coastal Zone Management and Lessons Learned

2.1 Adequate Regulatory Frameworks and Appropriate Institutions

Unsurprisingly, laws and regulatory frameworks receive a lot of attention in our case studies, but their inadequacy points to a need to adapt existing frameworks or design more practicable frameworks or enforceable rules and regulations.

In the Thailand case study (Chap. 16), a situation of widespread overfishing and IUU (illegal, unreported, and unregulated) fishing began to be effectively addressed following a revision of the fisheries law that introduced robust financial sanctions, new restrictions on destructive gear types, and the introduction and enforcement of an inshore zone reserved for small-scale fisheries, thus providing basic protection for artisanal fishers. In the Panama case study (Chap. 11), the authors compare management challenges across four study areas and show that existing natural or cultural heritage legal designations may provide a good foundation for successful management actions, but these must either be adapted to ensure local participation (see next section), or new methods developed and legislated.

The Saudi Arabia case study (Chap. 6) illustrates that competing human activities (artisanal fisheries, aquaculture, tourism development) may greatly impact the Red Sea environment and pose serious threats to the growth of a marine economy in Saudi Arabia. The development of legally binding management plans and new or improved regulation of human activities in the coastal zone is proposed as a basis for active management of multiple uses and sectors.

Regulatory frameworks may be needed for resources that move across national boundaries, and the Peruvian/Ecuadorian case study (Chap. 15) shows that the habitat for hundreds of common species of both countries is driven largely by the Humboldt Current system, which calls for transboundary management and conservation measures. Indeed, the regional level is increasingly recognized as critical for ocean governance and achievement of SDG 14, and a cornerstone for ecosystem-based management (Wright et al. 2017). Arguments for a transboundary approach to conservation and management of coastal resources could also be made in other tropical regions, such as for the Western Indian Ocean, where countries like Kenya and Tanzania share many marine resources. Industrial fisheries in general and particularly in the case of transboundary stocks can be more sustainably regulated through the implementation of FAO's Port State Measures through the development of inspection protocols to detect illegal fishing. Additional measures could include certification of their fisheries, so that they become more competitive in international markets.

While capture fisheries seem to already exceed the carrying capacity of many coastal and inland ecosystems in the tropics and sustaining or reducing current catch levels seem generally advisable, the mariculture sector seems to still have a great potential in many tropical areas (e.g., Saudi Arabia case study, Chap. 6). However, often a weak aquaculture/mariculture legal and regulatory framework is encountered and in many places, there is no clear strategy for mariculture development (e.g., Tanzania case study, Chap. 9).

Adequate regulatory frameworks are needed not only for extractive activities, but also to address the impacts of environmental degradation, pollution, and climate change. In the case study on *Vibrio* occurrence in Bangladesh (Chap. 13), complex interlinkages between climate change, activities in the coastal zone, and human health, justify a call for holistic approaches that integrate aquaculture practices, farming, sewage/pollution and coastal zone management in improving coastal health and human wellbeing. This emphasizes that management of coastal systems requires frameworks that not only cover a diverse range of activities but also integrate across different societal and administrative sectors—an approach already reflected in the concept of integrated coastal zone management harking back to the 1992 Earth Summit (UNCED).

The successful management of protected areas likewise hinges on adequate regulatory frameworks. As Cordero-Bailey and co-authors describe in their case study from the Philippines (Chap. 12), the National Integrated Protected Area System there provides a successful, comprehensive framework for the implementation and management of protected areas that integrates multiple stakeholders such as government agencies and representatives of local communities. The core of the framework, a dedicated management board that is a multi-sectoral body, provides an institutionalized structure for coordination and communication across multiple stakeholders. Agreements between the overall management board and local management units provide structural links across different levels of administration and outline clear responsibilities and accountabilities of all parties.

The challenges in developing adequate regulatory frameworks are also described in the Indonesian case study (Chap. 10), which traces the development of legislation on marine conservation and area-based management in the country. Key challenges are posed by competing and sometimes conflicting competences across sectors and levels of government, in part brought on by processes of political decentralization, a heterogeneity of management types and goals, both among sectors of government and in terms of customary marine management structures, as well as inadequate provisions for stakeholder participation, in particular local communities. Some of these challenges are addressed by new legislation issued in the last few years. Recent trends in legislation and policy debates around marine conservation point to an increased attention given to local communities and other forms of effective management besides Marine Protected Areas.

Closely linked to the existence of supportive regulatory frameworks and processes of stakeholder participation is the existence and/or involvement of appropriate institutions that underpin management.

The well-known Galapagos world heritage site where habitat conservation and resource protection are assured by a powerful, well-financed National Park Authority rather steals the limelight from other nearby efforts such as the MPAs in the Peruvian case study (Chap. 17), where the coordination between institutions and more flexible arrangements are vital. The importance of developing institutions fit for this purpose is particularly illustrated in the exploration of the potential for joint management of transboundary stocks in the Ecuador case study (Chap. 15). In these examples, there may be clear legally binding management and conservation plans that all stakeholders can refer to but implementing institutions and actual implementation need more attention.

NGOs as institutions(see the Panamanian and Peruvian case studies, Chaps. 11 and 17) were identified as very important potential mediators between local communities and authorities, although both, the implementation of management plans and the enforcement of conservation efforts goes beyond their capabilities alone if areas are not directly owned by the NGO. Common efforts between NGOs and governmental institutions were shown to be successful, provided that the executivepower of both is clearly defined. The authors emphasize that effective coastal management requires good integration between all institutions and stakeholders, otherwise personal interests can become predominant and may cause the failure of the effort.

In Balayan Bay in the Philippines case described by Bacalso and colleagues (Chap. 7), a successful mechanism for the cooperation across multiple management units and sectors that integrated the different stakeholders involved was a key to success. The technical working group formed under the auspices of the provincial government was instrumental in convening the stakeholders, collating scientific information and translating it into policy, and coordinating across the involved local management units. A similarly integrative structure, but at the national level, is described in the other Philippine case study (Chap. 12). Cordero-Bailey and colleagues describe how, under a national legislative framework for MPA management, a multi-sectoral management board provides an institutional architecture and support that provides a structure for the exchange among multiple stakeholders and for legislation at lower levels. A challenge in that case was the lack of a uniform funding structure, resulting in different approaches in each of the sites under the national framework that differed in their degree of success in financial sustainability. The challenge of coordinating across multiple entities and sectors that pertain to marine resources is illustrated in the Indonesian case study (Chap. 10), where ministries with different priorities (Ministry of Environment and Forestry and Ministry of Marine Affairs and Fisheries) as well as a range of customary institutions that are recognized to different extents co-exist, resulting in a situation that approaches legal pluralism. The recent establishment of a Coordinating Ministry for Maritime Affairs underlines the attempt to achieve better coordination and streamlining across sectors and agencies at the national level.

2.2 Meaningful Stakeholder Participation and Processes

Tropical coastal zones often need to withstand intense pressures from diverse and sometimes conflicting users whose very survival depends on the extraction of resources in contexts where government resource management is often challenged through lack of staff, finance, or presence in the area. Managing complex and fragile tropical coastal ecosystems in the context of poverty and highly dependent users seems to particularly demand processes of participation which adequately engage the affected stakeholders to the extent that involvement results in more effective implementation or enforcement (Christie et al. 2009; Pollnac and Pomeroy 2005).

In the Galapagos world heritage site (discussed in the Ecuador case study, Chap. 15), local communities are engaged through a co-management board which is comprised of representatives of all stakeholder groups of the archipelago and is considered essential for success. But the quality of the collaboration between the different stakeholders and ensuring alignment of common goals are issues that need to be continually managed. The Thailand case study (Chap. 16) is a good illustration of the need for adequate consideration and inclusion of multiple stakeholders in order to tackle complex issues such as IUU over-fishing. Likewise, the Bangladesh case study (Chap. 13) concludes by identifying the need for participation of a broad range of stakeholders to address the complex interplay of climate and environmental change, human activity, and health, and to develop participatory adaptation measures. In both cases, dedicated processes and institutions to facilitate such stakeholder participation remain to be developed.

The case study of Panama (Chap. 11) illustrates attempts to balance a developing economy with the needs of a diverse and often marginalized population. Success in generating consensus on the need for environmental management needs to build on more than just regulatory frameworks and implement genuine processes of participation through bottom-up initiatives to move on from the early stages of integrated coastal zone management in Panama.

In the Kenyan case study of Kuruwitu (Chap. 9), Benards and colleagues describe different forms of co-management, radiating from loose associations of fishers and fish workers, Beach Management Units (BMUs) enacted by law, and Locally Managed Marine Areas (LMMAs). The successes, challenges, and opportunities brought up by the Kuruwitu LMMA in Kenya indicate that the process of a bottom-up (or user-driven/participatory) approach was key especially as it closely resembled the traditional management systems, with the more formal and elaborate instrument having the added advantage of a legal basis and enhancing the ability to seek support from external sources. Providing legally-backed frameworks to locally-driven, bottom-up management approaches can combine local support and meeting of local needs with legal recognition, international support, and financial backing (Ferse et al. 2010; Gurney et al. 2021). The first Ghana case study (Chap. 4) illustrates the perils of inadequate participation, as multiple contrasting national strategies that did not account for the priorities of local coastal communities resulted in conflicts and an increase in IUU fishing activities.

The Balayan Bay case study from the Philippines (Chap. 7) shows how participatory, community-based fisheries management can be successful if it focuses on using participatory planning, adaptive management principles, cooperation across multiple management units, monitoring, and collaboration with scientists. The other Philippine case study (Chap. 12) similarly underlines that the success of the managed areas largely depended on the successful inclusion and participation of multiple local stakeholders and that challenges arise where internal conflicts among local stakeholders remain unresolved. Effective exchange among stakeholders and good communication was a key factor.

In the Indonesian case study (Chap. 10), the legal basis for meaningful participation by local stakeholders remains challenging, although the importance of the issue appears to be increasingly recognized, and policies explicitly address the role of local communities in resource use and management.

2.3 Adequate Knowledge Base and Appropriate Communication

The generation and communication of knowledge is an essential component of tropical coastal management. Whether this relates to the use of local and traditional knowledge, existing scientific knowledge, or the generation of new knowledge through scientific or even participatory research and surveys, a key issue is ensuring that the knowledge is communicated and available to decision-makers and resource users.

Knowledge of the functioning of coastal habitats and the dynamics of its biological communities is required to guide any protection effort, and scientific research plays a crucial role in selecting coastal management areas and measures. In addition, regular monitoring and evaluation of the effectiveness of the conservation efforts was found to be imperative.

In the transboundary example of the Peruvian/Ecuadorian case (Chap. 15), Ecuador and Peru together need to fill a range of information gaps about their common fisheries resources, which could be addressed by promoting binational research networks.

For artisanal fisheries, filling information gaps is similarly important, ranging from species diversity in catch and by-catch, to connections with fishmeal plants, the legal framework, institutional dynamics, and fisher involvement in illegal fishing activities. It is necessary to bring more attention to this sector and promote participatory research for the development of management schemes and alternative sources of income. In addition, a series of policies should be developed toward the modernization of this sector, including traceability and strengthening of fishing associations. Here, the expertise of Peruvian research institutions like IMARPE (particularly in traceability) can be crucial.

The artisanal sector and its importance need to be more visible to the eyes of consumers and stakeholders, together with its role in the fulfillment of their basic necessities. Improving the information base and integrating different forms of knowledge from a wide range of stakeholders calls for a transdisciplinary approach, where actors from different scientific disciplines and from outside academia jointly frame problems of societal relevance and generate new knowledge (Jahn et al. 2012). Yet, transdisciplinary work requires not only the willingness to engage by different actors, but also a new and different set of skills than those usually present in researchers and managers—both of which remain challenging in many tropical coastal settings as well as academic environments (e.g., Rölfer et al. 2022), and a key area in need of further development.

The Bangladesh case study (Chap. 13) demonstrates a complex relationship between climate change and human health, which could only be tackled by the integration of diverse types of knowledge—from climate science to etiology and human behavior—and adequate communication of this complex interplay to a diverse range of stakeholders, including coastal inhabitants and managers. In the Balayan Bay case study, Philippines (Chap. 7), monitoring and data collection was carried out jointly by managers and scientists and involved members of the local communities as data collectors. The generated information was communicated to policymakers as well as local stakeholders by the technical working group. This case thus constitutes an illustrative example of joint data collection, assessment, and dissemination of knowledge, where knowledge eventually led to action and implementation. As the Thailand case study (Chap. 16) well illustrates, assessing the success of a management intervention requires information to verify that goals are met, which depends on a clear definition of goals and success criteria. In that case study, information on the outcome of the project came from diverse stakeholders and types of knowledge, including anecdotal information from fishers and divers and dedicated data collection by a local NGO collaborating with a government department.

The need to jointly collect and discuss information across a range of different stakeholders is also discussed in the case study from the Cook Islands in the Pacific (Chap. 5). Ongoing monitoring of tourism impacts and the integration of tourists and local stakeholders in monitoring efforts via citizen science approaches is recommended to accompany further tourism development, increase tourist awareness and thus the sustainability of tourism, manage its impacts, and integrate the views of local and external stakeholders in the development of management plans.

In the Al Lith region of Saudi Arabia, a more in-depth understanding of the Red Sea environment, and respective research, is deemed critical to guide decision-makers (Chap. 6). Policies and spatial planning will not only have to address the interests of all stakeholders involved but also prepare the economy for future impacts of climate change and other anthropogenic disturbances. The study concludes that the inevitable increased exploitation of Red Sea resources needs a science-based governance to guide the development of these industries to support a sustainable economy of Saudi Arabia in the 'Post-Oil' era.

In one Ghana case study (Chap. 4), Abobi emphasizes conflicts between fisheries and other activities in the coastal zone such oil and gas explorations or the construction of tourism infrastructure. Here, decreasing fishing grounds, potential damages of fishing gears from oil and gas vessels, and interferences with large commercial fishing vessels are major concerns.

The adoption of a holistic, multi-sectoral approach is demonstrated in multiple case studies, such as that from Bangladesh, the NIPAS framework in the Philippines, the EAFM approach in Thailand, or the national MPA framework in Indonesia, yet the extent of exchange of information and co-creation of knowledge differs among those cases.

2.4 Sustainable Implementation

A major issue emerging as a real global threat is the mismatch between the research, policy, and information frameworks supporting commonly agreed action, and the actual implementation, enforcement, monitoring, capacity development, and sustained/ongoing funding of these actions.

A common theme in all the developing country examples is that of extreme resourcing constraints facing institutions trying to implement legislation or maintain and enforce management systems. This has led to a number of innovative approaches, but these should not mask the vital, but often overlooked, issue that environmental management institutions and systems are chronically under-resourced.

The Balayan Bay/Philippines case study (Chap. 7) provides a good example of a sustainable structure for adaptive management. It describes the development and implementation of a new management instrument, a closed season, and its subsequent continuation by local and provincial institutions. Key for success was the integration of local stakeholders throughout the process, a consideration of local livelihood needs, and the take-up of some of the funding support by local actors, which ensured funding and ongoing compliance independent of the initial project. The Thailand case study illustrates the potential contribution a holistic approach in implementation and financing can make, leading to more sustainable implementation of measures than if done by an individual institution alone.

The Kenyan KuruwituLMMA (Chap. 8) enabled regulation of the fishery, fisher training, and new income-generating ventures, but a major challenge emerged in terms of long-term funding and the lack of capacity for sustainable financing, causing even a well-planned project to stall and subsequent community disappointment. Nonetheless, the enclosure and the exploitation restrictions remain and the rapid decline in the fishery has slowed at least for now.

Another problem illustrated by Tuda and colleagues in the other Kenyan case study (Chap. 2) is that national capacity may be too low to implement resolutions of international and multilateral agreements to which the country is a party. In this context, the lack of local experts may preclude the effective engagement and participation in international discussions on the management of important straddling fish stocks and highly migratory fish stocks, including quota allocations and fisheries access arrangements.

ThisKenyan example highlights problems that emerge in most tropical countries: a slow legislation process, which means that new management plans may take too long to become codified into law and binding.

The Tanzanian case study (Chap. 9) shows that there are currently important activities in seaweed farming, mainly conducted by women, but also in shrimp and sea cucumber farming at medium and large scale. These activities provide several hundreds of employment opportunities. While the production potential appears high, hatchery production of sea cucumber seed is still very limited and represents a bottleneck for further expansion of this activity. It seems that more governmental effort should be dedicated to the enhancement of the mariculture sector, which could also contribute to reducing the fishing pressure on wild fish and invertebrate stocks.

3 Adaptability of Tropical Coastal Areas to Global and Local Change Impacts on the Tropical Shores

In the second case study from Ghana (Chap. 14), Effah and colleagues show how an assessment of the vulnerability of coastal communities to climate change revealed that increased warming and decreased and more erratic rainfall are already exposing local villagers to devastating drought and flooding events. As yet, no effective strategies are in place to cope with these risks. The authors suggest that communities be relocated to higher grounds to mitigate the adverse impacts of floods. This relocation of entire villages would require further studies on alternative village sites, strong involvement of all stakeholders in the planning, as well as a proactive engagement of the local authorities and policymakers.

In the Red Sea/Al Lith case study (Chap. 6), a drastic impact of global change on the coastal ecosystems of Saudi Arabia (e.g., its reefs and mangroves) is foreseen, and effects of a massive coral bleaching event in the year 2015 are described. While the northern reaches of the Red Sea seemed to be little affected since corals here seemed of an increased thermal tolerance, the massive coral bleaching event disturbed the southern and central reaches and places such as Al Lith, followed by a general decrease in coral cover and species richness across all reefs investigated in the central region. This further corroborated previously identified trends in terms of shifts in reef composition from branching, fast-growing species to more massive coral species. Hence, a projection of the impacts of the ongoing effects of climate change, in parallel with the identification of mechanisms and drivers conveying this observed thermal tolerance, is considered imperative. This calls for further studies and extensive interdisciplinary collaborations with the other Red Sea countries.

In the Asian region, the Bengal Delta case study area (Chap. 13) is definitely one of the regions most vulnerable to climate change impacts. In the recent decade, the majority of the low-lying regions of coastal Bangladesh are experiencing a sea level rise (SLR)-mediated increase in the salinity of groundwater. As a result, millions of people have no option but to use contaminated natural surface waters for household purposes including drinking, and therefore, are highly vulnerable to waterborne diseases such as Cholera (*Vibrio*spp.). In the Bay of Bengal, the mean sea surface temperature (SST) has been increasing at much higher rates than in the tropical Pacific and Atlantic Oceans. A positive correlation between temperature increase and the magnitude of cholera incidences after a time lag of several weeks was observed at the regional scale in Bangladesh. Frequent outbreaks of cholera epidemics were also observed after strong cyclones that coincide with seawater intrusion and seem to have increased in frequency and strength over the past years.

In this particular example, global change-induced effects of temperature and sea level rise and extreme climate events such as cyclones thus directly affect the health status of the local populations. However, this link between climate change and regional epidemics is often overlooked. As stated by the authors, holistic approaches integrating ecohydrological interventions, water and waste treatment, wise use of natural antimicrobial compounds, maintenance of adequate hygiene, and socio-economic perspectives are required to cope with the alarming future hazards to health and ecosystem services.

The South American case studies of Peru and Ecuador (Chaps. 15 and 17) describe how the Humboldt Current upwelling of cold and nutrient-rich water is recurrently impacted by ENSO (El Niño Southern Oscillation) events. Warm, nutrient-poor but oxygen-enriched waters from offshore and from equatorial latitudes intrude the coastal areas, disrupting the food chain with cascading effects from phytoplankton through herbivores and pelagic fish stocks up to higher predators. Any management and conservation plan needs to consider the ENSO impact on the ecosystem, and climate and ocean dynamic models are needed to allow predicting how global change-induced variations in ENSO strength and impact may affect the ecosystem in the future. El Niño-induced warming has also shown to cause coral bleaching and mortality in the warm waters of Panama and Ecuador (see Chaps. 11 and 15); however, deeper areas (>11 m) have been shown to act as refuges during warming events, and have also demonstrated resilience to ocean acidification. SLR-associated coastal erosion regularly impacts coastal areas in the region, affecting mangrove forests and thereby threatening the ability to store carbon.

To be able to adapt to the above-described climate impact on the tropical shores, stakeholders and policymakers need to incorporate climate-smart actions for coastal management and also for coastal development into plans. However, these plans assume adequately resourced essential resource management services exist; where they do not, this foundation therefore must be laid. Terrestrial, upstream, and watershed issues should be covered as well (as in the Ghana and Bangladesh case studies, Chaps. 13 and 14), not only in terms of relocation but with regards to climate-smart infrastructure, disaster risk reduction, and vulnerability assessments. This requires the uptake and use of the available knowledge on local climate change effects, paralleled by a constant environmental monitoring and, eventually, concrete actions such as the translocation of thermotolerant species (e.g., corals) to risk areas to increase ecosystem resilience, or the selection/introduction of better-adapted species for mariculture. In extreme situations (see Effah's example of Ghana, Chap. 14), village areas that are critically endangered by the effects of climate change may have to be replaced by better-suited new village sites, requiring the relocation of people.

4 Capacity Development and Knowledge Generation in Tropical Coastal Management: Present State and Further Needs

4.1 General Challenges and the Example of ISATEC

The need for capacity development has been formulated in several of the contributions of this book. In fisheries, which is the main human activity along most tropical coastlines, we usually find limited capacity for stock assessment and ineffective control and enforcement. The lack of local expertise may also preclude the effective engagement and participation in international discussions on the management of important straddling fish stocks and highly migratory fish stocks, including quota allocations and fisheries access arrangements (cf. first Kenya case study, Chap. 2). Country reporting on SDG 14.1 (proportion of well-managed resources) to the FAO is often difficult due to the uncertainty of the information that tropical coastal states have about the current status of fisheries resources within their national waters. Very often, infrastructure and human resource capacity is just too low for the needed monitoring, control, and surveillance, resulting in ineffective enforcement of fisheries laws and regulations and an increase in IUU fishing activities. Due to a limited knowledge, commitment, and involvement of stakeholders, the management of fisheries resources and protection of critical fish habitats may remain ineffective. Inadequate sharing of fisheries information at the international and regional level is another feature characterizing many of the tropical coastal countries. Capacity development in integrated coastal management and fisheries assessment and management is thus required in most tropical places, as well as an intensification of research and capacity development cooperation among partners in the Global South and/or among those from the Global North and the Global South. This enhanced North/South cooperation should include transdisciplinary approaches and needs to be mindful of diverse and potentially diverging interests and needs, differences in funding and associated power dynamics, authorship norms, and differences in research culture and training, particularly in the development of training programs (Mahajan et al. 2022). If we recall the challenges and success factors (a–d) for coastal management derived in Sect. 1 we can start to define the content of interdisciplinary training programs in this subject area and can also critically review those that are already in place.

Most contributors of this book have been trained by the international M.Sc. Program ISATEC (International Studies in Aquatic Tropical Ecology) at Bremen University in Germany, www.isatec.uni-bremen.de), which has focused on the interdisciplinary field of tropical aquatic resource management since 1999. As briefly described in Sect. 1, ISATEC was tailored to integrate ecological, social, and economic aspects of coastal management, putting emphasis on a holistic understanding of coastal social-ecological systems, and the skills for analysis and modeling of complex systems. In doing so, it was intended that ISATEC graduates obtain the knowledge and skills to either continue research or work in NGOs or governmental institutions dedicated to the management and conservation of the coastal zone and its resources.

After more than two decades, ISATEC has been evaluated three times by independent accreditation agencies. ISATEC obtained excellent scores each item and was considered innovative, relevant, and well-balanced in its different thematic fields. Its interdisciplinary focus was considered appropriate, modern, and timely, as was the interactive training approach and the international/intercultural setting of the program.

Over 90% of the graduates have found jobs (or research positions) immediately after graduation, and many of them have become decision-makers in their home countries.

When looking at other success factors of the program besides the concept, thematic orientation and training mode, it is worth highlighting that the program was continuously sponsored with 7–10 full-time scholarships per year (by the German Academic Exchange Service, DAAD), which enabled talented young scientists from developing countries to come to Bremen and take part in the international and multicultural group of young students from all over the world. A further success factor was that all ISATEC students did their thesis research project along tropical coastlines, thereby interacting and cooperating with tropical research partners on research topics of local relevance, allowing the students to learn much about the reality of tropical coastal areas and people.

To be successful, programs like ISATEC need to combine high-level academic training with practical research work in the tropics. Besides training in multiple academic disciplines, interaction with and integration of stakeholders beyond academia, i.e. transdisciplinary skills and approaches, should receive more attention in future training. Programs should seek financial support (for scholarships) from outside to enable talented students from topical areas to join the program, independent of their financial situation.

As ISATEC is a program associated to a university of the Global North, far away from the tropics, it is vital to consider developing such programs in the Global South, in tropical countries. Fortunately, this is occurring in many parts of the world including through so-called “twin programs” being developed with two universities (from the Global North and South, respectively) partnering in the education of their students. All these attempts are promising, if infrastructural and academic conditions can assure the high-level education needed in this complex field of interdisciplinary research.

4.2 State of the Tropical Coastline, Current Trends, and Needs for Enhancing Research and Capacity Development

In Part I of this book we asked if progress can be seen over the last three decades on the way toward reaching the Sustainable Development Goals (SDG) in tropical coastal countries and what the persisting crucial problems are that we need to focus our research, policy, and training actions on.

When looking back over the past decades, it must be recognized, that, despite our and similar worldwide efforts to enhance capacity development and knowledge accumulation in tropical coastal and resource management, the state of tropical coastal systems remains critical in many regions.

The past years have seen increasing demands on coastal and marine resources in terms of food, materials and space, in a process referred to as "Blue Acceleration" (Jouffray et al. 2020). The WWF Living Planet Index (LPI) Report. Almond et al. (2020) summarizes the main threats and their impacts on tropical coastal habitats such as coral reefs, mangroves and seagrasses, and provides estimates of the human ecological footprint. The index highlights the global damages observed on coral reefs due to massive bleaching events—as also reported in several of the contributions of this book—as well as area losses observed in mangrove and seagrass habitats. The Ocean health index (OHI,[1] https://www.nature.com/articles/nature11397), which is reported since the year 2012 based on social, ecological, and economic data analyzed by an interdisciplinary team(Halpern et al. 2012), gives reason for hope, as it shows some improvement over the last years. The overall score obtained from 221 regions, including all coastal countries (71/100 for the year 2019), sends a message that the ocean is not "dying" as many people may think. Indeed, there are positive examples of marine conservation from around the world that show sustainable use and management of marine systems and resources remains possible (Knowlton 2021). The often cited apocalyptic view of Worm et al. (2006), according to which the ocean shall be depleted of its fishery resources by the middle of this century, is also strongly debated in the scientific community, and there is solid evidence that a substantial stock rebuilding is taking place in many parts of the world (Branch 2008; Hilborn et al. 2020). However, the OHI score remains far from 100, indicating that marine life would fare better and more benefits would be obtained if the ocean was used in more sustainable ways. While the trends in goal scores across the 8 years of assessments vary among regions, globally an increase is reported in Artisanal Opportunities, Carbon Storage, Clean Water, Food Provision

[1] OHI: A healthy ocean sustainably delivers a range of benefits to people now and in the future. Goals are to obtain the maximum flows of ecological, social, and economic benefits. Each goal measures the delivery of specific benefits with respect to a sustainable target. A goal is given a score of 100 if its maximum sustainable benefits are gained in ways that do not compromize the ocean's ability to deliver those benefits in the future. Lower scores indicate that more benefits could be gained or that current methods are harming the delivery of future benefits.

and Tourism & Recreation, while scores declined for Biodiversity, Coastal Protection, Natural Products, and the Species sub-goal. Declines in scores for Coastal Protection were primarily driven by the substantial loss of coastal sea ice in sub-Arctic coastlines. The Large Marine Ecosystem (LME) research group of IOC, UNESCO, and UNDP (2016) has calculated the highest poverty and vulnerability scores for tropical regions, where extreme weather events and strong plastic pollution add to an extremely high contemporary threat index for these regions.

As observed in previous years, regions with stable and effective governance tended to score much higher than those where corruption, dictatorship, civil strife, war, and poverty have been chronic. Previous progress on sustainable development has been critically challenged and reversed in part by the recent global COVID-19 pandemic (UN 2021), which has severely affected artisanal fisheries and coastal fishing communities, particularly in the Global South (Bennett et al. 2020; Knight et al. 2020). This underscores that improving ocean (and coastal ecosystem) health will require efforts from all sectors to promote peace, justice, gender equality, socially-responsible business, and other aspects of civil health, because progress in those areas makes it much easier for communities and nations to improve the environmental and economic conditions needed to boost ocean health. This particularly holds for the countries of the tropical belt. In fact, when we look at the OHI for all the countries of our case studies presented, only the Philippines and the Pacific Island states have index values around the global mean of 71, while all other countries rank substantially lower.

Realization of the accelerating impacts of humans on the natural environment and implications for the future prospects of human development and life on this planet is reflected in a number of scientific, policy, and societal developments. The term Anthropocene used to refer to our current epoch on Earth (Crutzen 2002) acknowledges the intimate interrelationship between humans and their environment and recognizes humans as a force of nature. The concept of the Anthropocene has since featured prominently in various areas of ecology, natural resource and management research. Related to this, Sustainability Science has gained increasing prominence, with entire institutes and universities explicitly focusing on the science and practice of sustainability established in recent years (e.g., the Leuphana University in Lüneburg/Germany, or the Institute for Advanced Sustainability Studies (IASS) in Potsdam/Germany). Sustainability Science was internationally recognized as a new scientific discipline at the 2001 "Challenges of a Changing Earth" open science conference convened by the International Council for Science (ICSU), the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme on Global Environmental Change (IHDP) and the World Climate Research Programme (WCRP) (Steffen et al. 2002). An increasingly holistic view of human-nature relationships and attempts to improve these relationships by enhanced cooperation at the science-society-policy nexus has led to the establishment of the global Future Earth program, a global Sustainability Science program formally launched at the Rio+20 conference in 2012, which replaced the earlier International Geosphere-Biosphere Program and the International Human Dimensions Program and places a strong emphasis on transdisciplinary approaches and sustainability research (Mauser et al. 2013). National research funding bodies have established dedicated programs for sustainability research, such as the German Ministry for Research and Education (BMBF)'s Research for Sustainability (FONA) program. At the international level, funding initiatives such as the Belmont Forum's Transdisciplinary Research for Pathways to Sustainability program likewise address transdisciplinary research focused on sustainability. In international policy, the Sustainable Development Goals established by the United Nations through the Agenda 2030 process embody the attempt to establish common, international goals for sustainability and processes to reach them.

Most recently, the United Nations General Assembly has launched two Decades dedicated to the sustainable development of oceans and coasts and the restoration and rehabilitation of natural environments, the UN Decade of Ocean Science for Sustainable Development ("Oceans Decade"; Ryabinin et al. 2019) and the UN Decade on Ecosystem Restoration (see Waltham et al. 2020).

To tackle the ongoing challenges of resource degradation and overuse and effectively address the diverse and interrelated sustainability challenges that are manifest along the world's coastlines, including poverty, inequity, health, and other aspects of wellbeing, the next generation of coastal managers and researchers needs to be aware that tropical coastal zone and resource management requires a complex multilayered approach, which, first of all, needs to place the different users of the coastal zone in the appropriate socio-ecological and socio-political context. At the same time, a constant monitoring of changes of the coastal zone and of the drivers behind is crucial, as is the co-production of knowledge engaging all stakeholders and policymakers.

Since the social and political realities of tropical zones differ among countries and geographical regions, management priorities need to be adapted to the local needs and identified through a transdisciplinary, bottom-up approach of stakeholder involvement.

If we now ask if the ISATEC training program that we have conducted over the past two decades is still well tailored to the needs of knowledge and skills of a coastal manager or if there are important gaps that should be addressed in our and other future training programs, we can first of all state that the training that most of the authors of the case study contributions of this book have received appears to have qualified them well for their subsequent work in the coastal zone. They have managed to describe the complex situation in their study areas and were able to identify and holistically analyze the coastal management problems of their respective areas. Since most of the authors have been working in the study areas for some years after their graduation, training and work experience have been combined in their work.

If we look at more recent changes of the coastal zone and the driving forces, there may be a need for re-focussing and re-prioritizing the training program for the future as argued below.

It appears that climate change, while already a relevant topic 20 years ago, has greatly increased in importance for the coastal zone, and issues such as climate change-associated risks for the coastal zone, its resources and its inhabitants, have become much more prominent recently. In particular, questions of climate change adaptation to address the reality of unavoidable impacts unfolding already, and bound to increase in extent and magnitude, constitute a pressing need in most tropical coastal areas. As a consequence, the training on these aspects needs to be intensified and integrated into the other elements. The increase in the global tourism industry (ship-and land-based) with a special focus on tropical coastal areas, as well as other globally operating industries such as deep sea mining, maritime transport, or energy generation in the coastal zone (wind, solar, geothermal energy), are also increasingly changing the face of the coastal zone, and need to be looked at in training programs. GIS skills for coastal mapping and the knowledge and skills for the use of modern software for optimizing the use of the coastal zone is thus becoming increasingly relevant for training. In our times of great acceleration of change, of increasing inequality and of the transformation of societies and ecosystems, we have to strengthen a Social-Ecological Systems Approach and have to teach concepts on how to advance both environmental and human wellbeing at the same time. We need to focus on the keystone actors of the coastal zone, need to put emphasis on the ecosystem approach to fisheries and aquaculture, and need to train our students to apply a transdisciplinary approach when dealing with stakeholders.

In our training, we should emphasize that a prerequisite for reducing human pressures and drivers is to understand the nature of decision-making that results in environmental, social, and ecological degradation. System thinking offers a way to understand the root causes for unsustainable consumption patterns, destructive production patterns, malfunctioning governance structures, and short-term economic planning. When applied to food systems including fisheries, root causes include poverty traps, gender inequality, instruments such as harmful subsidies, and the concentration of power and the impacts on justice and equity (Bennett 2022)

We, trainers, researchers and editors of this book, have learned a lot over the years by interacting with students, colleagues, and coastal stakeholders. Some of our important insights may be summed up as follows: (a) the strongest driver of our global ecological crisis is our free market economy, which stimulates globalization, industrial development, concentration of wealth and power, inequality, and ecosystem destruction; (b) without changing the underlying rules and policies, and without implementing democratic, bottom-up systems of people inclusion for decision-making, our path toward the planet's destruction will continue and the SDGs will not be reached; (c) we scientists can help to understand how the world works and what is happening, but the society, including each individual citizen but particularly those setting the rules for commercial actors to operate, needs to act for our life supporting systems to be preserved.

References

Almond RE, Grooten M, Peterson T (2020) Living Planet Report 2020-Bending the curve of biodiversity loss. World Wildlife Fund

Bennett N (2022) Mainstreaming equity and justice in the ocean. Front Mar Sci 9:873572

Bennett NJ, Finkbeiner EM, Ban NC, Belhabib D, Jupiter SD, Kittinger JN, Mangubhai S, Scholtens J, Gill D, Christie P (2020) The COVID-19 pandemic, small-scale fisheries and coastal fishing communities. Coast Manag 48(4):336–347. https://doi.org/10.1080/08920753.2020.1766937

Branch T (2008) Not all fish will be collapsed in 2048. Mar Policy 32:38–39

Christie P, Pollnac RB, Oracion EG, Sabonsolin A, Diaz R, Pietri D (2009) Back to basics: an empirical study demonstrating the importance of local-level dynamics for the success of tropical marine ecosystem-based management. Coast Manag 37(3–4):349–373. https://doi.org/10.1080/08920750902851740

Crutzen PJ (2002) Geology of mankind. Nature 415(6867):23–23. https://doi.org/10.1038/415023a

Ferse SC, Costa MM, Manez KS, Adhuri DS, Glaser M (2010) Allies, not aliens: increasing the role of local communities in marine protected area implementation. Environ Conserv 37(1):23–34. https://doi.org/10.1017/S0376892910000172

Gurney GG, Darling ES, Ahmadia GN, Agostini VN, Ban NC, Blythe J, Claudet J, Epstein G, Himes-Cornell A, Jonas HD (2021) Biodiversity needs every tool in the box: use OECMs. Nature

Halpern BS, Longo C, Hardy D, McLeod KL, Samhouri JF, Katona SK, Kleisner K, Lester SE, O'Leary J, Ranelletti M, Rosenberg AA, Scarborough C, Selig ER, Best BD, Brumbaugh DR, Chapin FS, Crowder LB, Daly KL, Doney SC et al (2012) An index to assess the health and benefits of the global ocean. Nature 488(7413):615-+. https://doi.org/10.1038/nature11397

Hilborn R et al (2020) Effective fisheries management instrumental in improving fish stock status. PNAS 117(4):2218–2224

IOC, UNESCO, and UNDP (2016) Large marine ecosystems: status and TRends, summary for policy makers. In: United nations environment programme (UNEP), Nairobi

Jahn T, Bergmann M, Keil F (2012) Transdisciplinarity: Between mainstreaming and marginalization. Ecol Econ 79:1–10. https://doi.org/10.1016/j.ecolecon.2012.04.017

Jouffray JB, Blasiak R, Norstrom AV, Osterblom H, Nystrom M (2020) The blue acceleration: the trajectory of human expansion into the ocean. One Earth 2(1):43–54. https://doi.org/10.1016/j.oneear.2019.12.016

Knight CJ, Burnham TLU, Mansfield EJ, Crowder LB, Micheli F (2020) COVID-19 reveals vulnerability of small-scale fisheries to global market systems. Lancet Planet Health 4(6): E219–E219

Knowlton N (2021) Ocean optimism: moving beyond the obituaries in marine conservation. Ann Rev Mar Sci 13:479–499. https://doi.org/10.1146/annurev-marine-040220-101608

Mahajan SL, Estradivari, Ojwang L, Ahmadia GN (2022) The good, the bad, and the ugly: Reflections on co-designing science for impact between the Global South and Global North. ICES J Mar Sci. https://doi.org/10.1093/icesjms/fsac115

Mauser W, Klepper G, Rice M, Schmalzbauer BS, Hackmann H, Leemans R, Moore H (2013) Transdisciplinary global change research: the co-creation of knowledge for sustainability. Curr Opin Environ Sustain 5(3–4):420–431. https://doi.org/10.1016/j.cosust.2013.07.001

Pollnac RB, Pomeroy RS (2005) Factors influencing the sustainability of integrated coastal management projects in the Philippines and Indonesia. Ocean Coast Manag 48(3–6):233–251. https://doi.org/10.1016/j.ocecoaman.2005.04.003

Rölfer L, Elias Ilosvay XE, Ferse S, Jung J, Karcher DB, Kriegl M, Nijamdeen T, Riechers M, Walker EZ (2022) Disentangling obstacles to knowledge co-production for early-career researchers in the marine sciences. Front Mar Sci 9. https://doi.org/10.3389/fmars.2022.893489

Ryabinin V, Barbiere J, Haugan P, Kullenberg G, Smith N, McLean C, Troisi A, Fischer A, Arico S, Aarup T, Pissierssens P, Visbeck M, Enevoldsen HO, Rigaud J (2019) The UN decade of ocean science for sustainable development. Front Mar Sci 6. https://doi.org/10.3389/fmars.2019.00470

Steffen W et al (2002) Challenges of a changing earth: proceedings of the global change open science conference, Amsterdam, The Netherlands, 10–13 July 2001. https://www.vlebooks.com/vleweb/product/openreader?id=none&isbn=9783642190162

UN (2021) The sustainable development goals report 2021. United Nations, New York

Waltham NJ, Elliott M, Lee SY, Lovelock C, Duarte CM, Buelow C, Simenstad C, Nagelkerken I, Claassens L, Wen CKC, Barletta M, Connolly R, Gillies C, Mitsch WJ, Ogburn MB, Purandare J, Possingham H, Sheaves M (2020) UN decade on ecosystem restoration 2021-2030-what chance for success in restoring coastal ecosystems? Front Mar Sci 7. https://doi.org/10.3389/fmars.2020.00071

Worm B et al (2006) Impacts of biodiversity loss in the ocean ecosystem services. Science 314: 787–790

Wright G, Schmidt S, Rochette J, Shackeroff J, Unger S, Waweru Y, Müller A (2017) Partnering for a sustainable ocean: The role of regional ocean governance in implementing SDG14. PROG: IDDRI, IASS, TMG & UN Environment