Hubert-Jean Ceccaldi · Yves Hénocque ·
Teruhisa Komatsu · Patrick Prouzet ·
Benoit Sautour · Jiro Yoshida *Editors*

# Evolution of Marine Coastal Ecosystems under the Pressure of Global Changes

## Proceedings of Coast Bordeaux Symposium and of the 17th French-Japanese Oceanography Symposium

CNRS · Société franco-japonaise d'Océanographie · La mer 日仏海洋学会 Société franco-japonaise d'Océanographie

Springer

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Part of the scientific community taking part in the Coast Symposium at Bordeaux (Agora du Haut-Carré/University of Bordeaux). Copyright CNRS/EPOC

A part of the French-Japanese delegation visiting “La Maison de l’Huître” (Bassin d’Arcachon). Copyright Nicole Prouzet

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# Front page images

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Part of the symposium participants (Copyright CNRS)

Oyster culture in Matsushima Bay (Japan) (Copyright Patrick Prouzet)

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Benthic chamber to measure the primary production
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# Coast Bordeaux 2017: Knowing to Manage, Two Events to Answer

From 7 to 10 November 2017, an international event named Coast Bordeaux 2017[1] was organized by Centre National de la Recherche Scientifique (CNRS) and Société Franco-Japonaise d'Océanographie (SFJO) on "**Systemic and Biodiversity Evolution of Marine Coastal Environments under the Pressure of Climate Change, Natural and Anthropogenic Local Factors**".

This international event coincides with the 17th French-Japanese Oceanography Symposium which explains the significant contribution of the scientific Japanese community in those proceedings.

Coastal and estuarine environments at the interface of terrestrial and marine areas are among the most productive in the world. However, since the beginning of the industrial era, these ecosystems have been subjected to strong anthropogenic pressures intensified from the second half of the twentieth century, when there was a marked acceleration in the warming (climate change) of the continents, particularly at high latitudes.

Coastal ecosystems are highly vulnerable to alteration of their physical, chemical and biological characteristics (marine intrusion, acidification of marine environments, changes in ecosystems, evolution and artificialization of the coastline, etc.).

In contact with heavily populated areas, these environments are often the receptacle of a lot of chemical and biological pollution sources that significantly diminish their resilience. In this context of accelerated evolution and degradation of these areas important for food security of many populations around the world, it is necessary to better identify the factors of pressure and understand, at different scales of observation, their effects and impacts on the biodiversity and on the socio-ecosystems, in order to determine the degree of vulnerability of these coastal ecosystems and the risks they face. A transdisciplinary and integrated approach is required to prevent risks. Within this framework, operational coastal oceanography occupies an important place but also the implementation of a true socio-ecosystem approach in order to set up an environmentally friendly development.

[1] http://colloquebordeaux2017.socfjp.com/en/.

In addition, at the same time, a forum on "**Vulnerability to climate change, natural hazards and anthropogenic pressures**", underpinned by the strong cooperation between the French and Japanese scientific and professional communities[2] was organized.

This forum was structured around four main issues:

"*How can today's socio-ecosystems be resilient to adapt tomorrow not only to coastline changes, but also to natural disasters increasing frequency and strength on the coast?*"

Coastal areas are characterized by a very strong vulnerability to natural hazards which caused considerable material damage and thousands of human losses, with large-scale environmental, social and economic repercussions.

The effects and impacts of these exceptional and violent *phenomena* can be amplified by the increase in mean global sea level and in overall average intensity of tropical cyclones. Protections against giant waves or large-scale marine intrusion have shown their limitations and generated significant changes in coastal socio-ecosystems.

"*How to implement an integrated management approach for these interface and land–sea transition areas in order to minimize synergy of impacts from different uses and better adapt to the factors of change?*"

The synergetic effects of surface water warming, hydrological regimes and terrestrial pollution can lead to severe anoxic crises (particularly in estuarine silt plugs rich in organic matter), an increase in the occurrence frequency epizooty very detrimental to the economy of traditional fishing and aquaculture activities such as shellfish aquaculture, a change in the distribution of marine species by modifications in the dispersal of their prey or the distribution of their colonization areas. Acidification of marine waters has a direct impact on the development of shellfish species or crustaceans and more broadly on the specific composition of trophic chains, which could be another major cause of biodiversity shift.

"*How to ensure co-existence of uses and preserve the resilience of traditional activities such as fishing and shellfish farming facing new activities in the context of global change?*"

Blue energy development in France or more widely in Europe, within the framework of the energy transition policy, is a new space-consuming activity that creates new ecosystem services.

Furthermore, the implementation of marine protected areas is part of the French "National Strategy for Sea and Oceans" with an ambitious objective to have 20% of marine protected areas in waters under French jurisdiction. This is reflected in the

[2]Cooperation that goes beyond scientific relationships since in 1960, it was from Japanese spat that French oyster farming was revived and in 2011 after the tsunami destroyed many aquaculture facilities in Sendai Province, Japanese shellfish farmers were able to recover their production capacity more quickly thanks to the material sent by French shellfish farmers.

creation of marine parks such as those in New Aquitania, the “Bassin d’Arcachon” or the “Gironde–Mer des Pertuis”, thus contributing to the implementation of the Marine Strategy Framework Directive (MSFD).

“*How can traditional community management methods be used to co-build an integrated marine and coastal management approach as part of an integrated maritime strategy?*”

Japan has demonstrated a strong capacity to adapt the fisheries and aquaculture sector to factors of particularly abrupt changes, such as those caused by the catastrophic tsunami of March 2011.

The implementation of integrated approaches and large-scale habitat restoration programmes is a long-standing concept for this country. This is evidenced by the concept of “Sato-Umi” (sea and man in harmony), itself derived from the much older “Sato-Yama” (mountain and man in harmony).

The involvement of fisher communities in Japan in the environment restoration or sea restocking (fish and shellfish restocking, artificial reefs, replenishment of seagrass fields, etc.) constitutes a participative approach that is also found in France and Europe particularly in the context of the observation of highly migratory fish (salmon, tuna, sharks, etc.) or joint surveys or restocking of fish population (European eel in France for example). So, there are many points of convergence between these French and Japanese communities that deserve to be shared during this forum and particularly to illustrate the link between nature and culture.

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# Foreword

## Coast Bordeaux 2017: An Important Scientific and Technical International Event

In November 2017, the University of Bordeaux hosted in the Domaine du Haut-Carré in Talence around 300 participants on the occasion of the international Symposium Coast Bordeaux 2017. That event focused on exchanges among scientists, managers and professionals from the maritime industry and coastal management. That important scientific and technical event was organized by CNRS, FJSO, Ifremer, MNHN, University of Bordeaux and the New Aquitania Region. It corresponded also with the 17th French-Japanese Oceanography Symposium.

This international meeting was organized around two complementary events: (i) a symposium on the "Systemic and Biodiversity Evolution of Marine Coastal Environments under the Pressure of Climate Change, Natural and Anthropogenic Local Factors" open to the whole international scientific community working on the effects of global change on the marine living resources and the coastal, estuarine and lagoon areas, and (ii) a forum of exchanges on the following topic "Vulnerability to climate change, natural hazards and anthropogenic pressures", between Japanese and French scientists and managers discussing around the integrated coastal management and the exploitation of marine living resources (oyster, mussel, tuna, eel, etc.).

Issues concerning coastal and estuarine environments are of importance because of their high carrying capacity and biodiversity but also of their strong vulnerability facing anthropogenic (littoralization, coastal water pollution, shoreline modification, exploitation of marine resources, intensification of maritime traffic) and climate change pressures.

The biological balance of these environments is delicate, and its disruption may lead to a modification of the water cycle, a coastal erosion due to the rising level of ocean, a deterioration of water quality and a decrease of their capacity for resilience, but also of the occurrence of environmental hazards.

Thus, it appears essential to study and to understand the functioning of these complex environments, their evolutions and the risks associated with their modifications included the impact on food security of human communities. The management, or even the restoration, of these areas needs a collaboration between scientific communities (oceanographers, biologists, ecologists, sociologists, geographers), public managers and users of the marine resources.

As such, that scientific and technical event Coast Bordeaux 2017 has been exemplary as it allowed to gather all these actors working on coastal and estuarine environments at different scales: regional, national and international and coming from different countries of the world: Japan, Spain, UK, Italy, Maghreb and Sub-Saharan Africa.

That event has been also an achievement for the quality of communications presented, its organization as well as the international outreach given to the scientific studies undertaken on these topics in New Aquitania and particularly to those conducted in laboratories of the University of Bordeaux. So, our thanks go to Dr. Philippe Bertrand from the EPOC Laboratory and to the Scientific and Organization Committee without whom that event would not have been possible.

Prof. Manuel Tunon de Lara
President of the University of Bordeaux
Bordeaux, France

## A Need to Adapt the Region "Nouvelle-Aquitaine" to Climate Change

The Region "Nouvelle-Aquitaine" is naturally concerned by environmental issues, in particular the impacts of climate change on its 700 km of coastline. Observations and recent events have shown significant changes in the coastline, whereas forecasts in the coming decades highlight the increased risks of erosion and marine submersion for the territories and coastal populations.

This environmental and societal issue is one of the priorities of our regional public policies. Our commitment to adapt our territory to climate change, but also to limit its impact, is a strong marker and becomes the framework for the deployment of all our interventions.

The Region "Nouvelle-Aquitaine" was indeed the first in France, under the impetus given by President Alain Rousset, to draw up a state of play on the impact of climate change at the scale of the largest French region. This is the "AcclimaTerra" initiative whose scientific coordination has been entrusted to Hervé Le Treut. Another initiative, "Ecobiose", was also launched more recently on the issue of biodiversity.

Our institution thus has access to the scientific background concerning the regional impacts of climate change. This allows the Region to anticipate changes and develop strategies of adaptation for all its territories and ecosystems, but also for all the socio-economic activities.

It was therefore obvious and necessary for the Region “Nouvelle-Aquitaine” to support the multidisciplinary and international symposium Coast Bordeaux 2017. As a Region, we are very proud to have been associated with it.

Prof. Gérard Blanchard
Vice-President of the Region “Nouvelle-Aquitaine”
in charge of Research and Higher Education

## The Coastline: A Complex Subject of Study Heavily Exposed to Global Change

The coastline is a complex subject of study, in contact with lands and the offshore ocean. It is of interest not only to all oceanographers (biologists and ecologists, physicists, modellers, geologists and sedimentologists, chemists, ecotoxicologists), but also to researchers in the human and social sciences (economists, sociologists, geographers). At the heart of many socio-economic issues, the coastline is heavily exposed to the pressures of natural and anthropogenic changes. Thus, the knowledge of its evolutions and their causes, and even their predictions increasingly require the cooperation of all these disciplines. They also require the development of a strong link between the research communities, economic sectors and public managers. The very broad spectrum of presentations at the Coast Bordeaux 2017 conference perfectly illustrates these multidisciplinary interests and needs. The Centre National de la Recherche Scientifique (CNRS) fully recognizes this, since it attaches great importance to coastal oceanography and coastal sciences.

Oceanography and coastal sciences are more generally integrated into environmental sciences, where the approach consists in combining environmental observation, understanding of how they work and numerical modelling to verify the validity of our understanding of the marine environment and even to predict its evolution, thus helping public decision-making. Observations are of two types, in situ and remote sensing (most often by satellite), and increasingly involve the organization and coordination of large or very large research infrastructures, often on an international scale. It is important to note here that the recurring coastal observations made in New Aquitania are integrated into national and international networks, more particularly under the cover of the Institut National des Sciences de l’Univers (INSU), which is responsible for these infrastructures for CNRS.

This development of research infrastructures obviously raises the question of the proper articulation between national research policies, those developed at the international or European level, where CNRS plays its role alongside the Ministry of Higher Education, Research and Innovation (MESRI), and policies developed at the local or regional level, particularly by universities and regions. As such, Coast Bordeaux 2017 was an excellent opportunity to exchange ideas between researchers, professionals and public managers, with experience of the different countries' research organization and policies.

The international nature of the Coast Bordeaux 2017 conference corresponded well to the aspirations of CNRS when this project was launched, mainly in consultation with MESRI, Ifremer and the French-Japanese Society of Oceanography. First of all, Coast Bordeaux 2017 coincided with the 17th French-Japanese Symposium of Oceanography, with a large Japanese delegation made of scientists and managers. Many Spanish colleagues have also been involved, which shows that the Bay of Biscay coasts are a major European challenge for oceanography research, with regular highlights at specific conferences in which British scientists also participate. Several colleagues also came from the Maghreb countries, particularly Algeria and Sub-Saharan Africa. This shows that the "coastal" object is a research theme that goes far beyond the regional and climatic boundaries of the coasts studied, which should encourage the scientific community to develop north–south collaborations on these subjects.

Finally, CNRS would like to extend its warmest congratulations to the entire Conference Organizing Committee for the quality of the preparation, hosting and coordination of the event. On a personal note, I would like to express my special gratitude to Philippe Bertrand, my predecessor as Scientific Deputy Director for the ocean–atmosphere division of INSU, without whom these few introductory words would not have had the same flavour.

Dr. Bruno Blanke
Scientific Deputy Director for the Ocean–Atmosphere
Division of INSU/CNRS

## Coast Bordeaux Event: An International Symposium in the Continuity of the Three Last French-Japanese Symposia

As Presidents of the French-Japanese Society of Oceanography of Japan and the French-Japanese Society of Oceanography of France, we are both honoured to participate in the inauguration of this symposium in the presence of very high personalities from the world of research and technology in marine science.

We are very pleased to welcome the presence of Ifremer President and CEO, François Jacq; Director of the National Institute of Sciences of the Universe (INSU) Mrs. Pascale Delecluse; President of the University of Bordeaux Prof. Manuel Tunon de Lara, who kindly hosted this important event; Scientific Vice-President of the Regional Council Prof. Gérard Blanchard, who was also President of the University of La Rochelle; Representative of the Ministry of Research, Mr. Alain Lagrange; Prof. Hervé Le Treut, Director of the Simon Laplace Institute; Prof. Eric Feunteun, the National Museum of Natural History, as well as many representatives of research institutes from foreign countries, whose presence expands and enriches the scientific coverage of this 17th Franco-Japanese Conference on Oceanography, fully integrated into the Bordeaux 2017 Symposium.

A special mention must be made for the members of the Japanese delegation, which this year has 33 specialists.

On behalf of the two French-Japanese Societies of Oceanography (FJSO), we express our deep gratitude to Dr. Philippe Bertrand (CNRS/INSU Scientific Delegate) for the help and logistical and administrative support given to this event.

It is up to us, first of all, to pay a special tribute to two other major architects of the organization of this symposium: firstly, Dr. Patrick Prouzet (Vice-President of SFJO France), who spent without counting all over Aquitaine and beyond, without which nothing would have been possible, and then, Dr. Yves Hénocque (Ifremer/SFJO), who provided direct relations in Japan and France between the French and Japanese authorities.

We would also like to underline the support given by the French Embassy in Tokyo, Ambassador Thierry Dana and Councillor for Science and Technology, Dr. Jacques Maleval.

The support of the Maison Franco-Japonaise of Tokyo (Nichi-Futsu Kaikan), of which one of us (H.-J Ceccaldi) had the honour of being French director for four years, must be remembered, in particular because it is in this context that the dialogues between members of specialized societies in France and Japan are most often born and are particularly effective and friendly. This singular institution of cultural and scientific cooperation between Japan and France, created by Paul Claudel and Viscount Shibusawa Eichi, is a private Japanese Foundation supported by the Imperial Family.

The French-Japanese Society of Oceanography of Japan has been headquartered there for nearly 60 years, and here we must recall with gratitude and with some emotion the names of the previous Presidents of this society Profs. Imawaki Shiro (2008–2012), Sudo Hideo (2000–2007), Aruga Yusho (1990–2000), Uno Yutaka (1985–1989) and Sasaki Tadayohi, who was Founder and the first President.

We will recall especially that the French-Japanese Society of Oceanography of Japan was founded in 1960 and that we will soon celebrate its sixtieth anniversary. Since its creation, it has always published a scientific journal whose title “La Mer” is in French.

We are trying to clear together new areas of research, which we then explore. Such is the case of the concept of socio-ecosystem, which is different in the two countries, or of the Japanese ecological concept of Sato-Umi, which will be discussed again during this symposium.

We will continue to learn a lot from each other, not only in the scientific field but in the very broad field of knowledge of our reciprocal cultures.

There are several major problems facing us, some of which are taboo: the demographic development, not only continuous, but often exponential, which is the deep root of many imbalances created in the exploitation of natural resources, as well as the exploitation of the coastal domain by the development of the megalopolises.

The permanent erosion of biodiversity, the overexploitation of resources, the IUU Fishing which require the establishment of effective law enforcement forces against this looting of the marine environment.

The major problem that presents itself remains the becoming of our own existence in finite-dimensional and increasingly degraded environments.

Fortunately, there are some important reactions:

- The encyclical of Pope Laudato Si, who has taken the true measure of the dimensions of this subject: let us not wait for supernatural forces to solve terrestrial problems of ecology.
- The foundation of a specific subsidiary dedicated to biodiversity by "Caisse des Dépôts et Consignations", French Financial Institution; because the world of finance has come to realize that nature has a price and that not protecting it now would cost much more later.

But the general awareness is not yet made. We have in front of us large-scale projects, both to acquire new knowledge and to disseminate it to the greatest number.

We will recall here, together, simply the remark, that has become classic, of President Chirac: "Our house burns and we look elsewhere". It was in Johannesburg 15 years ago already.

Prof. Teruhisa Komatsu
President, FJSO Japan

Prof. Hubert-Jean Ceccaldi
President, FJSO France

## Coast Bordeaux 2017, A Scientific Vintage!

France and Japan keep an active and historical cooperation on marine sciences and technology development, as demonstrated by the two France-Japan and Japan-France Society of Oceanography which held their common 17th conference at “Coast Bordeaux 2017”. This historical cooperation is also illustrated through the holding of the official sessions of the France-Japan Joint Subcommittee for Ocean Development, every other year and alternatively in France and Japan. In 2018, in coordination between Ifremer and the Japan Ministry MEXT, the 27th Joint Subcommittee took place in Tokyo.

These alternate meetings, either under the France-Japan Conference or the Joint Subcommittee, show how effectively the collaboration between the two countries is active. These meetings are as many occasions to know each other better, create cooperation opportunities, and set up common projects that hopefully will multiply in the frame of the emerging “maritime dialogue” between the two countries.

Coast Bordeaux 2017 was not a mere scientific meeting, but gathered two symposia in one, each one held in parallel with common plenary sessions. The first symposium, international-type and strongly supported by CNRS, focused on coastal areas, very productive but also vulnerable to all sort of pressures including those inflicted by human activities, themselves amplified by the climate change impacts. The second symposium was more specifically organized by the two Franco-Japanese Societies of Oceanography, the main topic of which was about the same as the other one though with a stronger emphasis on the socio-ecosystem approach and man–nature relationship, more particularly in situation of natural hazards and post-reconstruction as it is the case in the north-western coast of Japan following the Great Tohoku Earthquake and subsequent highly destructive tsunami. Hence, the crossing of experiences and scientific considerations made the discussion particularly productive.

The following proceedings are very illustrative of both sides’ activities and the richness of the exchanges that took place in Bordeaux. “Coast Bordeaux 2017” has certainly gone a step further regarding the interactions between science and society, hence showing that scientific communities from both sides are keen to enhance their collaboration through the institution of the new “maritime dialogue”.

Before closing those few words, Ifremer would like to address its warm gratitude to all the members from both the Scientific and Steering Committees that hardly worked to this very special and successful double international event, with a special mention of the two main organizers and facilitators who were Patrick Prouzet (Ifremer/FJSO) and Philippe Bertrand (CNRS).

Dr. A. Renault
Scientific Director of Ifremer

Dr. G. Lericolais
Director of International and European Affairs of Ifremer

## Fifty Years of Franco-Japanese Cooperation in Marine Sciences: Jubilee of Prof. Hubert-Jean Ceccaldi

This book aims to pay tribute to the continuous efforts made by Prof. Hubert-Jean Ceccaldi to organize and carry out effective French-Japanese relations in the field of marine sciences for 50 years.

Professor Ceccaldi, then Assistant Professor at the Aix-Marseille University, was sent on a mission to Japan in 1969 to study the progress made in aquaculture and marine biology in that country. This mission was organized on the initiative of Prof. Jean-Marie Pérès, Director of the Endoume Marine Station in Marseille, a research and teaching laboratory where he worked. It was prepared from contacts previously established by Prof. Ceccaldi with several specialists in marine science in Japan.

In this country, very interesting contacts were established at the University of Fisheries of Tokyo, where the French-Japanese Society of Oceanography of Japan was founded in 1960 by Prof. Sasaki Tadayoshi, at the time of the French bathyscaphe dives FNRS-3 in the waters of Japanese marine pits. To date, this society brings together about 200 members and publishes a scientific journal for more than 50 years, whose title “La Mer” is French.

At the University of Tokyo, thanks to Prof. Hirano Reijiro of the Faculty of Agriculture, several of his colleagues and many of his friends, trips and visits to important research centres were organized. On this occasion, the main lines of future cooperation were established, in particular in aquaculture technologies, in biology, in physiology, in nutrition, in coastal management.

Outside of Tokyo, contacts and more in-depth programmes were established and implemented with several universities and aquaculture research centres in Fukuyama, Hiroshima, Nagasaki and Kagoshima.

In 1972, after becoming Director of the Laboratory of Biochemistry and Marine Invertebrate Ecology at the “Ecole Pratique des Hautes Etudes” (Higher Education Establishment), Hubert-Jean Ceccaldi led research teams and supervised numerous theses. A dozen young researchers from this research team, often Ph.D. students, completed part of their thesis in Japanese laboratories.

A first French-Japanese symposium dedicated to aquaculture was organized in Montpellier in 1983. With several of his colleagues Yves Hénocque, Catherine Mariojouls, Denis Bailly and Nadine Lucas, practising in several universities and research centres, Prof. Ceccaldi founded the French-Japanese Society of Oceanography of France, of which he became President. Since then, the French-Japanese conferences have been held in France and Japan: Sendai, Marseille (3), Shimizu, Nantes, Hiroshima, Higashino, Tokyo (4), Paris, Kobe, Boulogne-sur-Mer and Bordeaux, the last one in 2017.

Many joint research collaborations have been established under his leadership, mainly with Kaiyodai–Kagoshima, Nagasaki, Shizuoka, Higashi-Hiroshima, Kitasato, Rikadai and several research organizations. They led to joint publications, PhDs and symposiums and proved to be very fruitful for both partners: artificial reefs, aquaculture, nutrition, lipid metabolism, digestive enzymes, crustacean blood proteins, pigments, sterols, metabolism of adult organisms and larvae, shoreline developments, pollution, plankton, etc.

Successful contacts have also been established with several ministries and universities of Otaru, Tsu, Kyoto, Osaka, Kobe, Kitasato, Fukuyama, Higashi-Hiroshima, Shimonoseki, Fukuoka, Nagasaki, Kagoshima, Okinawa, to name only the main ones. Other relationships and exchanges have been established with many public and private laboratories such as JAMSTEC, the Fisheries Research Agency, field research stations in various prefectures, the Suntory Bio-oceanic Research, the Marine Environment Research Institute and several others, located in many parts of Japan: Sanriku-cho, Nemuro, Sendai, Kesennuma, Onagawa, Ishinomaki, Niigata, Onjuku, Hasaki, Shizuoka, Kashiwazaki, Niigata, Abiko, Chiba, Yokosuka, Takamatsu, for example.

The 2011 tsunami has increased exchanges with laboratories and organizations that have suffered from this disaster. Professor Ceccaldi raised funds from foundations and various organizations to donate seventeen microscopes and binoculars to laboratories that had been hit the hardest.

These collaborations were successful with excellent partners such as Prof. Komatsu Teruhisa and Koïke Yasuyuki, President and Vice-President of the French-Japanese Society of Oceanography of Japan, both of whom were received at the French Embassy in Tokyo, the rank of Officer in the French National Order of Merit.

Many other high-quality partners have been Profs. Nakagawa Heisuke, Kittaka Jiro, Kanazawa Akio, Yagi Hiroki, Arakawa Hisayuki, Nomura Tadashi, Teshima Shin-Ichi, Hirano Reijiro, Nakano Toshiki, Yoshida Jiro, Takeuchi Toshio, Tominaga Masahide, Katoh Juichi, Aruga Yusho, Matsu-ura Fumio, Kakimoto Hiroshi, Okaichi Tomotoshi, Fukuyo Yasuwo, Kazutoshi Kase, Kayama Mitsu, Ina Kazuo, Hamano Akira, Hirayama Kazutsugu, Kiyono Michiyasu, Toshio Iibushi, Okoshi Kenji, Sato-Okoshi Waka, Mimura Toru, Tsuchiya Makoto, Takahashi Hideyuki, Yamane Takeshi, Tanoue Hideaki, to name only the most outstanding of his close colleagues. Most of them have done research in France.

Between 1988 and 1992, the Ministry of Foreign Affairs appointed Prof. Ceccaldi as Director of the Franco-Japanese House in Tokyo. This historic establishment, home to 26 French-Japanese learned societies, is home to young French specialists of Japan. He then directed several research programmes, organizing seminars and symposia as well as 120 conferences in several disciplines, thanks to the support of its Japanese Bureau and the French Embassy.

Continued relations have been established with the Ministries of Foreign Affairs and the embassies of both countries, as well as with the support of the Academy of Sciences, the National Center for Scientific Research (CNRS), the French Institute for Exploitation of Oceans (Ifremer) and many French universities.

These collaborations have identified new concepts and approaches to the relationship between mankind, marine environments and their resources. They open up areas in which the human and social sciences and the cultural characteristics of both countries are more important.

Professor Ceccaldi has directed more than 50 PhDs and is author of nearly 300 publications. He is Knight of the National Legion of Honour, Knight in the National Order of Merit, Commander of Academic Palms and Commander of the Order of the Japanese Rising Sun and received the Military Value Cross with a quote.

He is Resident Member of the Academy of Sciences, Letters and Arts of Marseille.

He is now Honorary President of the French-Japanese Society of Oceanography of France. The latter is assured of continuing this essential mission of exchanges between the two countries in the field of marine sciences, thanks to the dynamism of a team united around a core of French specialists particularly familiar with Japan: President Patrick Prouzet, the two Vice-Presidents Yves Hénocque and Prof. Catherine Mariojouls, as well as several high-level scientists passionate about Japan, Prof. Jean-Claude Dauvin, Mathias Girault, Franck Lagarde, Bernard Tramier, Corinne Bret, François Galgani, Jérôme Dyment or Japanese experts such as Kumiko Uehara and Yasuyuki Koike.

There is no doubt that this motivated and relevant team will continue with pertinence and success the French-Japanese cooperation established for many years in the field of marine sciences.

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# Contents

# Introductory Communications

# Our Future and the Oceans

**Hervé Le Treut**

The alert given by the scientific community about climate change is sometimes perceived as the same message immutably reiterated from year to year. This represents a very strong misperception of a problem which is on the contrary evolving very quickly, while the range of solutions offered to mitigate it has been constantly diminishing throughout the last decades.

As already understood since the historical work of Revelle and Suess (1957), the oceans play a key role in determining the very complex temporality of the climate problem. This is specifically true in response to $CO_2$: The change in its atmospheric content does not significantly depend on its chemistry, but rather on photosynthesis and exchanges with the oceanic and continental surfaces. The fact that the $CO_2$ being emitted into the atmosphere does not easily manage to penetrate into the ocean determines the very long $CO_2$ atmospheric lifetime: while one half of the $CO_2$ emitted by anthropogenic emissions is quickly absorbed by the continents and the oceans, the "half-life" of the remaining part is of the order of 100 years. $CO_2$ therefore tends to accumulate in the atmosphere. This effect is also increased by the quickly evolving rate at which anthropogenic emissions themselves have been increasing. Between the Second World War and today, the amount of $CO_2$ emitted into the atmosphere due to the use of fossil fuels has been multiplied by a factor of about 10, from about 1 Gt of carbon per year to about 10 Gt nowadays[1] (Fig. 1).

$CO_2$ is only the most important of the different long-lived gases which may stay decades in the atmosphere: methane, nitrous oxide, and CFC.

These gases stay enough to be well mixed. Above our heads, the relative amount of greenhouse gases coming from different parts of the world is therefore unchanged, wherever we may stand. The atmospheric persistence of these gases has another

[1]To convert carbon emission into $CO_2$ emission, the coefficient factor used is 3.7.

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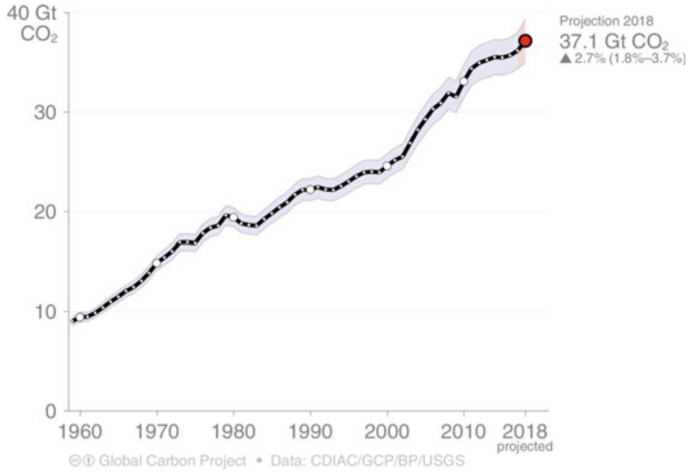


**Fig. 1** Global fossil $CO_2$ emissions from the global carbon project (http://www.globalcarbonatlas.org/en/CO2-emissions)

effect: today's emissions will make tomorrow's climate, and from this point of view, the climate of the next 20 years is largely written, irremediably, as demonstrated by climate models. And our ability to limit the warming in the following decades also depends on what we do now.

All that does not come as a surprise: it basically confirms computations which were carried out much earlier. One of the most important early alerts on climate risks was expressed 40 years ago, in 1979, in a report to the US Academy of Sciences, based on the first climate models and coordinated by a highly respected scientist, Professor Jule Charney. This anticipation became progressively a reality in the nineties.

At the same time, the prospect of what can be achieved to limit the effects of climate warning also evolved strongly and negatively. We have now entered a new phase where many of the early objectives will be extremely difficult or impossible to meet. At this stage also, the role of the oceans is essential: the irreversibility of what is happening depends on the capacity of the oceans to capture and store more than 90% of the warming caused by greenhouse gases. The consequences are very large. The four scenarios proposed by the latest IPCC report to limit global warming below the level of 1.5° are most probably socially and politically unsustainable. They rely with varying degrees on a strong use of nuclear energy and on the—still uncertain—possibility of capturing and storing billions of tons of carbon each. Even in these conditions, the carbon balance needs to be reached before 2050, to satisfy a 1.5° limit—which means no uncompensated use of fossil fuels, a complete revolution of the world in three decades.

What does it take to allow a positive approach of such a situation: certainly, a more frank confrontation with the reality of the problems. It will be inevitable to live on a planet which will be warmer, more populated, more urbanized, with a biodiversity threatened by a whole range of different processes, and facing extreme meteorological events which will probably be more frequent and more intense. There is, of course, a very wide range of actions that need to be taken urgently to diminish the related damages, through the development of a much more sober society. But this will not be enough. The same Earth will have to feed 8–10 billion human beings, to preserve its living resources, its climate, and there will be a necessity to arbitrate contradictory choices. The oceans have a special status in this context. They constitute partly a solution, because an increasing part of the world population relies on them for their alimentation. They require protection, because they suffer twice from the effect of greenhouse gases, in terms of temperature and acidification, also because of the strong vulnerability or the Arctic and Antarctic oceans. But their potential in many areas still requires to be fully assessed, as is, for example, the case for energy production or carbon storage capacity.

We enter a new world, and the ocean will constitute a very precious help for mankind. But such a wealth of opportunities, such a variety of risks, cannot be left to arbitrary decisions, and they require a strongly oriented science-based management.

## Reference

Revelle R, Suess H (1957) Carbon dioxide exchange between atmosphere and ocean and the question of an increase of atmospheric $CO_2$ during the past decades. Tellus 9:18–27

# General Guidelines for Future Exchanges in Marine Science and Technology Between the Two Sociétés franco-japonaises d'Océanographie

**Hubert-Jean Ceccaldi**

**Abstract** The economic systems of production and consumption, as well as the social models that have prevailed so far, are no longer adapted to serious contemporary situations. It is urgent that humans protect the ecosystems on which their present life depends and the existence of future generations, especially marine ecosystems. In France, Japan and other countries, man must now clearly differentiate the disturbances produced by natural phenomena, against which he can do nothing, from those which depend on his own activities. The meetings, the numerous colloquiums, the seminars organized between the members of the two Sociétés franco-japonaises d'Océanographie, and especially their fruitful cooperation, had, from the beginning, pragmatic objectives: to better know and compare the marine environments of the two countries and their various uses such as fishing, aquaculture, artificial reefs, shoreline developments. During their recent meetings, members of both societies have deepened many new concepts and made progress on the major changes affecting marine ecosystems and our societies. They are now orienting their future relationships by taking into account the need to study these themes in greater depth in the light of other disciplines. The dialogue between scientists sheds light on the new relationship between man and the marine environment, its resources and their exploitation. Traditions, eating habits, customs and even religions complete the basic scientific knowledge acquired so far. Our current objectives must be clearly defined to provide decision-makers with our knowledge and expertise, to understand the deep motivations and challenges of the professions and organizations that exploit marine resources, to enable man to live in a world in symbiosis with nature. Several new approaches have been identified integrating elements of economy, sociology, demography, law, foresight, culture, studies of traditions and certain religious activities. Beyond anthropocentric approaches, consideration should be given to the possibility of granting legal personality to non-human entities so that they can be protected. This multidisciplinary work will facilitate better integration of man within the ecosystems, especially marine ones and will help his survival.

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**Keywords** Cooperation between France and Japan · Multidisciplinary approach · Sustainable development

## 1 Introduction: End of Traditional Models

The importance of the ocean in the activities of humanity is considerable: protein supplies, temperature exchanges with the atmosphere, carbon sinks, oxygen production, port activities, coastal tourism, etc. In many countries, humans have benefited a lot, as in France and Japan, countries largely focused on the marine environment.

We are at the beginning of an era of new and major ecological, economic, industrial, financial and social changes (Gaudin 2009), which presents for humanity immense future challenges on which it must act quickly (Jancovici and Grandjean 2009). The goals of our societies should no longer be to grow endlessly, while our world is limited in size and space, or to fill bank accounts, regardless of the environmental price. Our overriding goal is to keep life on Earth in conditions at least equal to those in which evolution has led it so far. We must make our contribution.

The conclusions of the IPCC (Intergovernmental Panel of Experts on Climate, (or GIEC: Groupe Intergouvernemental d'Experts sur l'Evolution du Climat) are now accepted by all: global warming is continuing alarmingly. The sea level continues to rise (Cazenave et al. 2014), exponentially, today between 3.3 and 4.8 mm per year (Nerem et al. 2018), putting in danger, in the medium term, very numerous populations in the world: small islands, large deltas, diked littoral zones, polders, etc. In the 2050s, the world population will exceed 9 billion people, which is an increase of 34% over today, according to the United Nations. Food resources will have to increase by 50%.

At the same time, because of the rising waters, the survival of millions of people will be directly at stake in many parts of the world: after the Kiribati Islands, it is, for example, a quarter of Bangladesh, New Orleans and much of from Louisiana, Ho Chi Minh City and the great deltas of Viet Nam, Jakarta to Indonesia, Abidjan to Ivory Coast, etc., which will be the inevitable victims. While they have been clearly expressed for thirty years, but little listened to, these forecasts are strongly imposed, every day more, to our societies.

Remarkably, closer to home, the Netherlands, where almost half of the population lives in areas won over by the sea, have already made original arrangements to continue to provide a normal life for their citizens.

The time is no longer to congratulate us on the global economic development, because this growth necessarily uses new natural resources, especially at sea, while they are already too heavily damaged, despite real efforts in recycling.

The classic economic studies now show their limits and the *Homo economicus* is a model less accepted by the economists themselves (Tirole 2016), even rejected. The blind pursuit of the classic economic development in a closed and limited space (our planet) can only lead to disasters. Industrial fishing will not be able to continue its destruction in large upwellings and on their ocean floor to increase the material wealth of some. Man must integrate more fully with the existing ecosystems of which he is a part.

A new awareness of much more economic and frugal behaviour is developing in many countries and in our societies.

French and Japanese scientists are already contributing to understanding the functioning of ecosystems, the protection and the use of marine resources. They must establish the maximum values that natural production can bring to human consumption.

Cooperation with our Japanese colleagues will, therefore, continue to progress in these new fields, centred on the preservation of life in the oceans, according to the corresponding strong changes in the societies of each country. Together we must make a positive contribution to the future conditions of human life on the planet.

## 2 Numerous and Important Results Obtained

The results of research conducted in cooperation with our Japanese colleagues are too numerous to be exposed here. They concretize the relationships established for more than 50 years, and during our 16 previous symposiums, always very rich and always friendly. They have given rise to hundreds of papers, scientific publications and numerous collaborations (Koike 2015; Mariojouls and Prou 2015; Ceccaldi 2019).

Many research topics have been explored and will be developed together in the future: physics, chemistry, deep mineral resources, study of the ecosystems and biological cycles of the organisms that compose them, creation of marine habitats for different marine species, progress in aquaculture new species, new and efficient methods for exploiting marine natural resources, all topics discussed during the 13th Franco-Japanese Oceanography Symposium ‘Global Change: Mankind-Marine Environment Interactions’, held in Marseille in 2008.

They were taken up during the 14th Colloquy on the theme: ‘Toward Sustainable Use and Management of the Oceans’ which took place in Kobe and Tokyo in 2010. These themes were deepened during the 15th Franco-Japanese Symposium. Oceanography ‘Marine Productivity: Disturbances and Resilience of Socio-Ecosystems’, and during the 16th Symposium ‘The sea under the human and natural impacts: Challenge of Oceanography to the Future Earth’, which took place in Shiogama and Tokyo in November 2015.

Several of these very similar approaches have been expressed by Magnan and Gattuso (2016) on changes in the oceans related to climate change (Munoz and Martinez-Rodriguez 2010).

New concepts have emerged: socio-ecosystems, the role of Sato-Umi, the functioning of cooperatives, social relations between seafarers, modes of exploitation of artificial reefs, coastal management, new law of the sea, marine protected areas, etc.

# 3 Extensions in the Future of Results so Far

## *3.1 General Oceanography*

### 3.1.1 Tectonics

The direct observation of tectonic plate movements in Japan has given rise to a great deal of French-Japanese research (Le Pichon et al. 1987a, b; Fûri et al. 2011). Very recently, JAMSTEC has carried out a submarine observation network laid on the seafloor, the DONET 1 network, consisting of about 20 complex sensors at the level of the Nankai tectonic line, where Nakano et al. (2013) have already observed a strong activity. This program will be extended very soon by the establishment of a DONET 2 network, which will be more precise (Honsho et al. 2009; Fûri et al. 2011).

### 3.1.2 Currents

The realization of real-time dynamic mappings of eddies, gyres and the state of the oceans can only be achieved at the international level. Exchanges between French and Japanese teams are already yielding many results thanks to complementary work, using in situ data and those of specialized satellites (Yamada et al. 2004; Ponte et al. 2013).

The position, the three-dimensional displacements and the thickness of the great currents, the movements of the ice in the Arctic and peri-arctic zones under the influence of the winds and the marine currents, will be better known during this period of warming of the marine waters (Herbaut et al. 2015).

### 3.1.3 Coastal Evolution

The detailed characteristics of the coasts are an essential element for a good management of the littoral environments (Le Berre et al. 2005; Komatsu et al. 2012), They are better known by the use of the improved multibeam echosounders giving real-time results (Hamana and Komatsu 2016), as well as Light Detection and Ranging or Lidar techniques (Mallet and Bretar 2007) and photogrammetric drones. Direct observations of the state of vitality of coral reefs are obtained by Lidar imagery based on data collected by specialized vessels (Sasano et al. 2015). The importance of aggregate removals ultimately modifies the coastline in each of the two countries (Desprez 2000).

### 3.1.4 Data Provided by Satellites

The role of satellites in observing oceans and their colours is invaluable (Butler et al. 1988; Longhurst et al. 1995; Carr et al. 2006; Chassot et al. 2011). The global 'Copernicus' program includes a series of 'Sentinel 2' satellites, which collect data on vegetation, soil, coastal areas and waterways. It is completed by the series 'Sentinel 3 A and B'(temperature, colour of the ocean surface) in 2018, then 'Sentinel 4', which measures several gases and aerosols contained in the atmosphere.

The Japan Aerospace Exploration Agency's (JAXA) Japanese IBUKI satellite recently showed that the $CO_2$ content of the atmosphere exceeded 400 ppm. Its measurements provide very valuable data on the relationships between ecosystems and fisheries management (Friedrichs et al. 2009; Chassot et al. 2011) including model variations over time and space (Chiba et al. 2013).

The joint use of new results at increasingly finer scales (Sagawa and Komatsu 2015) will complement the global syntheses homologous to those of Meteosat in meteorology. The use of new floats—Deep Ninja by JAMSTEC in Japan and Deep Armor by Ifremer in France—is destined to give new and very original results in the measurement of the transport of calories by deep currents.

### 3.1.5 Sea Level Rise

There are already, today, on the planet, more climate refugees than refugees following the wars. Arctic populations are having their way of life completely upset. Many islands whose altitude is very low will be submerged during the rise of the sea level (Duvat and Magnan 2012) as Malé, capital of Maldives, populated of 110,000 inhabitants, hardly protected from storms by a modest peripheral dike. In 2012, the UN predicted 250 million displaced people worldwide in 2050.

The Republic of Kiribati, in the Gilbert Islands Marine Protected Area, (Uakeia 2013) will need to take concrete action when the rising waters force people to leave their islands. Many other Pacific islands, Fiji, Marshall Islands, Nauru, Samoa, Tonga, etc, are in the same situation. In Japan, the very low altitude of umetate, embankments characteristics of the ports of the megalopolis of the Pacific coast, and in particular of the artificial islands of the city of Kobe, the airports of Haneda, Kansai, Faaa in Polynesia, and even of Marignane and Nice in France, will inevitably be affected by the rising waters.

### 3.1.6 Dissolved Gas and Temperature

The present situation of humanity is unprecedented. Oceans absorb large amounts of heat (Gleckler et al. 2016). It is now admitted that this increase is irreversible. They also dissolve huge amounts of $CO_2$, which are increasing (Kurihara 2008), methane ($CH_4$) (Kirschke et al. 2013) and nitrogen oxide ($N_2O$) decreasing at the same time, so harmful, their dissolved oxygen content (Keeling et al. 2010; Carstensen et al.

2014; Capet et al. 2016). The increase in the $CO_2$ concentration of the atmosphere increased the concentration of dissolved $CO_2$: the pH decreased from 8.2 to 8.1, greatly affecting the calcification capacities of many species. The question of the conservation of the present characteristics of ocean waters arises now.

### 3.1.7 Treatment of Collected Data

Our activities are gradually digitized in all areas of our lives. The study of marine ecosystems, observation of their operation by many underwater or aerial sensors and their exploitation by artificial intelligence will develop in France and Japan.

Standardization of the techniques used by oceanographers, new common methodologies and finally the use of new computer techniques and data processing, will make it possible to synthesize many results obtained by the direct observation: colour, contents and characteristics of pigments (Suzuki et al. 1998; Devred et al. 2007), photosynthesis (Kim et al. 2000; Yamada et al. 2004; Platt et al. 2009), particles (Many et al. 2016) temperature, currents, all the same more precise and significant than they are (Poggiale et al. 2001). A new cyberspace is emerging, specific to the marine world: the current computing resources allow many integrations of data essential for a good understanding of these natural phenomena. The new—and future—possibilities of the computing centres of the Brest-Iroise technopole and the Earth-Simulator at JAMSTEC open up new fields for research.

New paradigms allow cooperation between different disciplines of marine science, between physical oceanography and human activities (Dauvin and Ruellet 2009; Le Tixerant et al. 2012), between modelling teams and computational specialists, which will also open new research areas.

Due to the complexity of ecosystems, relevant quality criteria in more or less variable environments are not yet established (Chevassus-au-Louis et al. 2009).

## *3.2 Evolution of Ecosystems*

The evolution of the ecosystems must be known with precision in order to evaluate their global production, their instantaneous productivity, and to predict their fate, their protection and their possible use by the man.

It is important to know the biogeochemical cycles of elements such as iron or silicon, necessary for marine organisms (Quéguiner 2013, 2016). Ecosystems are subject to seasonal, meteorological (Furuya 1993) or accidental variations and most of these have been modified by human influence (Soto and Bianchi 1990; Ceccaldi and Komatsu 2015).

Measurements have been made recently to evaluate in real-time the temporal variations of planktonic ecosystems (Davis et al. 2004; Dugenne et al. 2015) in particular to be able to measure toxic unicellular algae contents during climate change, as well as their variability, data of great interest to shellfish farmers in both countries.

Coral bleaching is one of the most visible manifestations of the large-scale consequences of global warming (Salvat 2015). Genetic features of the resilience of these corals to changes in the marine environment are being explored (Palumbi et al. 2014). The economic consequences will be considerable: drop-in tourism, a sharp decline in coastal fisheries, and a very significant loss of biodiversity (Hughes et al. 2017).

The increase in temperature affects, more or less strongly depending on the species, the mechanisms of oogenesis, spawning and larval growth. The synchronism between the growth phases of many species and the availability of their food or prey is still far from known.

### *3.3 New Living Forms*

Abyssal environments are still unknown to us at 95%, and bottom currents studies are new subjects of the greatest importance (Yanagimoto and Kawabe 2007; Kawabe et al. 2009; Yanagimoto et al. 2015).

Numerous discoveries remain to be made in the study of deep hydrothermal watershed ecosystems, where new benthic species are frequently described and each time, they bring their batches of novelties (Fisher et al. 2007). This is also true for pelagic species (Pesant et al. 2015), especially in the oceans little studied so far (Girault et al. 2015), in coral reefs (Salvat 2004; Salvat and Wilkinson 2008) and even in our temperate climates.

In systematics and evolution of marine organisms, the use of molecular tools, the certain identification of the organisms constituting the ecosystems, the specific biochemical and molecular mechanisms of the species subjected to variations of temperature and salinity represent major ways of future researches. This is all the more necessary as many marine species have not yet been discovered or identified.

Thus, genome sequencing of a yet common species octopus, *Octopus bimaculoides,* has brought surprising results: its genes are more numerous than those of man (Albertin et al. 2015), which may partly explain why this mollusc be endowed with real intelligence. Systematic exploration of the different phyla of marine species will necessarily bring great unexpected facts as to the basic affinities of classical zoological, botanical, unicellular and marine viruses (Ogata et al. 2011; Claverie and Abergel 2018).

For its part, the systematics of all arthropods (Giribet and Ribera 2000) and that of archaeas are fundamentally overhauled (Muller et al. 2010; Petitjean et al. 2014). Finally, some very interesting work on larval behaviour has been done recently, for example by Satoh et al. (2017). The number of systematists specializing in marine organisms must be greatly increased in France and Japan. It is essential to know the forms that exist today in natural environments—before they disappear forever—and then to allow effective dissemination of this new knowledge.

### 3.4 Exploitation of Marine Resources

France and Japan are among the world's largest importers of seafood products. Overexploitation due to poaching and illegal fishing is estimated to 20 million tons for a landing estimated to 70 million tons on the period 2011–2013 (Gros and Prouzet 2014). Sea fishing has reached a situation of overfishing close to breakage. Often, the number of fishing boats built has been overvalued under social or political pressures and not taking into account the production potential of the exploited ecosystems. Fishing will now need to be based on a systemic approach to manage resources appropriately (Garcia et al. 2003, 2005; Prouzet 2010), based on a better understanding of ecosystem production (Trenkel et al. 2013, 2015; Rochet and Trenkel 2014).

Scientists will be confronted with a sharp increase in global human populations, which will increase the consumption of products from the oceans. It is imperative that birth control takes place at the global level. The subject seems taboo. The classic reactions on this subject, relate to Malthus, racism, cultures, religions for example, but very rarely the capacity of regions, states or territories to be able to feed, subsist and educate the too prolific populations that are there who live there and for whom they are responsible.

The world population will reach 10 billion in 2053, while it is 7.4 billion currently. The African population is expected to reach 2.5 billion by 2050, the largest increase on any continent. Despite scientific and technical progress, living marine and mineral resources (sand, gravel) already insufficient, will not suffice. Marine aquaculture itself, which will long depend on «forage fish», is now starting to reach its limits.

Other methods have been developed at the Ifremer Center in Boulogne-sur-Mer (Marchal et al. 2015) to correctly describe the marine dynamics of the marine ecosystems exploited in the English Channel.

A new approach, used by Lehuta et al. (2015) has established a spatial model of demersal fisheries in the English Channel. The correct delineation of marine protected areas aims to improve fisheries management (Le Pape et al. 2014; Marchal et al. 2015) based on a good knowledge of these ecosystems. The case of copepods in eutrophic harbour areas was addressed by Tanaka and Akiba (2015). This field is also expected to develop (Brun et al. 2016).

Finer studies in the exploitation of fish stocks and sub-stocks are beginning to be well used to preserve the very existence of exploited species, as did Andrews et al. (2006) for *Gadus morhua* stocks in the North Atlantic or Reecht et al. (2015) for fisheries in the English Channel.

Human activities affect different marine ecosystems in a particular way (Duarte Santos 2014; Boudouresque et al. 2009). Halpern et al. (2008) undertook a general map of human impacts on these ecosystems. Le Tixerant et al. (2012) have developed models that reflect the development of these human activities.

In addition, the work of fishermen is changing in Japan as well as in France (Prouzet et al. 2001). In Japan, professionals are becoming older and increasingly rare: younger generations are turning away from random and tiring tasks. Decreasing resources in natural environments affect poor working conditions (Takahashi et al. 2012). Also, studies on the ergonomics of fishermen and the partial robotization of certain fishing boats have been conducted experimentally in Japan (Takahashi 2013, 2015). The results of this work should inspire significant improvements in the work of fishermen in Japan, France and other countries.

## *3.5 Aquaculture*

### 3.5.1 The Role of Aquaculture in Human Nutrition

On the period 2011–2013, 66 million tons of aquatic products consumed by humans come from aquaculture for a global aquatic food supply estimated to 136 million tons (Gros and Prouzet 2014).

Since the 1980s, aquaculture of fish, crustaceans, molluscs and algae has given rise to numerous exchanges and cooperation between members of the two Sociétés franco-japonaises d'Océanographie. Aquaculture can only grow from juvenile forms harvested in the wild, such as eels (Nielsen and Prouzet 2008). The life cycle of the main species that structure marine ecosystems is often only roughly known (Ceccaldi 2016).

Since the 1960s, large-scale aquaculture has made considerable progress for both freshwater and marine species: reproductive technologies, new hatchery technologies (Harun et al. 2012), novel compound feeds, conditioning of juveniles to particular sounds, influence of photoperiod and illumination wavelength of larval and juvenile forms, influencing their survival, growth, aggressiveness, etc (Coatanéa 1974).

The overexploitation of natural populations will lead to a strong development of aquaculture, reinforced by the increase of the world population, by higher consumption of noble proteins, by better information on the balanced diet.

### 3.5.2 Evolution of Feed Used in Aquaculture

Most of the marine species raised today are fed mixed feeds containing fishmeal and marine oils rich in omega-3 polyunsaturated fatty acids.

The replacement of fishmeal in feed for aquaculture of marine animals with products from (terrestrial) agriculture will continue (Lim et al. 2008; De Francesco et al. 2007; Médale et al. 2013; Burel and Médale 2014). The situation is quite different in France, a country with strong agriculture and in Japan, which imports a large part of the consumption of agricultural products.

The adaptation of the digestive potential of marine animals to terrestrial food (Panserat et al. 2009) containing carbohydrates—which characterizes terrestrial higher plants and in particular grasses—deserves much more study in-depth (Enes et al. 2011). They will also be used for detailed analyses of the food webs of coastal ecosystems.

These data need to be refined: different individuals from the same population show particular characteristics with regard to compound foods containing different levels of vegetable proteins. This fact shows different genetic variability and growth performance depending on the individual (Dupont-Nivet et al. 2009; Le Boucher et al. 2013).

In addition, the bacterial populations of the digestive tubes change significantly depending on the animal or vegetable origin of the food, which opens a new area of research (Silva et al. 2011; Desai et al. 2012; Gatesoupe et al. 2014).

### 3.5.3 Impact of Aquaculture on Surrounding Environments

Aquaculture necessarily modifies the natural environments in which it is established (Kristofersson and Anderson 2006). The presence of aquaculture facilities in natural environments deserves special attention because a supplement of usable food is injected into natural ecosystems.

The high density of fish in cages induces the proliferation of various parasites, the appearance of diseases and mycoses, which requires, to limit their development, the use of chemicals, most often synthetic, harmful to humans consumers and neighbouring species. The intrusion of synthetic chemicals into ecosystems has often been denounced (Hites et al. 2004).

This area will be the focus of much future work, including on the effects of pesticides (Shaw et al. 2006) and, conversely, the beneficial presence of polyunsaturated fatty acids, for example, in salmon (Foran et al. 2005) and other species.

The animal meal used comes from the exploitation of stocks of 'forage fish' whose fishing represents, worldwide, 16 million tons on the period 2011–2013 (Gros and Prouzet 2014). These are low-cost pelagic species (sprat, anchovy, sardines, blue whiting, etc.). These fisheries deprive natural predators (carnivorous fish, turtles, seabirds, marine mammals, etc) of their usual prey (Garcia et al. 2003). It, therefore, becomes urgent to be able to establish and use reliable indicators (Rochet and Trenkel 2014) to measure this decrease and identify the critical phases of future imbalances.

### 3.5.4 Optimal Conditions of Growth

We need to learn more about the optimal conditions for the survival and growth of organisms raised in aquaculture under controlled conditions (Wabete 2005; Pham 2016). The optimal combinations between salinity, temperature (Yagi and Ceccaldi 1985; Yagi 1988; Ceccaldi and Yagi 1990; Yagi et al. 1990) and the effects of the light factor intensity, photoperiod, wavelength, feeding in the larval, then juvenile, then adult, and then reproductive stages are known only in a very small number of species (Trellu and Ceccaldi 1980; Coatanéa 1974; Kinoshita 1985; Hotta et al. 2003). It is essential to know the optimal conditions of each life-history stage of the species considered. These farming charts allow to know the evolution of the ecosystems when the environmental conditions vary (Kiyono and Kido 2011).

### 3.5.5 Physiology

The physiological functions of farm animals need to be better known for optimal aquaculture conditions (Nakano et al. 2013), nutrition and reproduction (Nakagawa and Ceccaldi 1985). The combined effects of decreased pH and increased temperature bring new scientific challenges in ecophysiology.

The exchanges between Japanese and French researchers focused on the potential for rearing algae, macrophytes or unicellular species, in particular the species *Saccharina japonica*, *Undaria pinnatifida, Porphyra tenera, Eucheuma* and *Gracilaria* sp, sometimes showing their capacity to use their biomass to produce methane (Yokoyama et al. 2008).

In addition to the use of $CO_2$ in the atmosphere, marine unicellular plants produce many metabolites with pharmacodynamic effects. Their varied potentials are high. They are very dependent on the results of basic research on existing species in the oceans and their pigments (Kim and Chojnacka 2015).

Aquaculture will therefore certainly still provide an opportunity for future cooperation between France and Japan.

### 3.5.6 Digestive Enzymes

In spite of the already old works (Bauchau and Mengeot 1965; Brun and Wojtowicz 1976; Trellu 1978; Van Wormhoudt 1981; Zwilling et al. 1981; Ceccaldi 1982; Titani et al. 1983; Ceccaldi 2006) much remains to be done to get to know the control of the synthesis and biochemistry of digestive enzymes of marine organisms and their ability to use the elements present in their ecosystem, or compound feeds. Knowing these variations will allow fine analyses of the functioning of ecosystems, particularly in the study of the dialogue between genotype and environment, leading to the concept of *ecogenetics* (Van Wormhoudt 2015).

Physiological regulation (Van Wormhoudt et al. 1972, 1980; Trellu et al. 1977, 1978a, b; Galgani et al. 1988; Le Vay et al. 2001), depending on the quality of food (Furutani et al. 2012; Murashita et al. 2015) deserve more fruitful developments. Variations in their life cycles (Van Wormhoudt 1973) or their ovarian reserves during breeding cycles open up new areas of research, especially for newly discovered species.

## *3.6 Effective Protection of Marine Protected Areas*

In a pithy way, it can be said that, in most cases, marine protected areas have little or no protection. Some areas are well marked, and others are monitored by effective police forces, but this is rarely the case. Effective, military, if necessary, international use of air assets or satellites must be established quickly. The use of drones to monitor marine protected area boundaries has already been suggested (Ceccaldi 2015):

they are already used to monitor national parks and protect decimated mammals by poachers (Lotter et al. 2016).

Definitions of marine protected areas vary: no take, or poorly exploited, with or without artificial reefs (Ceccaldi 2015), possibly accessible to tourists. The responsibility for their creation, existence and protection is not yet well established (Amako 2015). Future French-Japanese work should study the functioning and performance of undisturbed or restored ecosystems in disturbed environments (Médioni and Lardic 2011).

An operation that takes into account local production by riparian fishermen may be a better solution than unnecessarily isolating too large undeveloped marine areas (Halpern 2003; McClanahan et al. 2005, 2006).

Similar considerations were expressed by Al-Abdulrazzak and Trombulak (2012), and by Ceccaldi (2015). This area needs to be explored with our Japanese colleagues (Tanaka and Ota 2015) from their own experiences. The example of traditional fishing cooperative practices in Japan needs to be carefully considered (Yanagi 1998, 2005; Hénocque 2015a; Komatsu and Yanagi 2015; Tanaka and Ota 2015).

## *3.7 Ecological Engineering*

### 3.7.1 Offshore Construction

This new sector of applied ecology touches on many areas: offshore construction, artificial reefs, floating aquaculture cages, wind turbines and tidal turbines, etc. It opens up many future possibilities, in the physical, chemical and materials fields as well as in the field of environmental law (Cazalet 2009; Quimbert 2005; Bas and Gaubert 2010; Regnery 2013). Coastal or submarine developments—dikes, docks—should not disrupt the natural functioning of marine ecosystems and, to the extent possible, should improve them through habitat creation (Ceccaldi and Nakagawa 2003).

For example, the Port of Marseille has recently developed a major GIREL program (Management of Infrastructures for the Ecological Restoration of the Coast) including brown algae transplants *Cystoseira mediterranea*. Specific habitats intended to partially cover harbour structures: dikes and docks have been developed to house the juveniles of their predators (Mercader et al. 2016). This operation NAPPEX (Artificial Nurseries for Exemplary Ports) derived from the Biohut project, equips at the experimental level several Mediterranean ports, as well as other experiments carried out with the Baltimore aquarium in the United States.

The construction of Kobe Airport on an artificial island in Osaka Bay has led to special underwater developments around this construction. This is an unexpected example of an artificial marine protected area.

### 3.7.2 Artificial Reefs

This is undeniably one of the techniques of ecological engineering that, despite its seniority, has a great future, as the biological cycles of each of the species present and their habitat needs to be better known at each stage of their growth (Charbonnel et al. 2001).

Japan has installed almost all of its coasts, more than in any other country. In reinforced concrete, steel, stone, wood or plastic and their shapes can be both very complex and varied. Since 1985, the two Sociétés franco-japonaises d'Océanographie have exchanged information, published and carried out numerous experiments on this theme (Brégliano and Ody 1985; Delort et al. 2000; Ceccaldi 2011; Charbonnel and Bachet 2011).

The methods of designing and developing modern artificial reefs make it possible to create habitats that are much more diverse and more numerous than those offered randomly by natural environments (Ceccaldi 2015). They present habitats for a greater number of species and are intended to maintain high biodiversity. They will not be accessible to fishermen (Ceccaldi 1999).

Complex artificial reefs harbouring many benthic species use organic production of plankton that would sink to the bottom without being used (Cresson et al. 2014). They increase the local biomass and increase the biodiversity of the ecosystem where they are located. This theme will require further research (Ceccaldi 2011; Cresson et al. 2014).

### 3.7.3 Wind Turbines and Tidal Turbines

Renewable marine energies such as floating or bottom-mounted wind, possibly wave energy, sea thermal energy and tidal power will benefit from progress in the design and construction of artificial reefs. Effective principles and achievements will be transferred to these offshore constructions and will provide new habitats for marine organisms.

The intrusion of large constructions in natural environments brings new comparative law problems in France (Schneider 2013) and in Japan. These new activities compete with other human activities: fishing, tourism, sailing, transport, nurseries of marine species, etc. Currently, it is difficult to establish appropriate rules on the transfer of responsibility or compensation that will be linked to these new coastal activities (Bas and Gaubert 2010).

## 4 New Ways of Cooperation in Marine Science and Technology

Many new topics were discussed during the exchanges between the two Sociétés franco-japonaises d'Océanographie. They open new paths to the future.

The joint explorations are very fruitful: the use of research vessels by mixed teams, detailed and complex analysis platforms, oceanographic satellites, laboratories specializing in planktonology, nanotechnologies, aquaculture, physiology, artificial reefs, etc.

### *4.1 Effects of Global Change at Different Levels*

Today, humanity faces new heatwaves, droughts, forest fires, floods, storms, rising sea levels, ocean acidification, temperatures, water shortages, etc. Their effects are felt at different levels, from biological structures and ecosystems to humans.

The primary productivity and the metabolism of micro-organisms are modified but in proportions that we hardly know, which opens new common fields of research. Phytoplankton, zooplankton and larval, post-larval and juvenile forms that feed on them are affected in turn. The risks of developing toxic algal blooms will increase (Moore et al. 2008). Calcification mechanisms are affected, disrupting all organisms, microscopic and macroscopic, which transform calcium into various types of limestone (Andersson et al. 2011; Gattuso and Lavigne 2009; Gattuso and Hansson 2011; Noisette 2013). This is the case of oysters, mussels, sea urchins (Kurihara et al. 2007, 2009, 2012; Ivanina et al. 2013). At the end of the chain, human activities are reached at various levels: fishing, aquaculture, coastal management, tourism, animal and human health.

### *4.2 Increasing Littoral Megacities on the Marine Environment*

The size of cities is increasing all over the world, especially for large coastal agglomerations. They end up joining together and create megacities. Examples are numerous, particularly in Japan, the United States, India, the Philippines, Indonesia, China, etc.

The big coastal capitals: London, Tokyo, Amsterdam, New York, Miami, Venice, the huge areas of the polders in the Netherlands, countless coastal settlements, especially those built on the great deltas of Asia modify all the environments natural neighbours.

From the particular ports or geographical sites that make up their origin, the seaside towns spread and consume the coastal areas and disrupt coastal ecosystems. They often build huge embankments at sea in order to continue their development.

This is the case in Singapore, Hong Kong, several cities in China, Tokyo, Yokohama, Osaka and Kobe where, in addition, square kilometres of artificial islands have been built.

During their growth, the redistribution of urban and coastal functions generates new situations whose ecological, economic and sociological aspects will have to be taken into account.

### *4.3 Food Habits and Exploitation of Marine Resources*

Man is only a recent production of evolution of nature and yet he shows great propensity since the Neolithic, to modify, then to destroy, of conscious or unconscious, perhaps because it does not resist him. Rightly or wrongly, he has always regarded animals as his enemies, except perhaps for certain domestic animals and the seafood he feeds on.

The different marine species are variously appreciated according to the customs and traditions of each country. So far, marine aquaculture, shellfish farming and even the structure of artificial reefs have mostly focused on species highly demanded by the market—and therefore under the direct influence of dietary habits, which vary greatly from region to another region. Western consumers, for example, consume sea bass, sea bream, red mullet, sole, flounder, turbot, penaeid shrimp, lobster and rock lobster. In Japan, in addition to these species, many other varieties are consumed, which has led to the creation of specific aquaculture enterprises, such as some species of algae (nori, wakame), tetrodon (fugu), of ascidians (hoya), which are high, not to mention fishing species that are rarely consumed in other countries, such as cod gonads (mentaiko), whale meat (kujira), gonads males of several species of fish (shirako), fry of sardines (chirimen jako), jellyfish (kurage), sea cucumbers (namako) and many species of crabs, fish and molluscs, all highly appreciated. This is all the truer as Japanese consumers consider that there is a particular taste, the ‘umami’, in some marine products (Kurihara 2015).

### *4.4 Relationship Between Tradition and Exploitation of Natural Resources*

This very important subject has not often given rise to detailed studies. In both Japan and France, the choice and consumption of food from the marine environment obeys customs and rules, sometimes religious, quite strict, so we know little hidden springs. The place of lobsters or prawns of the species *Penaeus japonicus* (Kuruma ebi) in major festivals in Japan, or that of oysters for Christmas in France, or bouillabaisse in the Provencal region are good examples.

On another scale, we must place Japanese mentalities in their Shinto framework, which attributes notions of divinity to the environment in which everyone lives: god of the mountain, the rock, the source, etc. Integration into the natural environment is then much easier than in a western monotheist setting.

It is important to mention the great interest of the Japanese Emperors themselves in scientific research on marine organisms. It is a remarkable living symbol for the Japanese people.

In another setting and in other places, Philippe Descola (2005, 2010, 2011) has shown with great pertinence the close links between nature and culture, which explain, in various peoples, certain behaviours that must be explained in the field of anthropology.

We discover together the discrete, but essential, influence of Shinto, adding to deep basics of Buddhism, sources of Japanese spirituality, that mark the behaviour of an entire people. Several forms of poetry, often very old as tanka and haiku, marked by the sacredness of nature, Murazaki Shikibu, Basho Matsuo, the monk Manzei or Arakida Moritake, whose poems are imbued with nature and of its variations during the seasons.

Remarkable Japanese ecologists advocate closer relations between man and nature. This is the case, Masanobu Fukuoka, a precursor of farming without fertilizers, Yoichi Kuroda, Hirofumi Yamashita, Yoshikazu Kawaguchi, advocate of natural farming, the primatologist Imanashi (2011) who first, the notion of explicit animal culture among primates and even Miyazaki Hayao, the creator of remarkable animated movie, or cartoons, in which various aspects of the forest and nature play a large role (Fournier 2013). The list of Japanese books, old and new, where nature plays a major role, would be too long to be discussed here. They are just as many positive discoveries. We will not forget to mention Jean-Henri Fabre, the famous French entomologist who is undoubtedly better known in Japan than in France.

In the western world, what is considered 'civilized' is what depends on the spirit of reason, and what is 'barbaric' is associated with the state of nature. Nature is unconsciously opposed to culture and civilization. In East Asia, the most cultivated state is the most natural. The seascapes, the gardens, the themes of the prints of the masters of the ukiyo-e are a striking illustration. Utamaro dedicated a part of his work to organisms—algae and shells—abandoned on the beaches. The silk paintings of Jakuchû sometimes represent fish whose colours and the precision of the lines are admirable. They have no equivalent in France or in Europe.

In the West, we begin to understand the need for close contact with nature. 'Man is, no doubt, a part of nature. It is therefore included in it. But it is equally certain that man understands nature, which is, therefore, an idea or a human representation' (del Vecchio 1961).

Moreover, it is extremely significant that today, Pope Francis was at the origin of the writing of an encyclical (François Saint-Père 2015) quite new in the history of Christianity. For the first time, man is no longer considered a species apart, whose role on Earth is to dominate other species.

This encyclical is a new religious questioning about the concept of anthropocentrism. It is a new 'sacred' that seems to be differentiating today, indicating that other living beings should not be considered as pure objects, subject to arbitrary human domination.

All countries of the planet are subject to the same rules of ecology. General awareness is then imposed on all countries (Schellnhuber et al. 2016), even those who reject or ignore them.

The rules that we must impose must be disseminated, with very important means and well-adapted pedagogies, to the countries which have no real ecological culture, nor any tradition of the imperative need to preserve and keep undisturbed the natural spaces.

Indeed, it is very difficult to make known the true current situation of the marine world and the aquatic environments in the regions of the world which refuse the laws of the biological evolution, which have no practice of the rigorous management of the natural environments and where the belief of a supernatural creative power would be at the origin of all things. The small number of schools and the content of their school programs, where biology is absent or poorly represented, constitute a huge obstacle to the basic ideas of protecting the natural environment for the very survival of these countries themselves.

The high birth rates of these regions, leading to stands that are far too different from local resources, especially marine ones, induce displacements of populations that become imbalances at regional or even global scales. 'The real education is to lead people to think for themselves' (Noam Chomsky 2010).

## *4.5 Sato-umi Concept and Coastal Management*

The history of Japan, which remained closed for more than two centuries during the 'Sakoku', or closure of the country (1641–1853), led each village to live from the natural resources and local productions closest to them. Overall, the country then lived in near-autarky, and carefully managed its land-based and marine resources in close relationship with the frugal needs of its inhabitants. For the villages on the coast, the sobriety of the management of land and marine wealth also applied, inducing local behaviours that are very resource-efficient and which still strongly influence Japanese culture today.

The integration in our reflections of the Japanese concepts of sato-yama (village of the mountain and forest) and sato-umi (village of the sea) have enlightened our French-Japanese exchanges about the place that the man occupies *vis-à-vis* the natural environment and in particular the littoral environments. These ancient concepts mark the functioning of fishermen's cooperatives and local, regional, and even national economies (Hénocque 2015a; Komatsu and Yanagi 2015). Protective practices were then established in order to pragmatically establish reasoned management of resources.

A major idea linked to the 'sato-umi' will have to lead every human community not to consume more than its territory produces. We must consider another mode of development, of 'heterodox' type, for sustainable development (Maillefert et al. 2010; Zuindeau 2012). Together with our Japanese colleagues, we will be able to expand our fields of interest, such as the review of Claude Lévi-Strauss's works on Japan, Philippe Descola's remarkable school, and Augustin Berque's in-depth studies (Berque 1986, 2004) on the relationship between man and nature.

During our French-Japanese meetings, the notion of 'Service rendered' to humanity, generally used by economists, was gradually abandoned. It has been replaced by the notion of 'Socio-ecosystem', which wants to highlight the fact that man is not only there to use the goods produced by nature. These functional ecosystems he used extensively already existed well before he existed himself. It must realize that it is an integral part of today's ecosystems, or even of past ecosystems, such as fossil forests (coal) or the remains of fossilized algal stands (crude oil). Man, today, draws upon his immediate needs in these various ecosystems, for his own use and often beyond, and he must be clearly aware of them. We need to generalize this fruitful idea of a generalized sato-umi to the entire planet, and to realize that the populations of the Earth themselves must live, no longer on credit on the future, but in autarky vis-à-vis productions of our planet—because there is no other.

## *4.6 Elements of Governance*

Coastal zone management, in France as in Japan, must take into account all users of coastal areas. It involves different levels of governance, from the most local to the largest (Lozachmeur 2005; Lozachmeur and Dauvin 2008; Hénocque 2006, 2010, 2011, 2015b; Henocque and Denis 2001; Hénocque and Tandavanitj 2006; Monaco and Prouzet 2014a, b; Jones et al. 2016) and will aim at the strict protection of the natural environment and not the only economic development.

In France, in order to facilitate joint management of natural areas, the law in 2017 established the French Agency for Biodiversity (AFB). It brings together several services and organizations including the Marine Protected Areas Agency and the Technical Workshop on Natural Areas (Aten).

This new approach will be, as in other countries, a questioning—progressive—of practices and legal rules established for many years. The evolution of the law of the sea will aim at the functional maintenance of socio-ecosystems, and not the exploitation of marine resources, even if it is declared 'sustainable'.

From synthetic studies like that of Kumamoto (1989), we must continue with our Japanese colleagues the confrontation of our knowledge in the evolution of the Rights of the littoral, because it plays a role in the new local and regional governances imposed by the green and blue frames or in the operation of fishermen's cooperatives or aquaculturists for example. Some court judges begin—finally—to take to heart the defence of natural environments according to their personal training.

We need to inform the authorities about the need to put in place governance of armed and even punitive protection forces, 'blue helmets of the seas', which will take the protection of the natural environment—which largely depends on the future life of the country and humanity on our planet—before all other considerations, be they political, economic or even social. The general interest, the best interest—the maintenance of living forms on the planet that natural processes have taken millions of years to create and differentiate—must pass before particular interests in the short term.

Other important topics will lead to the emergence of stricter rules:

- in the areas of drugs hormones and antibiotics that enter the marine environment with wastewater (Petit et al. 2015). They reveal strains of anti-bio resistant bacteria (Martinez 2008) affecting the physiological functions of marine organisms and have effects on ecosystems at the international level, enhanced education of the populations of developed countries and developing countries, by various routes, including that of large aquariums such as Océanopolis in Brest, Nausicaà to Boulogne, the magnificent aquariums of Tokyo, Osaka, Kobe for example, by new and multidisciplinary methods (Gourmelon et al. 2011).
- against the risk of privatization of marine areas and their natural resources, to prevent large financial groups and some environmental NGOs from appropriating for their sole benefit fishing rights, quotas, coastal and marine areas.

It is remarkable to note that Japan has, for years, been content with a very low growth rate, close to 1%, which allows it, while still being in the leading countries in science and technology, to conserve its culture, its natural ecosystems and its social equilibrium, even if they are not perfect, and despite the difficulties due to the aging of the population, without resorting to outside stands and foreigners that would disturb its society. Japan reacted in its own way to two recent disasters: the tsunami and the Fukushima accident. Its people always find their remarkable ancestral qualities of frugality and economy. As in nature, their socio-ecosystems waste nothing.

## 5 Conclusions: Common Openings to the Future

We have here limited ourselves to the French-Japanese relations, and to a limited number of temperate, tropical, cold-climate ecosystems, as well as to the only social groups in which they are integrated and fully understood.

We must now bring with our Japanese colleagues our modest contribution to the solution of theoretical or concrete problems in marine sciences that will present themselves to us: in-depth knowledge of the functioning of ecosystems, better efficiency of aquaculture, development of an inventive marine ecological engineering, for example.

All human activities are now facing new major challenges: the demographic explosion resulting from uncontrolled reproduction resulting in misery and migration, digital revolutions that disrupt the functioning of economies and societies, for example.

We will have to face these challenges (Védrine 2018). Politicians and scientists will have to face hard and long-term factors that threaten global ecologies. Fields of action open up in the fields of the sciences of nature when we consider man in his new direct relations with nature, which itself is already highly anthropized.

We even tend to use the term ‘environment’ less, which necessarily implies that man occupies a central position in relation to the surrounding physical and ecological elements, whereas he is only one of the living elements among others, in various terrestrial and marine ecosystems.

Man must necessarily maintain the biodiversity in which his species has evolved, that is to say, all forms of life on Earth, that natural processes have taken millions of years to develop, even before the human race does not exist.

France and Japan will have to make strong recruitment of specialists in zoology and botany (disciplines too long dangerously neglected), in fundamental biology, in marine biochemistry, in study of marine ecosystems.

The goal we must now reach is that man be integrated as much as possible into natural processes.

Today we are tackling new aspects: economic, sociological, anthropological, demographic, legal, prospective, cultural, artistic, aesthetic, traditional, food, religious, festive which can explain the exploitation of marine resources, their consumption and the obscure foundations of man’s relationship with nature in both countries.

We will rely on the irreplaceable role of the seniority of interpersonal relations, as well as the discreet importance of the Maison franco-japonaise de Tokyo, which allows to keep in touch with Japanese intellectuals in most of the disciplines.

The means at our disposal, we scientists, consist in the acquisition of new knowledge on the real state of the land and sea, to make known the imperative need to preserve natural environments, to highlight original concepts and to disseminate it to our colleagues, students, administrators and politicians, without break, pause or rest.

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# Identification and Analysis of Environmental Stressors

# The Japan Sea: A Changing Pacific Asian Marginal Sea

**Tomoharu Senjyu**

**Abstract** The Japan Sea includes its own deep-water formation mechanics and a thermohaline circulation system similar to those of the Mediterranean Sea. Long-term trends of warming and decreasing oxygen concentration owing to global warming have been reported in the deep water of the Japan Sea. Although the minimum oxygen decrease rate of about 1000 m suggests a relatively active supply of new deep water to the depths, the overall deep-water formation has been stagnant since the 1970s throughout the water column. In addition to the gradual linear trends, interdecadal variation occurs in the temperature and oxygen concentration of the abyssal Japan Sea. The correlation between the interdecadal variation and the Arctic oscillation index indicates that the deep-water formation in the Japan Sea is modulated by Arctic oscillation via sea surface temperature in the East China Sea. This is an example of a teleconnection system on the marginal seas scale. For these reasons, we propose a collective name for this system: the Pacific Asian marginal seas system.

**Keywords** Marginal seas · Deep-water formation · Warming trend · Decreasing oxygen concentration · Global warming · Climate change · Decadal-scale variations · Arctic oscillation · Teleconnection · Winter monsoon

## 1 Introduction

The Japan Sea is a marginal sea located in the northwestern North Pacific (Fig. 1).

Its comparison with the European Mediterranean Sea has revealed several common features between the two seas. First, both seas are semi-closed marginal seas that are connected with adjacent waters through shallow and narrow straits. Second, both seas are mid-latitude marginal seas located in almost the same latitude band. Therefore, these seas show clear seasonal variations in their hydrography. The third important feature is a deep-water formation within the seas. A massive cold and

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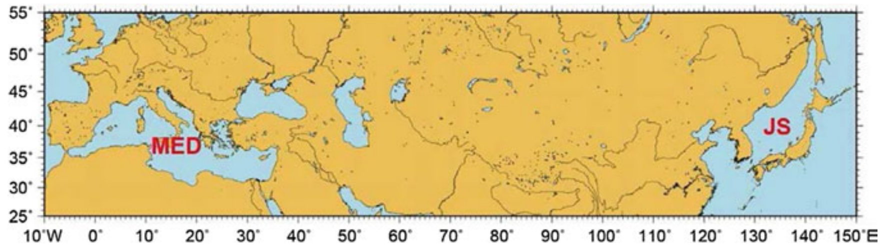


**Fig. 1** Location of the Japan Sea (JS) and the Mediterranean Sea (MED)

dense water produced in the northern part of the seas by surface cooling in winter sinks into a deep layer to circulate the interior region (e.g., MEDOC Group 1970; Senjyu et al. 2002). A large difference is that part of the dense water flows out to the North Atlantic through the Strait of Gibraltar from the Mediterranean Sea, although the deep water in the Japan Sea is perfectly isolated from the surrounding waters.

According to the Japan Meteorological Agency (JMA) (http://www.data.jma.go.jp/gmd/kaiyou/english/long_term_sst_japan/sea_surface_temperature_around_japan.html), the sea surface temperature (SST) around Japan is increasing at a rate of +1.11 °C per 100 years, which corresponds to 2.1 times the global mean value of +0.54 °C per 100 years. Regional results indicate that the highest rate, + 1.71 °C per 100 years, was found in the central part of the Japan Sea. This long-term warming trend has been reported in the deep layer of the Japan Sea as well in as the sea surface; decadal-scale variations have also been reported. In this article, we introduce the changing Japan Sea in reference to recent studies on its deep water.

## 2 The Japan Sea Proper Water

Although the areas of the Japan Sea that are deeper than 200 m are completely isolated from other seas, four narrow, shallow straits connect the sea with the North Pacific Ocean, East China Sea, and Okhotsk Sea (Fig. 2).

The mean and maximum depths of the Japan Sea are 1667 and 3796 m, respectively, and the sea includes deep three basins. These topographic features indicate that the deep water in the Japan Sea originated within the sea rather being imported from other seas.

A typical vertical distribution of potential temperature (PT), salinity (S), dissolved oxygen (DO), and potential density referred at the sea surface ($\sigma_\theta$) for the Japan Sea is shown in Fig. 3.

The layer below the main thermocline, at >300 m, is occupied by cold water at <1.0 °C that is less saline, at 34.06–34.07. This water is known as the Japan Sea Proper Water (JSPW) and occupies more than 80% of the total volume of the Japan Sea (Uda 1934; Yasui et al. 1967). Worthington (1981) reported that the JSPW is one of the

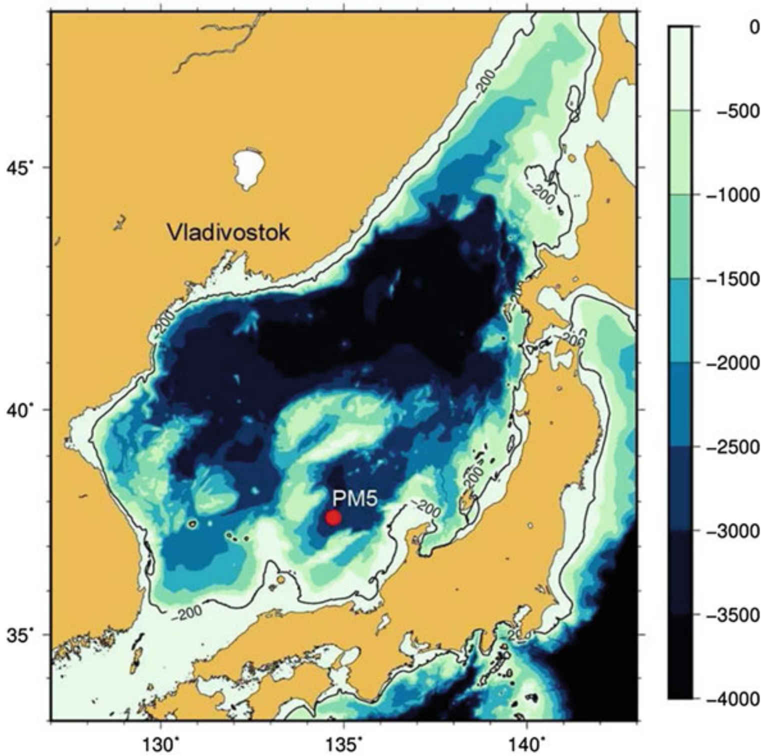


**Fig. 2** Bottom topography of the Japan Sea. The 200 m isobaths are drawn to show the shallowness of the straits. A red circle indicates the location of Station PM5 (37° 43′ N 134° 43′ E) by the JMA

most homogeneous water masses in the world. Another important characteristic of the JSPW is its richness in DO, at >200 μmol $kg^{-1}$.

The JSPW is formed in the northwestern Japan Sea in winter by deep convection (Sudo 1986; Senjyu and Sudo 1993, 1994; Senjyu et al. 2002).

Figure 4 shows the climatic winter distribution of the isopycnal surface corresponding to the upper portion of the JSPW (32.03$\sigma_1$, where $\sigma_1$ is potential density referred to 1000 dbar and this $\sigma_1$ surface nearly coincides with the 27.32$\sigma_\theta$ surface in the Japan Sea, Senjyu and Sudo 1994). An outcropping of the isopycnal surface appears south of Vladivostok, and in this region, deep convection develops as a result of sea surface cooling. Two coastal mountain chains around Vladivostok (The Shikhote-Alin Mountains and the Hamgyong Mountains) converge the cold northwesterly monsoon to form jet-like wind that effectively cools the sea surface in this region (Seung and Yoon 1995; Kawamura and Wu 1998). These effects explain the homogeneity, low temperature, and DO-rich characteristics of the JSPW.

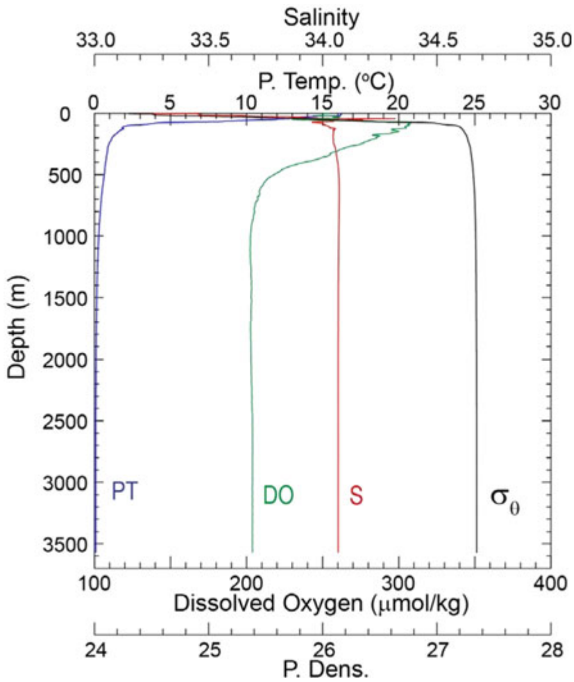


**Fig. 3** Typical profiles of potential temperature (PT, blue), salinity (S, red), dissolved oxygen (DO, green), and potential density ($\sigma_\theta$, black) in the Japan Sea, which were measured at 40° 49.34′ N 137° 59.18′ E on November 13, 2015, by the JMA

## 3 Long-Term Trends in the JSPW

Long-term trends of increasing PT and decreasing DO have been reported in the JSPW (Gamo et al. 1986; Minami et al. 1999; Kim et al. 2001). The time series of PT and DO at Sta. PM5 in the southeastern Japan Sea (Fig. 2), as measured by the JMA, are shown in Fig. 5. The gradual warming and decreasing of DO during the recent few decades are recognizable throughout the water column from 500 to 2500 m. The increasing rate of PT monotonically decreases with depth (Table 1). However, the decreasing rates of DO show a minimum in a depth range of 1000–1200 m, with values of $\leq$0.6 μmol kg$^{-1}$ per year. This suggests a relatively active oxygen supply to the depths.

As a cause of the warming and decreasing DO in the JSPW, global warming has been suggested (Gamo 1999; Minami et al. 1999; Kim et al. 2001). Gamo et al. (2001) proposed a mode shift in the water mass formation. In the past, successive cold winters frequently caused deep convections to develop down to the bottom layer, and a large volume of the JSPW was produced every year. However, at least since the 1970s, moderate winters accompanied by global warming have reduced the deep convections, with enhancement of the intermediate water formation at ~1000 m. In fact, winter air temperature at several points along the Russian coast shows clear increasing trends (Gamo 1999). The minimum oxygen decrease rate at depths of about 1000 m supports the mode shift of the water mass formation. However, the

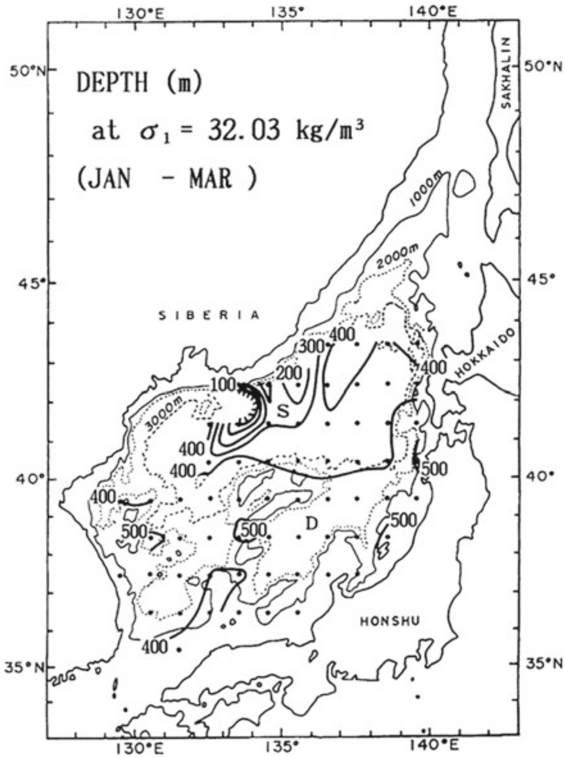


**Fig. 4** Winter distribution of the isopycnal surface corresponding to the upper portion of the JSPW ($32.03\sigma_1$) (Senjyu and Sudo 1994)

overall JSPW formation has been stagnant since the 1970s, as indicated by the warming and decreasing trends in DO throughout the water column (Table 1) (Cui and Senjyu 2012).

## 4 Interdecadal Oscillations in the JSPW

In addition to the linear trends, an interdecadal periodic change in PT and DO in the JSPW has been reported (Watanabe et al. 2003; Cui and Senjyu 2010, 2012). The time series of PT and DO at 1000 m of Sta. PM5 showed an almost out-of-phase variation (lower panel of Fig. 6); the observational data showed positive (negative) deviations from the linear trend in the 1970s and 2010s in PT (DO).

However, negative (positive) deviations were prevalent in PT (DO) from 1985 to 2000. The correlation coefficient between the PT and DO deviations from the linear trends was −0.58 ($p < 0.01$, $n = 48$). Similar interdecadal fluctuations in PT and DO occurred throughout the depth range of 500–2500 m (Fig. 5).

It is known that the interdecadal variation in the JSPW correlates with the Arctic oscillation index (AOI, upper panel of Fig. 6) (Cui and Senjyu 2010). This fact

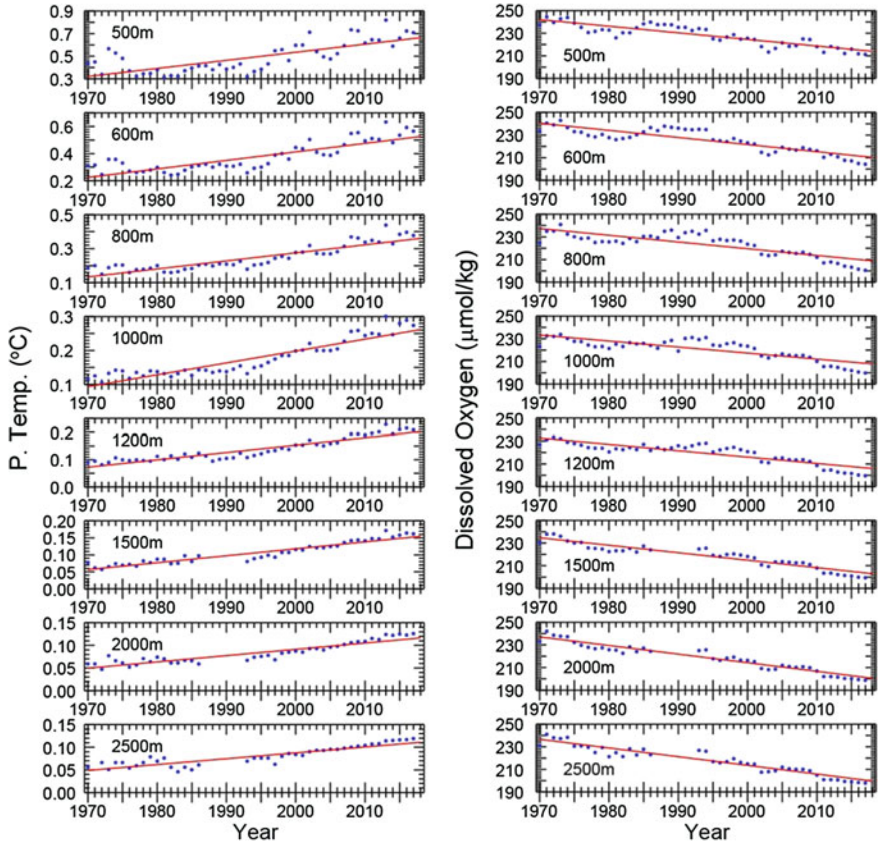


**Fig. 5** Time series of PT (left) and DO (right) at Sta. PM5 in the southeastern Japan Sea from 500 m to 2500 m. Blue dots denote the yearly mean observational data, and red lines indicate the linear trends

**Table 1** Linear trends of PT and DO with 95% confidence intervals at each layer shown in Fig. 5

| Depth (m) | PT (°C year$^{-1}$) | DO (μmol kg$^{-1}$ year$^{-1}$) |
|---|---|---|
| 500 | +0.0073 ± 0.0014 | −0.5954 ± 0.0993 |
| 600 | +0.0064 ± 0.0011 | −0.6414 ± 0.1089 |
| 800 | +0.0048 ± 0.0008 | −0.6072 ± 0.1093 |
| 1000 | +0.0036 ± 0.0006 | −0.5441 ± 0.0971 |
| 1200 | +0.0028 ± 0.0004 | −0.5709 ± 0.0958 |
| 1500 | +0.0021 ± 0.0004 | −0.6747 ± 0.1129 |
| 2000 | +0.0014 ± 0.0002 | −0.7769 ± 0.1273 |
| 2500 | +0.0013 ± 0.0002 | −0.7846 ± 0.1299 |

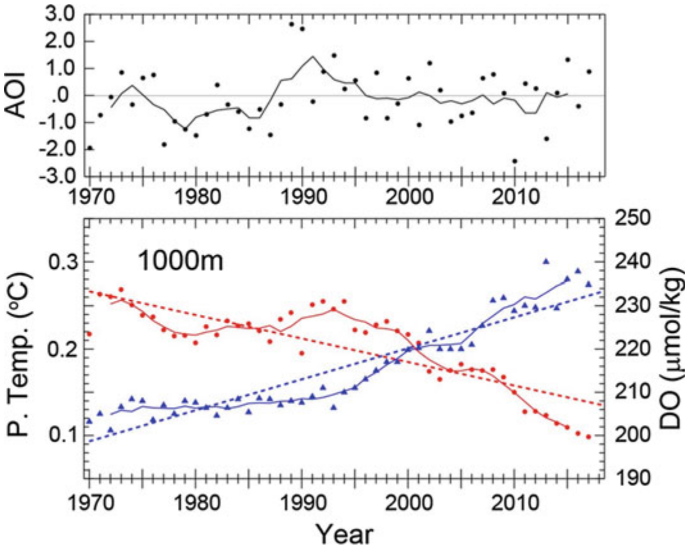


**Fig. 6** Time series of winter-mean AOI (upper) and those of PT (blue) and DO (red) at 1000 m of Sta. PM5 (lower). The thin lines indicate five-year running averages. The broken lines in the lower panel denote liner trends

indicates that the JSPW formation is modulated by Arctic oscillation (AO), which is one of climatic oscillation patterns having opposite polarity between the North Pole and mid-latitude areas (Thompson and Wallace 1998). Because AO has positive polarity in the Aleutian Low on the North Pacific Ocean and negative polarity in the Siberian High on the Eurasian Continent at mid-latitudes, the east–west atmospheric pressure gradient over the Japan Sea becomes large during the periods of negative AOI. This means that a strong winter monsoon tends to occur during the negative AOI periods, which is favorable for JSPW production. However, interestingly, PT (DO) tends to decrease (increase) in the periods of positive (negative) AOI (Fig. 6).

Atmospheric disturbances have an important role in the formation of the JSPW, as well as in the Mediterranean Sea (MEDOC Group 1970). Figure 7 shows a typical example of atmospheric conditions favorable for JSPW formation during January 26–29, 2003, including sea level pressure, wind, and air temperature. An atmospheric low pressure occurred in the East China Sea on January 26. At that time, weak easterly winds blew over the Japan Sea, and the 0 °C contour in the air temperature was located at 42–45° N. When the low pressure moved into the Japan Sea on January 27, strong cyclonic winds prevailed over the sea. The low pressure reached the northern Japan Sea on January 28 and finally moved into the Okhotsk Sea on January 29. During this period, jet-like northwesterly winds originating near Vladivostok, which are considered to be cold-air outbreaks, developed as a result of the strong northeast–southwest gradient of the atmospheric pressure. These strong winds brought cold air to the Japan Sea. On January 28–29, cold air lower than 0 °C spread rapidly

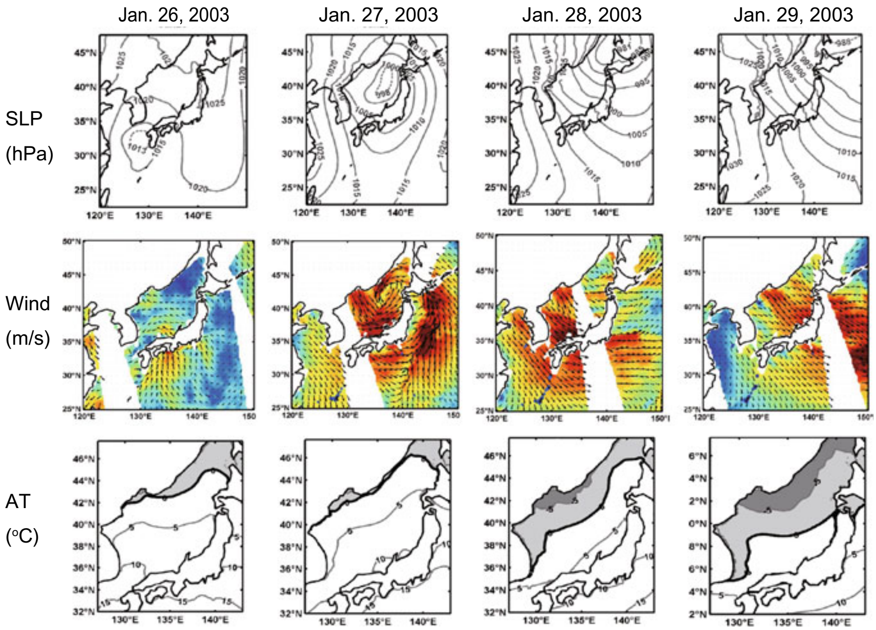


**Fig. 7** Distributions of sea level pressure (upper), wind (middle), and air temperature (lower) during the period January 26–29, 2003 (Cui and Senjyu 2010)

southward, and air colder than −5 °C appeared south of Vladivostok, which is the formation area of the JSPW.

The development of atmospheric disturbances is associated with SST in the East China Sea (Isobe and Beardsley 2007). In years of positive AOI, the winter monsoon is weak. Accordingly, the SST in the East China Sea shows a warm anomaly, and atmospheric disturbances easily develop in the sea. As a result, atmospheric disturbances frequently migrate into the Japan Sea, and cold-air outbreaks over the sea become active, which results in the formation of a large volume of JSPW. Therefore, PT (DO) in the JSPW negatively (positively) correlates with AOI.

## 5 Concluding Remarks

We have shown a linkage between the deep-water formation in the Japan Sea and the SST in the East China Sea. This indicates that the Japan Sea and the East China Sea are a single system connected by the atmosphere. This is an example of a teleconnection system on the marginal seas scale. Because several marginal seas lie in the Pacific Asian region, similar linkage systems are expected among the seas. We propose naming them collectively as the Pacific Asian marginal seas system.

The Japan Sea is often referred to as a "miniature ocean" because its wind-driven and thermohaline circulations are similar to those occurring in oceans. Although the JSPW is very homogeneous water mass, its characteristics fluctuate depending on the conditions during its production. The Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) reported that owing to its limited size, the Japan Sea is easily subject to climate changes and responds quickly to those forced changes from the surface through the entire depths (Bindoff et al. 2007). To understand the influences of global warming and climate change on the ocean, continuous monitoring of the Japan Sea is desired.

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# Statistical Analysis of Surface Circulation in Sagami Bay Using High-Frequency (HF) Radar

**Haruka Nakano, Mai Matsusaka, Issei Nishimura, Hiroyuki Yoritaka, Masao Nemoto, and Jiro Yoshida**

**Abstract** Surface circulation in Sagami Bay located in the south of Honshu, Japan, was analyzed using high-frequency (HF) radar located at Izu Oshima Island and at Arasaki (the Miura Peninsula). Prominent current direction indicated counterclockwise circulation in the western part and could not be defined in the eastern part of Sagami Bay. EOF 1st mode score indicated that surface circulation is influenced by the inflow of the Kuroshio water. Stronger currents inflow via Oshima east channel generated counterclockwise circulation in the northern part of Sagami Bay. Weaker currents inflow via Oshima east channel led to clockwise circulation. Kuroshio warm water inflow from Oshima west channel led to counterclockwise circulation. These circulations were defined by sea level anomalies at Mera, Oshima, and Kozu islands. The EOF 2nd mode implied wind-driven current. Higher modes indicated dipole modes (North–South or East–West) and eddy-like mode. Consequently, three or more patterns for surface currents were found in Sagami Bay.

**Keywords** Sagami Bay · HF radar · Surface circulation

## 1 Introduction

Sagami Bay is surrounded by Kanagawa Prefecture and Shizuoka Prefecture and has a wide mouth facing the Kuroshio region in the North Pacific Ocean through the Oshima West Channel (OWC) and the Oshima East Channel (OEC) (Fig. 1). Oshima

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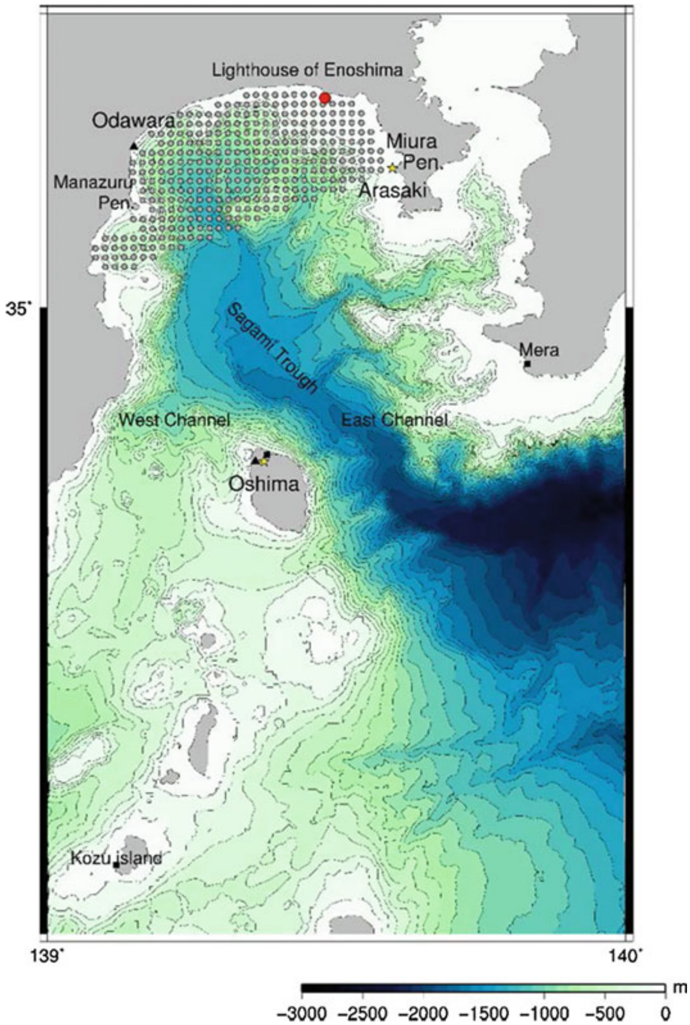



**Fig. 1** Sagami Bay with contours of depth (m), ☆: HF radar bases, ▲: Meteorological observatory, ●: Lighthouse of Enoshima, ■: Tide stations, ●: HF radar observed points. The color bar indicates depth contours

is located at the entrance of Sagami Bay, and the northern side from Arasaki to the Manazuru Peninsula is generally referred to as the northern part of Sagami Bay.

Warm water is originating from the Kuroshio, and cold water is originating from the Oyashio flow into Sagami Bay through the OWC and the OEC. These two types of water in Sagami Bay support abundant biological resources. Therefore, fixed net fisheries and marine recreational activities are abundant on and around the vast continental shelf area of Sagami Bay. Multiple oceanic physical phenomena, such as currents and coastal trapped waves, have been studied because the knowledge gained is expected to decrease damage to fisheries and prevent marine accidents.

In Sagami Bay, moored current meters track the counterclockwise circulation in the northern region of Sagami Bay and the direction of prevailing currents toward offshore of the Manazuru Peninsula (Iwata et al. 1980). In the southern part of Sagami Bay, when the Kuroshio path took the nearshore Non-Large Meander (nNLM), clockwise currents along the northern coast of Oshima have been observed and the relationship between the surface currents and inflow volume of Kuroshio warm water have been studied (Taira and Teramoto 1986). If the Kuroshio path was the typical Large Meander (tLM) traveling along the western side of the Izu Islands, there would be Kuroshio warm water inflows from the OWC, clockwise currents along the northern area of Oshima, and counterclockwise circulation in the northern part of Sagami Bay (Kawabe and Yoneno 1987). However, weak clockwise currents were observed when the Kuroshio was characterized as an nNLM, and when the Kuroshio path was more like a tLM, the Kuroshio axis moved close to Sagami Bay and the clockwise currents along Oshima and counterclockwise circulation in Sagami Bay both showed signs of strengthening (Iwata and Matsuyama 1989).

Hinata et al. (2003) measured surface currents using high-frequency (HF) radar in the southern part of Sagami Bay, which indicated there was clockwise circulation along the northern area of Oshima and counterclockwise circulation in the southwestern part (around Manazuru Peninsula) of Sagami Bay when the Kuroshio took a nNLM path that was similar to a tLM path. The strength of the currents changing with the inflow speed of the Kuroshio warm water was observed, and the counterclockwise currents through the OEC were measured over a two-day period.

Taken together, the relationship between the direction of surface currents in Sagami Bay and the Kuroshio path is a particularly important issue because the direction of surface currents in Sagami Bay changes (i.e., clockwise or counterclockwise) with the type of the Kuroshio path. However, most previous studies used fixed-point observations by moorings or trajectory observations by drifting buoys in the northern part of Sagami Bay, and only a few months of HF radar data in the southern part of Sagami Bay were analyzed.

Accordingly, in this study, the relationship between surface currents in the northern part of Sagami Bay and the location of the Kuroshio was investigated using relatively long-term HF radar current data for eight months. While we have been conducting observations since 2012, this study focuses on an eight-month period that displayed a relatively high degree of continuity and stability. Because the sea level (SL) was found to be a key factor affecting the surface currents in previous research, the Empirical Orthogonal Function (EOF) score was compared with temporal changes in the SL. To the best of our knowledge, this is the first report that statistically analyzed surface currents in relation to with SL in the Sagami Bay.

# 2 Data and Methods

## *2.1 Currents Data Detected by HF Radar*

### 2.1.1 Observations

In the northern part of Sagami Bay, the Hydrographic and Oceanographic Department of Japan Coast Guard (JHOD) installed HF radar equipment manufactured by Nagano Japan Radio Co., Ltd. in Arasaki, and Oshima (Fig. 2). The frequency of the HF radar is 24.5 MHz, and its observation interval distance is roughly 1.5 km. The directional accuracy is 7.5°, and flow velocity accuracy is 3 cm/s. Daily data can be downloaded from the HOD Web site.

Observations were conducted at 330 points, where radar's lines of sight intersect for 10 min every hour (Fig. 1 gray points). The measurement data were averaged in 10 min and were considered as hourly data. Output data included the observation location (latitude, longitude, and grid number); current vector data (East–West component and North–South component); significant wave height; significant wave period; mean wave direction; and quality information. As stated previously, this study focuses on 8 months of data (i.e., from Dec. 1, 2013 to Aug. 11, 2014). During this period, the data acquisition rate exceeded approximately 90%, and the maximum data loss time was limited to seven hours.

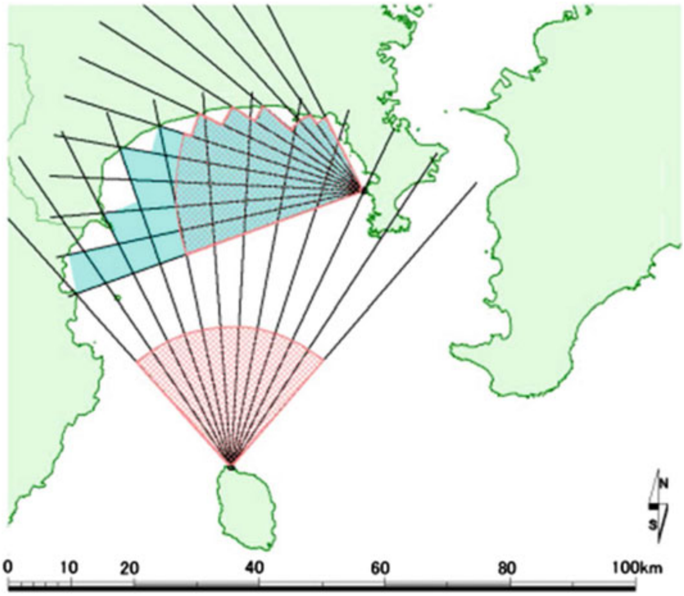



**Fig. 2** Observation site detected by the HF radar in Sagami Bay (blue shade: the area of velocity measurements and pink shade: wave height measurements)

The quality of HF radar current data was verified with drifting buoy observations to validate the HF radar data by the research vessel KAIYO belonging to the Japan Coast Guard on October 31, 2012. The buoys were manufactured by Senar and Burns Co., Ltd., and the experiment area was relatively far (about 10 km) from the Enoshima lighthouse. The average difference between the speeds obtained by HF radar and those from the drifting buoys was ±5 cm/s.

#### 2.1.2 Data Processing

Linear interpolation was conducted to generate the current vectors data, and period components shorter than two days were eliminated using a 48-h tide killer filter (48TK filter). Drift currents can be estimated from HF radar data (Yoshikawa and Masuda 2009; Yoshikawa et al. 2007, 2010), but was not included as part of this study because the circulation in Sagami Bay was characterized by steady-state conditions. Therefore, statistical analyses such as the EOF were conducted to find the cause of changes in circulation.

### *2.2 Tide and Wind Data*

SL data at Mera, Okada, and Kozu islands located near Sagami Bay were used to clarify effects of the Kuroshio warm water. The data were filtered by the 48TK filter and converted into daily average data, and atmospheric pressure correction was then performed (atmospheric pressure measured at Tateyama for Mera, at Oshima for Okada, and Kozu Island). Also, wind data at Ohshima–Kitanoyama and Odawara measured at every hour were used. Periods shorter than one day were eliminated using a 25-point running mean.

## 3 Circulation Patterns in the Surface Layer of Sagami Bay

In this section, circulation patterns of Sagami Bay were verified. During the period of analyses, the Kuroshio Path took an offshore Non-Large Meander (oNLM) path until May 1, 2014, and then an nNLM path. Yoshida et al. (2014) indicated that negative SL anomalies at Kozu Island appear with oNLM, and slightly positive SL anomalies appear with nNLM (average value of SL anomaly ~0), and the actual SL anomaly of Kozu Island was approximately zero (±10) before June 2014, and then was largely positive from July 16–24, 2014 (Fig. 3). This indicated that during this period, the Kuroshio axis moved to the north approaching Sagami Bay.

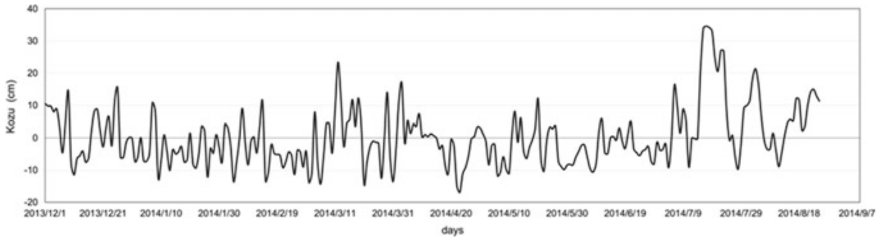



**Fig. 3** Temporal variation in the sea level (SL) anomaly at Kozu Island. Average SL values were zero in this study

## *3.1 Characteristics of Circulation Patterns of Sagami Bay from the Distribution of Current Direction*

The distribution of currents direction was examined in the northern part of Sagami Bay (only data extracted from 79 stations are shown in Fig. 4, and the eight current directions were used for classification analogous to wind rose). From the occurrence frequency of currents direction, Sagami Bay was divided into three areas, including Area A located southwest of the Manazuru Peninsula, Area B located from the

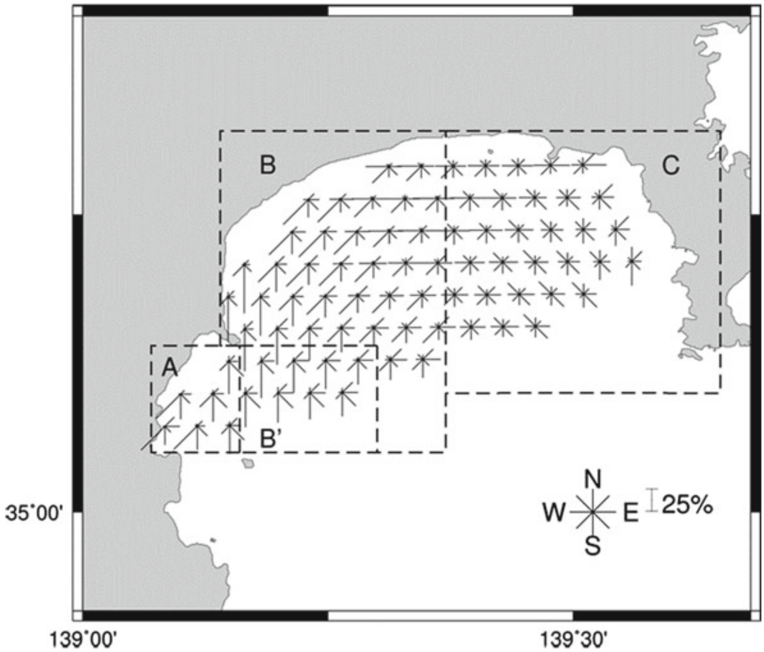



**Fig. 4** Distribution of current direction between December 2013 and August 2014 (some observation points were omitted)

Manazuru Peninsula to the center of Sagami Bay, and Area C located on the east side of Sagami Bay including almost of all continental shelf zone.

In Area A, the southwestward currents exist near the Izu Peninsula, whereas the southward currents were dominant offshore. In Area B, predominant currents were along the coastal line, but not along the coastal lines of the Manazuru Peninsula. Especially in the sub-Area B' located southeast of the Manazuru Peninsula, the surface water flowed toward the southeast offshore. This tendency was consistent with the observed result reported by Iwata et al. (1980). Additionally, in the northern part of Area B, the percentage of westward and eastward currents was almost identical. In Area C, the southeastward and the northwestward currents appeared with almost the same ratio, but the frequency of northeastward currents toward the coast increased in areas close to the Miura Peninsula. In the northern part of Area C, the proportion of westward currents and eastward currents were almost the same. There was no prominent current direction in the center of Sagami Bay. These directional frequencies indicate that multiple types of circulation such as clockwise circulation, counterclockwise circulation, and others exist in the northern part of Sagami Bay.

## *3.2 EOF Analysis*

Based on the data obtained in this study, the structure of surface circulation was investigated using EOF analysis. The cumulative contribution rates up to the EOF 4th mode were about 80% (EOF 1st mode: 51%, EOF 2nd mode: 19%, EOF 3rd mode: 8%, and EOF 4th mode: 5%).

Eigenvectors of the EOF 1st mode indicated that whole currents in the northern part of Sagami Bay were either clockwise or counterclockwise, and those of the EOF 2nd mode displayed remarkable northward or southward currents in northeastern part of Sagami Bay (area C in Fig. 4). Eigenvectors of the EOF 3rd mode indicated that the current direction reversed in the central parts of the bay, and that of the EOF 4th mode indicated that the current direction reversed in the eastern part and western part of the bay (Fig. 5). Additionally, counterclockwise circulation was predominant in the northern part of Sagami Bay (Fig. 5e).

First, the EOF 1st mode was examined and was compared with temporal changes in SL, winds, and the state of circulation in the bay (Figs. 5 and 6). We focused on three instances when the score was relatively large.

Case 1 was defined by the appearance of counterclockwise circulation (Fig. 7a), when the score of the EOF 1st mode was largely negative during the period of December 6–21, 2013 (−200 to −250, Fig. 6a). During this period, the SL anomalies at Mera $SL_M$ and Okada $SL_O$ were higher than the average SL at each station indicated by the line at 0 in Fig. 6b. Also, the difference in the SL anomaly $Diff_{MO}$ defined as the difference between $SL_M$ and $SL_O$ is expressed as Eq. 1.

$$Diff_{MO} = SL_M - SL_O. \quad (1)$$

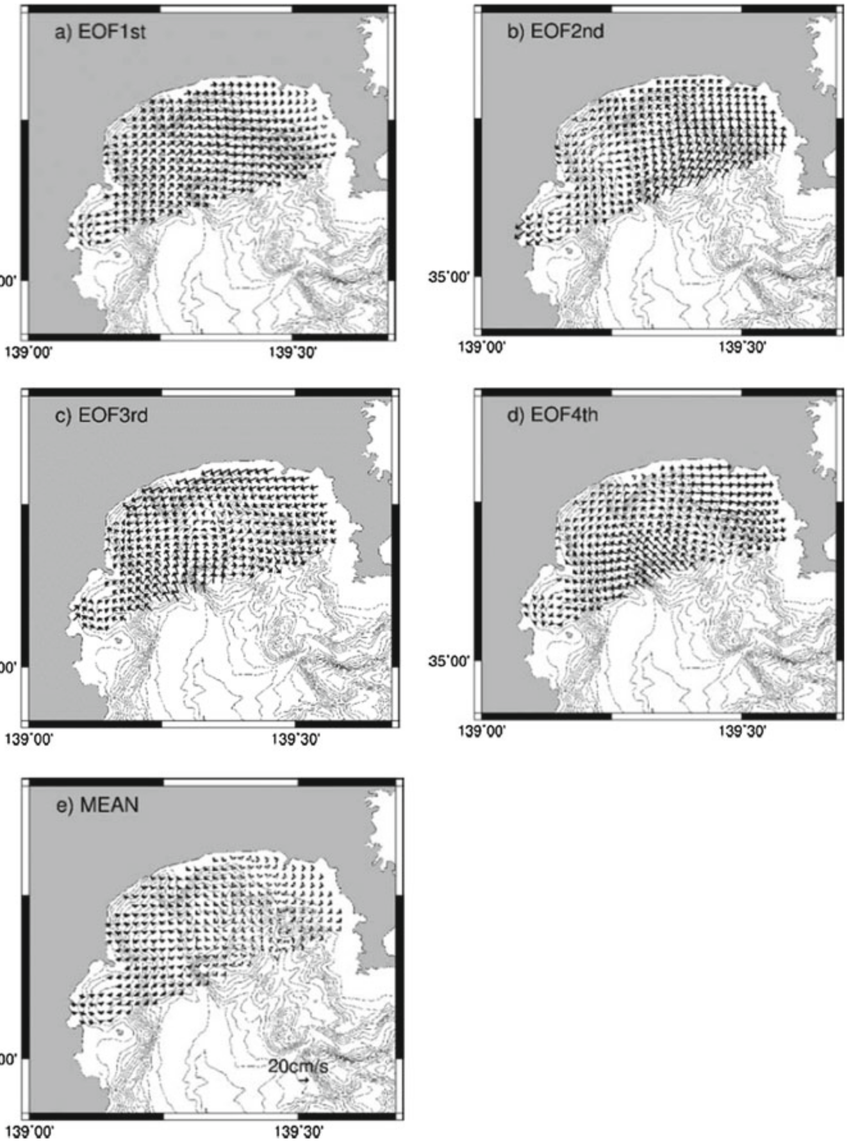



**Fig. 5** Eigenvector vector plots of **a** EOF 1st mode, **b** EOF 2nd mode, **c** EOF 3rd mode, **d** EOF 4th mode, and **e** Mean current during the study period

A positive $Diff_{MO}$ value indicated that the increase of SL at Mera was larger than that at Okada (Fig. 6c). During this period, inflows of the Kuroshio warm water from OEC were confirmed by the Quick Bulletin of Ocean Conditions off Kanto Tokai (Fig. 8a). Thus, the outstanding rise in $SL_M$ compared with $SL_O$ suggested a

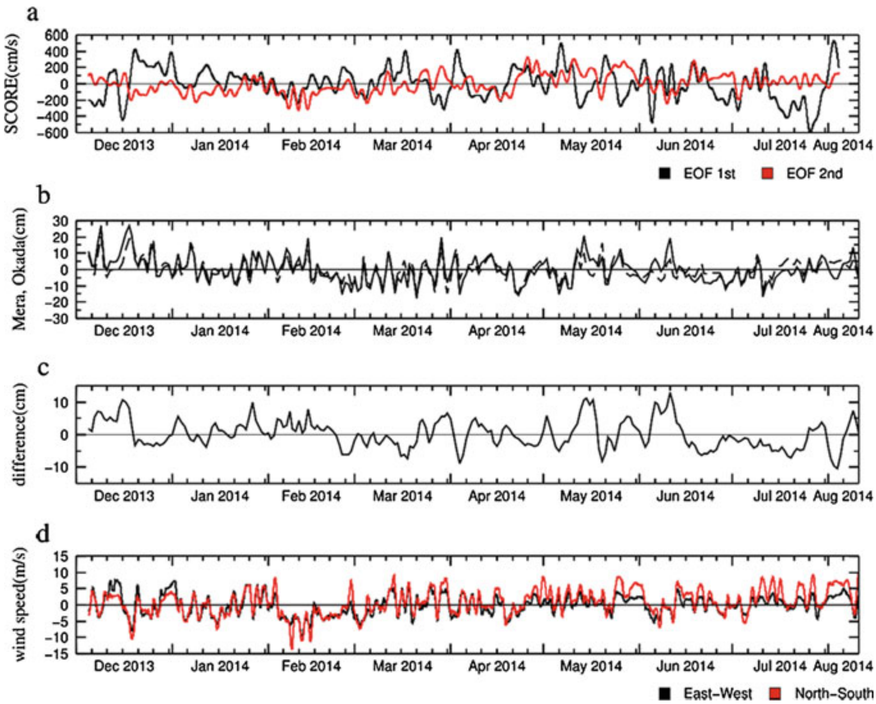



**Fig. 6** Time series of **a** scores of EOF 1st mode (black) and EOF 2nd mode (red), **b** sea level anomaly at Mera (solid line) and Okada (dashed line), **c** $Diff_{MO}$, **d** wind speed at Oshima–Kitanoyama, black: E-W component, red: N-S component, negative value means that wind direction is east (north)

geostrophic balance according to the Kuroshio warm water flowing from the OEC to the OWC.

Case 2 was defined by the appearance of clockwise circulation (Fig. 7b), when the score of the EOF 1st mode was largely positive during the period of December 21–31, 2013 (200 to 250, Fig. 7a). In this case, inflows of the Kuroshio warm water from OEC were confirmed (Fig. 8b), and positive $SL_M$ and $SL_O$ values indicated that the Kuroshio warm water spread near the OEC (Fig. 6b); however, the $Diff_{MO}$ was negative unlike the conditions observed in Case 1. This indicated that the direction of the geostrophic balance according to the Kuroshio warm water flowing from the OEC to the OWC is the same as Case 1, but gradient of sea surface in Case 2 is weaker than that in Case 1. Therefore, inflow speed in Case 2 was slower than Case 1.

Case 3 was characterized by the appearance of counterclockwise circulation (Fig. 7c), when the score of the EOF 1st mode was largely negative during the period of July 2–25, 2014 ($\geq$200, Fig. 6a). Inflow from the OWC was confirmed by the Quick Bulletin of Ocean Conditions off Kanto Tokai area (Fig. 8c). Counter-clockwise circulation was provided by inflows of the Kuroshio warm water from the OWC. $SL_M$ and $SL_O$ took approximately mean values ($0 \pm 10$ cm), and the $Diff_{MO}$

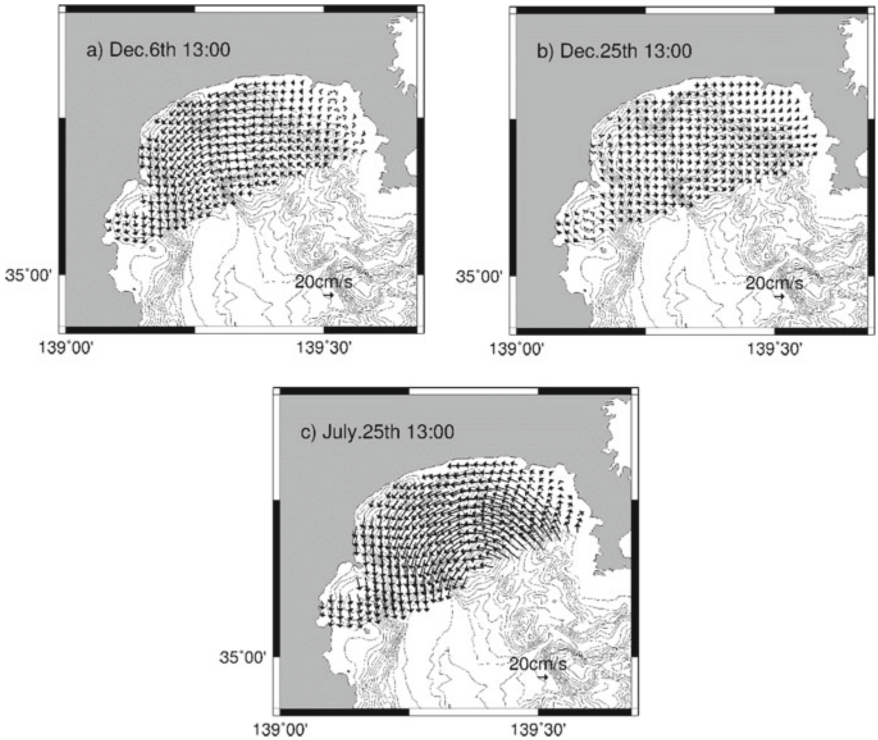



**Fig. 7** Composite vectors of EOF 1st–4th mode and mean currents at **a** 13:00 December 6, 2013, **b** 13:00 December 25, 2013, and **c** 13:00 July 25, 2014

value was negative during this period (Fig. 6b, c). In Case 3, the Kuroshio axis was located near Kozu Island. Therefore, the absolute value of the score was the highest during the analysis period because warm water strongly inflowed into the Sagami Bay.

As shown in Fig. 9, the number of days with EOF 1st mode score exceeded the threshold value (250 cm/s for positive values, −250 cm/s for negative) was 61 days (i.e., 24%). In this case, clockwise circulation was confirmed for 27 days, and almost all the $\mathrm{Diff}_{MO}$ values were negative during the days (Fig. 9). By contrast, 34 days of counterclockwise circulation were confirmed, and in this pattern, inflows from the OWC were confirmed for 9 days when the Kuroshio path followed an nNLM, and the $\mathrm{Diff}_{MO}$ was negative. On the other days, inflows from the OEC and positive $\mathrm{Diff}_{MO}$ values were confirmed (Fig. 9). However, counterclockwise circulation appeared with negative $\mathrm{Diff}_{MO}$ values for 10 days during this period. In this situation, relatively cold water spread in the area around Mera.

Although the relevance of cold water to the circulation is a subject for future study, small $\mathrm{Diff}_{MO}$ values are indicative of a slow Kuroshio warm water velocity from the OEC and vice versa. In conclusion, we found that $\mathrm{SL}_M$, $\mathrm{SL}_O$, and $\mathrm{Diff}_{MO}$ were key

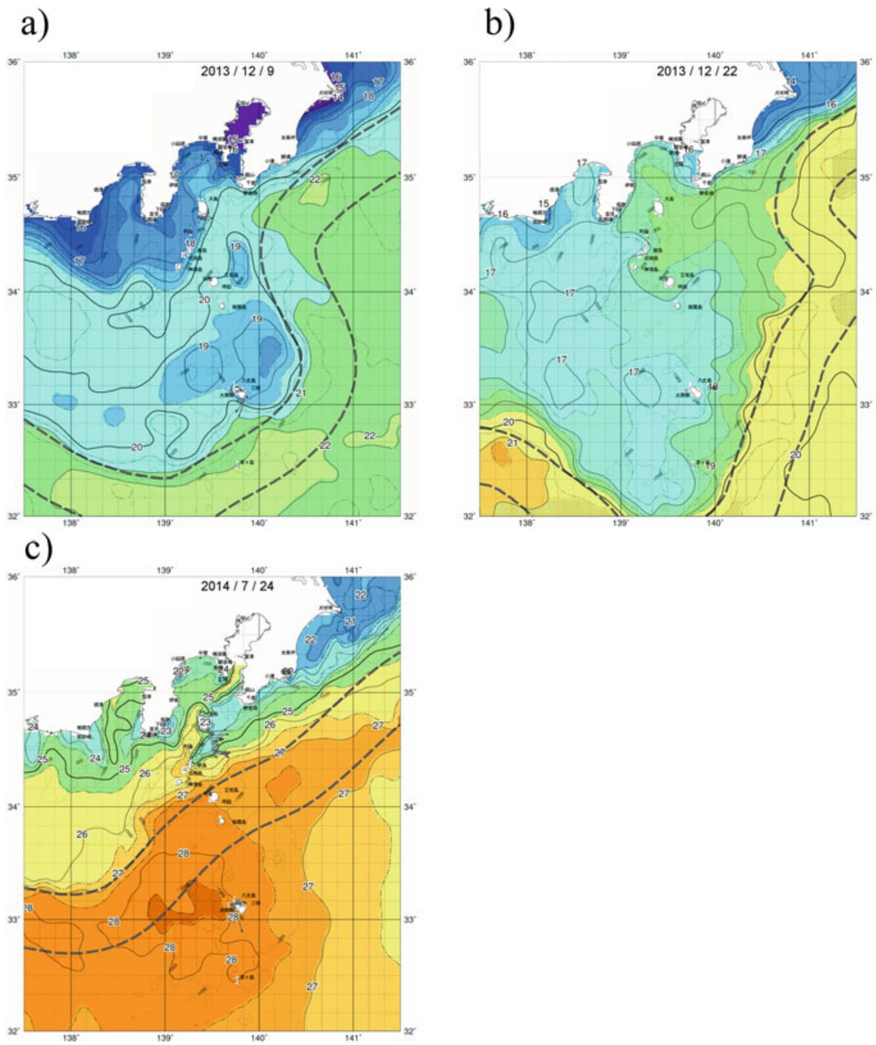


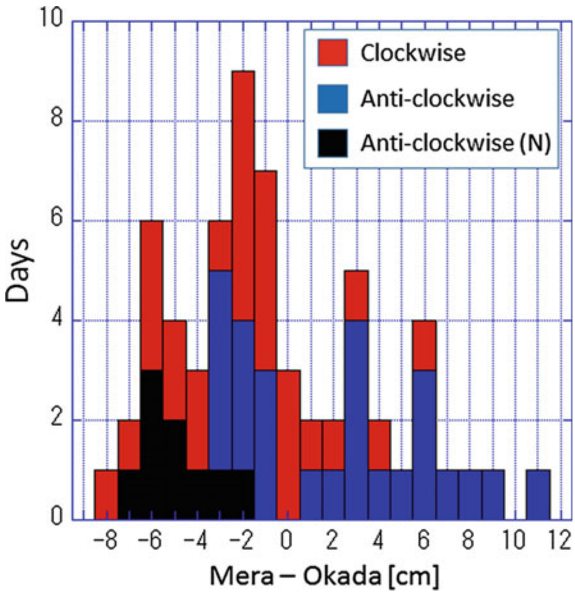

**Fig. 8** Observed horizontal distribution of surface temperature of **a** December 9, 2013, **b** December 22, 2013, and **c** July 24, 2014, near offshore areas of Kanto Tokai regions from Quick Bulletin of Ocean Conditions off Kanto Tokai area (Kanagawa prefectural Fisheries Technology Center)

points for understanding the circulation of Sagami Bay because the $Diff_{MO}$ values were indicative of the strength of the Kuroshio warm water inflow and its entrance.

Next, the EOF 2nd mode was examined because absolute values of the EOF 1st mode score were smaller than that (Fig. 5a, from February 9–16, 2014).

A strong positive correlation was found between the EOF 2nd mode and the southwestern wind at a cycle of 2–3 days (Hinata et al. 2003). Therefore, the relationship between the score of the higher mode and winds measured at Odawara and

**Fig. 9** Cumulative bar chart of occurrence days categorized by flow patterns in analysis period against sea level difference between Mera and Okada (black and blue boxes: counterclockwise circulation, red clockwise circulation)




Oshima–Kitanoyama was verified. The correlation coefficient of the EOF 2nd mode was higher than those of the 1st mode and other higher modes (East–West wind of 0.46 North–South wind: 0.55, Table 1). Also, the lag correlation coefficient was at its maximum value after 4 h for the North–South wind and 2 h for the East–West wind. Time lags were shorter than the inertial period of Sagami Bay (21 h), because velocities were detected at surface. Therefore, the EOF 2nd mode suggested there was a drift current driven by winds (Fig. 10).

Therefore, we focused on comparing wind with the EOF 2nd mode score. The coherence was about 0.6 at 4.3 days in both the North–South and East–West winds (Fig. 10). The prominent period of the EOF 2nd mode and that of winds almost coincided at a cycle of 3–5 days (3.3 days, 3.9 days, Fig. 11). Taken together, currents were considered induced by winds in the northeastern part of Sagami Bay.

EOF 2nd mode was predominant in the northeastern part of Sagami Bay (area C in Fig. 4). The wind direction measured at the weather stations (Miura, Tsujido) in

**Table 1** Correlation coefficients between EOF score and wind speed

| | Odawara | | Oshima | |
|---|---|---|---|---|
| | N-S | E-W | N-S | E-S |
| EOF 1st mode | −0.24 | −0.05 | 0.18 | 0.06 |
| EOF 2nd mode | 0.01 | 0.53 | 0.46 | 0.55 |
| EOF 3rd mode | 0.26 | 0.03 | −0.38 | −0.02 |
| EOF 4th mode | −0.01 | −0.07 | 0.07 | −0.11 |

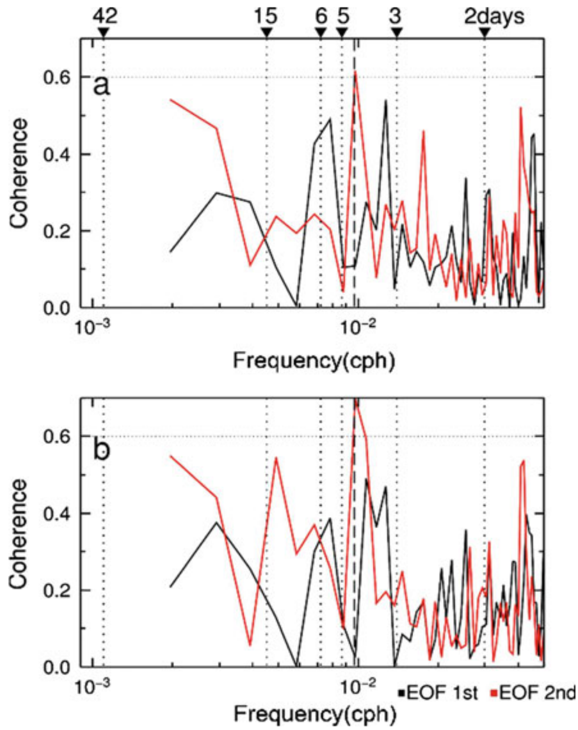



**Fig. 10** Coherence between EOF score and winds of **a** North–South and **b** East–West components. Dashed line indicates 4.3 days

the eastside of Sagami Bay was the same as that measured at Oshima–Kitanoyama. By contrast, the wind direction was not the same at the weather stations on the west side of Sagami Bay (Odawara, Inatori, and Ajiro). Wind direction on the east of Sagami Bay was constant from north to south because the wind direction was heavily influenced by the nearby mountain ranges.

Hence, we focused on the period during February 9–16, 2014. The absolute wind speed in this period was at its maximum during the whole study period. Fluctuation of winds was consistent with the variation in the EOF 2nd mode score (Fig. 6a, d). Strong northeast winds were measured, and southwestward currents were observed. Wind speed in north reached 10 m/s at Oshima–Kitanoyama. During this period, a maximum speed of 12.3 m/s was observed in Tsujido in the northeastern part of Sagami Bay and a maximum speed of 6.2 m/s was observed in Odawara in the northwestern part of Sagami Bay. Taking together, the EOF 2nd mode score corresponded to the driven currents induced by the local wind.

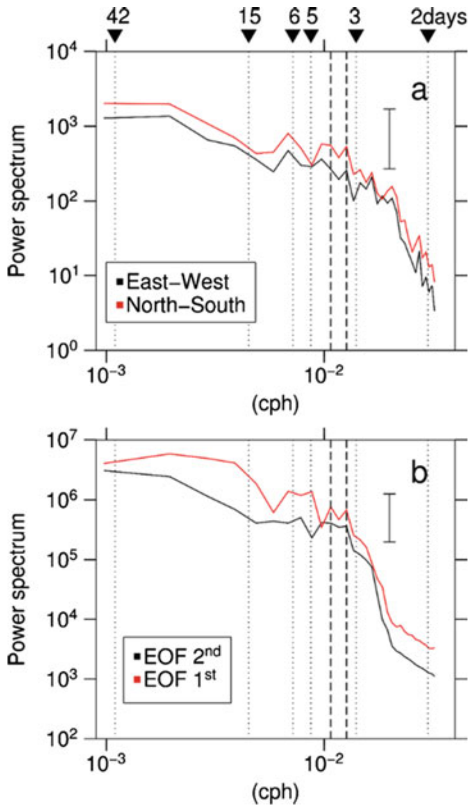



**Fig. 11** Power spectrum of **a** winds and **b** score of EOF. Error bar indicates a 95% confidential interval. Dashed lines show 3.3 days (right) and 3.9 days (left), respectively

# 4 Synthesis

In this study, surface circulation patterns in the northern part of Sagami bay were examined. The data were obtained from December 1, 2013 to August 11, 2014. The Kuroshio took an oNLM path until May 2014, and then took an nNLM path.

EOF analysis was conducted because the frequencies of current direction indicated that multiple types of circulation, including clockwise circulation, counterclockwise circulation, and others exist in the northern part of Sagami Bay.

The EOF 1st mode score indicated that clockwise circulation or counterclockwise circulation existed in northern part of Sagami bay. Temporal change in the EOF 1st mode score was found to be related to sea level and the location of Kuroshio axis (the Kuroshio path). These relationships are summarized in Fig. 12.

The EOF 2nd mode corresponded to the wind-driven currents induced by the locally breezing wind in the northwestern part of Sagami Bay, and the EOF 3rd and 4th modes showed dipole structures of surface circulation.

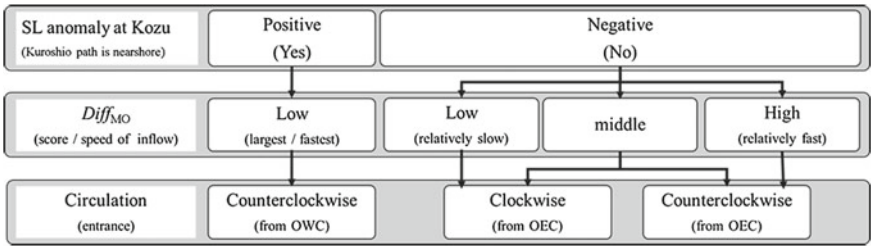



**Fig. 12** Flowchart of surface circulation pattern in the northern part of Sagami Bay

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# Statistical Analysis of High-Frequency $pCO_2$ Data Acquired with the ASTAN buoy (South-Western English Channel, Off Roscoff)

**Jean-Philippe Gac, Thierry Cariou, Éric Macé, Marc Vernet, and Yann Bozec**

**Abstract** Since 2007, in the context of the SOMLIT network, we installed a CTD (SeaBird SBE19+) below the ASTAN buoy located in the Western English Channel (WEC) off Roscoff (48° 46′ 40 N 3° 56′ 15 W; depth 5 m) between the SOMLIT-Coast and SOMLIT-Offshore sampling sites. These sensors provided high-frequency (HF) measurements (hourly) of sea surface salinity (SSS), sea surface temperature (SST), fluorescence and dissolved oxygen (DO) all year. Since 2014, we added a SAMI-$CO_2$ sensor, which measured the sea surface partial pressure of $CO_2$ ($pCO_2$) to investigate the seasonal dynamic of the $pCO_2$ and associated air-sea $CO_2$ exchange at the ASTAN site. From this high-frequency database, we were able to separate the signal according to the tide to determine the physicochemical and biological characteristics of two water masses: the coastal water mass (CWM) and the offshore water mass (OWM). These two water masses were strongly influenced by the biological productivity of the environment, more importantly in the CWM, and limited by the available light. Surface waters at the ASTAN site were near equilibrium with the atmosphere with an annual air-sea flux of 0.12 mmol C $m^{-2}$ $d^{-1}$ during 2016. The year can be divided into three distinct regimes: at the beginning of the year (winter period), the ASTAN site was a source of $CO_2$, controlled by thermodynamic at 1.23 mmol C $m^{-2}$ $d^{-1}$, from April to September (spring–summer), it became a sink of $CO_2$ with an important impact of biological activity (−0.64 mmol C $m^{-2}$ $d^{-1}$), and at the end of the year (fall), it reversed to a weaker source of $CO_2$ at 0.26 mmol C $m^{-2}$ $d^{-1}$. In order to further assess the signal, we used signal processing tools such as wavelet analysis. From the frequency/time representation, it was possible to follow how the signal varied over time, and thus deduce the presence of the two water masses due to the tidal effect, but also observes a significant impact of the day/night cycle on the biological parameters.

**Keywords** High frequency · Air-sea $CO_2$ flux · Autonomous sensor · Wavelets analysis

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## 1 Introduction

Long-term studies of the global ocean have shown an acidification linked with rising atmospheric $CO_2$ (IPCC 2007; Takahashi et al. 2014) at rate unpreceded during the last 250 years (Zeebe 2012), reaching 407 ppm at Mauna Loa (Hawaii) in 2017 (NOAA). The world ocean absorbs 26% (2.3 ± 0.4 Pg C $year^{-1}$) of anthropogenic $CO_2$ (Le Quéré et al. 2009, 2010), and this massive absorption of atmospheric $CO_2$ can change the chemistry of the oceans (Feely et al. 2004). The open ocean is globally a sink of atmospheric $CO_2$ at−1.6 ± 0.9 Pg C $year^{-1}$ (Takahashi et al. 2009). Recent studies have focused on the role of the coastal environment in $CO_2$ air-sea flux. These environments represent only 7% of the surface of the global ocean, but they are significant and sometimes poorly understood in terms of carbon exchanges with other environments (terrestrial, open ocean and atmosphere, e.g. Chavez et al. 2007; Hales et al. 2008; Liu et al. 2010). Laruelle et al. (2014) recently estimated the importance of the coastal environment, which represents globally a sink of atmospheric $CO_2$ at −0.19 ± 0.05 Pg C $year^{-1}$. It represents only 8% of the open ocean sink, but with major uncertainties associated with this estimate. Coastal ecosystems are very diversified, they can be characterized by high biological productivity, driven by the interplay between temperature, light and nutrient inputs from land, remineralization in shelf sediments and upwelling or downwelling of nutrients from the open ocean. Thus, it is difficult to propose a general model to assess the dynamic of all these shelves.

The Western English Channel (WEC) is part of one of the world's largest margins, the North-west European continental shelf. Characterized by relatively shallow depths and intense tidal level, the WEC hosts three different hydrographical structures: all-year well-mixed, seasonally stratified and thermal front structures. The WEC can be separated in two water masses according to the presence of the thermal front during spring and summer: the south part (sWEC), characterized by the strongest tidal currents, with a well-mixed water column (Wafar et al. 1983), and the north part (nWEC), where tidal streams are less intense and a seasonal stratification occurs (Smyth et al. 2009). The light availability is the main factor controlling phytoplankton production in the well-mixed waters of the sWEC (Boalch et al. 1978; Wafar et al. 1983; L'Helguen et al. 1996; Marrec et al. 2014a, b). It is this factor that is primarily responsible for triggering phytoplankton blooms.

Previous studies in this area highlighted the seasonal variability of $CO_2$ air-sea fluxes (Borges and Frankignoulle 1999, 2003; Frankignoulle and Borges 2001; Schiettecatte et al. 2006, 2007; Thomas et al. 2005). Biological processes were shown to be the main drivers of the $CO_2$ dynamic, which is representative of the coastal environment of northern Europe (Borges et al. 2006; Bozec et al. 2005, 2006). Litt et al. (2010) also showed that sea surface temperature (SST, solubility), chlorophyll (metabolic) and salinity (advection) exert a high control on the air-sea exchange of $CO_2$ in these environments. Recent spatio-temporal study of fluxes on the Western English Channel demonstrated the biogeochemical control of $CO_2$ air-sea fluxes between the different parts of the channel (Marrec et al. 2014a, b, 2015).

In this study, we rely on high-frequency data from a fixed buoy to further asses the $CO_2$ air-sea exchanges in the sWEC and to understand the influence of physical and biological parameters from diurnal to inter-annual scales on the $CO_2$ dynamic in this area.

# 2 Materials and Methods

## *2.1 High-Frequency Measurements: The Astan buoy*

We investigated the sWEC using the buoy of opportunity ASTAN, a cardinal buoy used to make *in situ* measurements (48° 46’ 40 N 3° 56’ 15 W, Fig. 1). This location was chosen by its midway position between a very coastal and very productive environment, and an offshore environment mixed all year round. Since 2007, a CTD SBE16+ measured conductivity (range 0–9 S/m, accuracy 0.005 S/m, resolution 0.00005 S/m), sea surface temperature (SST, −5 °C to 35 °C/0.005 °C/0.0001 °C) and pressure (0–600 m/0.1%/0.002%). From these data, sea surface salinity can be calculated (SSS, 0–42/0.005‰/0.0005‰). Auxiliary sensors are embedded, for determination of oxygen saturation (%$O_2$, 0–120%/2%) and fluorescence (0–5 µg/L, lim 0.03 µg/L, expressed in Volt for comparing several measurements). The Submersible Autonomous Moored Instrument for $CO_2$ (SAMI-$CO_2$) is a compact and autonomous instrument for measuring the partial pressure of $CO_2$ ($pCO_2$) on seawater, with an accuracy of ±8 µatm (Degrandpre et al. 1997). It was deployed under the buoy at 5 m depth below the CTD in 2014.

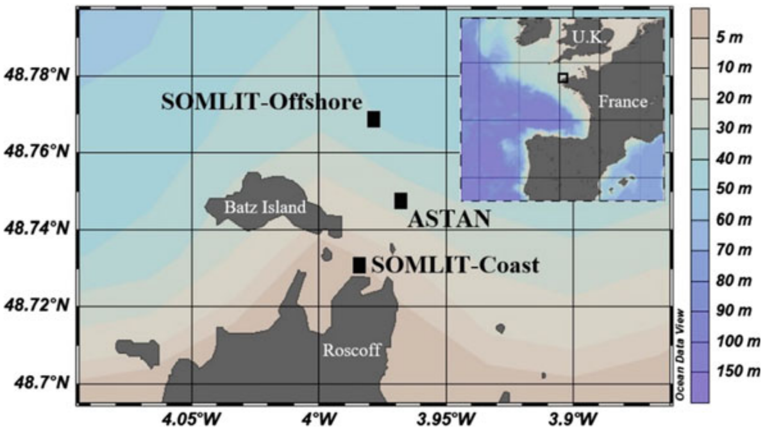


**Fig. 1** Map and bathymetry of the study area, with the location of the ASTAN buoy and the sampling points SOMLIT-Offshore/SOMLIT-Coast

## 2.2 Low-Frequency Measurements: Weekly Discrete Sampling for $CO_2$ Analysis

Weekly measurements were performed to follow the calibration of the sensors and correct the offsets due to maintenances. To estimate the carbonate system of the seawater, four parameters can be measured: the negative log of the hydrogen ion concentration (pH), the partial pressure of $CO_2$ ($pCO_2$), dissolved inorganic carbon (DIC) and total alkalinity (TA). To calculate $pCO_2$, it is necessary to measure at least two of the other carbonate species (Park 1969; Millero 1995; Millero et al. 2007). For this study, pH and TA were sampled and analysed at the laboratory. From March to December 2017, 36 discrete samples for the determination of TA and pH were collected in 500-mL borosilicate glass bottles and poisoned with 50 μL of saturated $HgCl_2$. TA was determined with around 51 g of weighted sample at 25 °C using a potentiometric titration with 0.1 M of HCl, realized by a Titrino 847 plus Metrohm. The balance point is determined by Gran method (1952), described in the article of Haraldsson et al. (1997). The accuracy of this method is ±2.1 $\mu$mol kg$^{-1}$ (Millero 2007). The method is verified by Certified Reference Material (CRM 131) provided by A. Dickson (Scripps Institute of Oceanography, University of South California, San Diego, USA). pH was determined with an accuracy of 0.002 pH units by spectrophotometry (Perin-Elmer Lambda 11) with the method of Clayton and Byrne (1993) and corrected by Chierici et al. (1999), using the sulphonephthalein diprotic indicator of meta-Cresol Purple (mCP).

## 2.3 $CO_2$ System and Air-Sea Flux Calculation

In order to clearly distinguish the impact of biological activity and thermodynamic on environmental parameters, dissolved oxygen and $pCO_2$ were converted to oxygen saturation ($\%O_2$) and $pCO_{2,\text{non-therm}}$.

The calculation of the oxygen saturation ($\%O_2$) makes it possible to take into account only the impact of the biology on the variation of the dissolved oxygen of an environment. It was calculated from Eq. 1, taking into account temperature, salinity and dissolved oxygen.

$$\begin{aligned} \ln C^* &= A_1 + \left(\frac{A_2 \times T}{100}\right) + \left[A_3 \times \log\left(\frac{T}{100}\right)\right] \\ &\quad + S \times \left[\left(B_1 + \left(B_2 \times \frac{T}{100}\right) + B_3 \times \left(\frac{T}{100}\right)^2\right)\right] \\ \%O_2 &= \left(\frac{O_2}{e^{\ln C^*}}\right) \times 100 \end{aligned} \tag{1}$$

where $C^*$ may be either the solubility from water saturated air at a total pressure of one atmosphere, the $A$'s and $B$'s are constants described in Weiss (1970), $T$ is the absolute temperature and $S$ the salinity in per mil.

To compute $pCO_2$, we used the combination of TA, pH, SSS and SST as input parameters in the $CO_2$ chemical speciation model ($CO_{2sys}$ Program, Pierrot et al. 2006) using equilibrium constants of $CO_2$ proposed by Mehrbach et al. (1973), refitted by Dickson and Millero (1987) on the seawater pH scale, as recommended by Dickson et al. (2007).

With the Takahashi et al. (2002) method, $pCO_2$ can be estimated by the impact of thermal and non-thermal processes on their variations. This method uses the well-constrained temperature dependence of $pCO_2$ versus temperature (4.23% $°C^{-1}$) (Takahashi et al. 1993). It helps to construct the thermally forced seasonal $pCO_2$ cycle ($pCO_{2,therm}$, Eq. 2) or remove the thermal effect from observed $pCO_2$ ($pCO_{2,non\text{-}therm}$, Eq. 3).

$$pCO_{2,\text{therm}} = pCO_{2,\text{mean}} \times e^{0.0423 \times (T_{\text{obs}} - T_{\text{mean}})} \tag{2}$$

$$pCO_{2,\text{non-therm}} = pCO_{2,\text{obs}} \times e^{0.0423 \times (T_{\text{mean}} - T_{\text{obs}})} \tag{3}$$

For $CO_2$ air-sea flux determination, atmospheric $pCO_2$ ($pCO_{2,air}$) was calculated from the $CO_2$ molar fraction ($xCO_2$) from the Mace Head site (53° 33′ N 9° 00′ W, southern Ireland) of the RAMCES network (Observatory Network for Greenhouse gases) and from the water vapour pressure ($pH_2O$) using Weiss and Price (1980) equation. Atmospheric pressure ($P_{atm}$) in the middle of the WEC (Western English Channel, 49° 50′ N, 4° 00′ W) was obtained from NCEP/NCAR re-analysis project (Kalnay et al. 1996). The dissociation constants were determined by Millero (2010). Calculations were made on the total scale of hydrogen, and the dissociation constant of the hydrogen sulphate used is calculated by Dickson (1990). $CO_2$ flux (F, in mmol C $m^{-2}$ $d^{-1}$, Eq. 4) at the air-sea interface is determined from dissolved $pCO_2$, atmospheric $CO_2$, surface temperature, surface salinity and wind. This flux is calculated from the difference of $pCO_2$, between the seawater and the air ($\delta pCO_{2\ seawater} = pCO_{2\ seawater} - pCO_{2\ air}$).

$$F = k \times \propto \times \delta p\text{CO}_2 \tag{4}$$

where $k$ represents the gas transfer velocity (m $s^{-1}$) and $\alpha$ represents the solubility coefficient of $CO_2$ (mol $atm^{-1}$ $m^{-3}$) calculated by Weiss (1970). The exchange coefficient $k$ (Eq. 5) is calculated according to the wind speed with the algorithm of Nightingale et al. (2000).

$$k = \left(0.222 \times u_{10}^2 + 0.333 \times u_{10}\right) \times \left(\frac{\text{Sc}}{660}\right)^{-0.5} \tag{5}$$

where $u_{10}$ represents the wind speed at 10 m height (m $s^{-1}$) and Sc the Schmidt number at surface temperature in situ.

# 3 Results and Discussion

## *3.1 Data Overview*

During the 3 years of operation of the SAMI-$CO_2$, we acquired 58,002 data points for SST; 39,124 for SSS; 41,299 for dissolved oxygen (DO); 39,124 for fluorescence; and 22,504 for $pCO_2$ (Fig. 2). A seasonal pattern is observed for all the parameters during the 3 years of observation. This pattern can be confirmed by a PCA, taking into account all the data of SST, SSS, DO, fluorescence and $pCO_2$ during 2016 (Fig. 3). This PCA makes it possible to clearly highlight the temporal cycle, caused by the seasonal cycle. This seasonality represents more than 80% of the signal, with a first main component (52.5%) which groups the biological influences, represented by the fluorescence, DO and $pCO_2$ variations, and the second main component (29.7%) grouping the physical influences, represented by SST and SSS.

### 3.1.1 Physical Structure of the Study Site

The ASTAN buoy is a station located in the all-year well-mixed water column system of the sWEC (Wafar et al. 1983). As shown in Fig. 2a, b, physical parameters SST and SSS showed a very marked seasonality. These parameters followed a classical dynamic for this environment, with warmer SST and higher SSS during summer, and cooling and lower SSS from autumn to winter. During winter, SST was around 9 °C and reached 17 °C in summer. SSS varied more during winter, ranging between 34.6 and 35.3, compared to 35 to 35.3 during summer. This variability is explained by the tidal cycle coupled with the larger freshwater inputs during winter responsible for much lower SSS at low tides. The variability of SSS varies a lot from one year to another. Kelly-Gerreyn et al. (2006) showed that this variability is linked to the freshwater discharges from Brittany Rivers or transport of lower SSS compared to the surrounding Atlantic waters from the Loire plume.

### 3.1.2 Dynamics of Primary Production

%$O_2$, fluorescence and $pCO_2$ can be used as indicators for the biological processes. Figure 2c, d shows that these parameters followed a seasonal pattern characteristic of the Western English Channel as described by Collignon in (1991). They were characterized by a strong spring bloom, due to the availability of nutrients accumulated

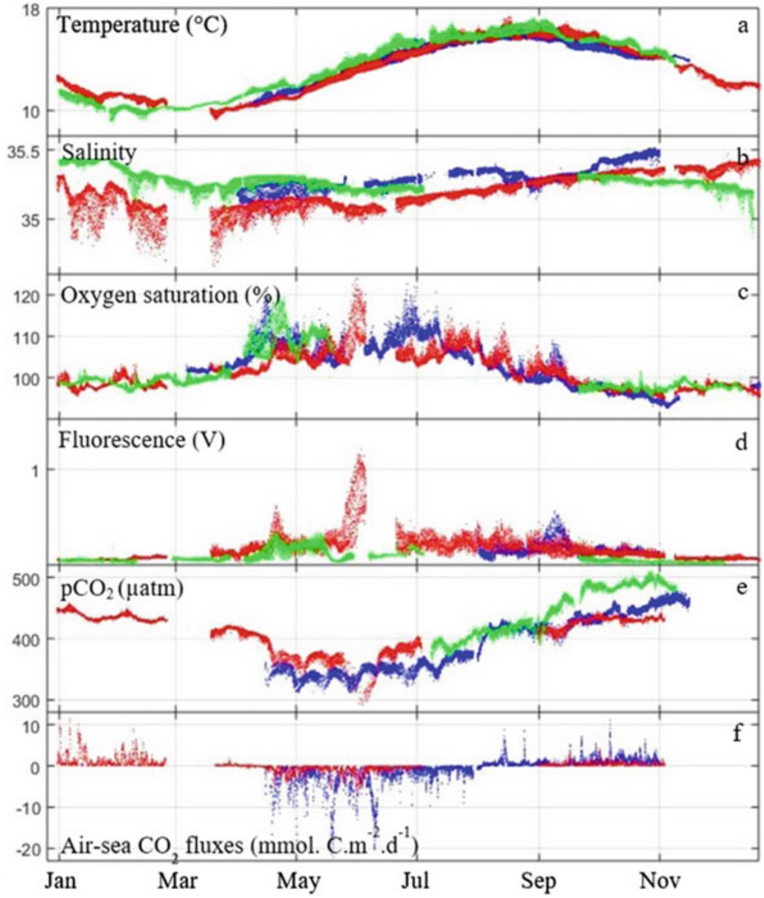


**Fig. 2** **a** Sea Surface Temperature (°C), **b** Sea Surface Salinity (PSU), **c** %$O_2$ (%), **d** fluorescence (V), **e** $pCO_2$(µatm) and **f** air-sea $CO_2$ fluxes (mmol C $m^{-2}$ $d^{-1}$) over time for the years 2015 (blue), 2016 (red) and 2017 (green)

during the winter and higher light availability. This was visible from the fluorescence in April 2016 and 2017, as well as a very sharp peak in 2016 in July, reaching 1 V, and close to 0.2 V during the productive months. The effects of this primary production were also visible from the oxygen saturation with values to 120% from April to October, and $pCO_2$ with values below atmospheric equilibrium around 350 µatm during the same period. During the winter season, the fluorescence remained close to zero, %$O_2$ close to100% and $pCO_2$ levels slightly higher than 400 µatm. Inter-annual variability was significant, with high fluorescence signals observed during 2016 in early May and June, whereas only observed during May for the bloom of 2017. These inter-annual differences were also observed by Marrec et al. (2014a,

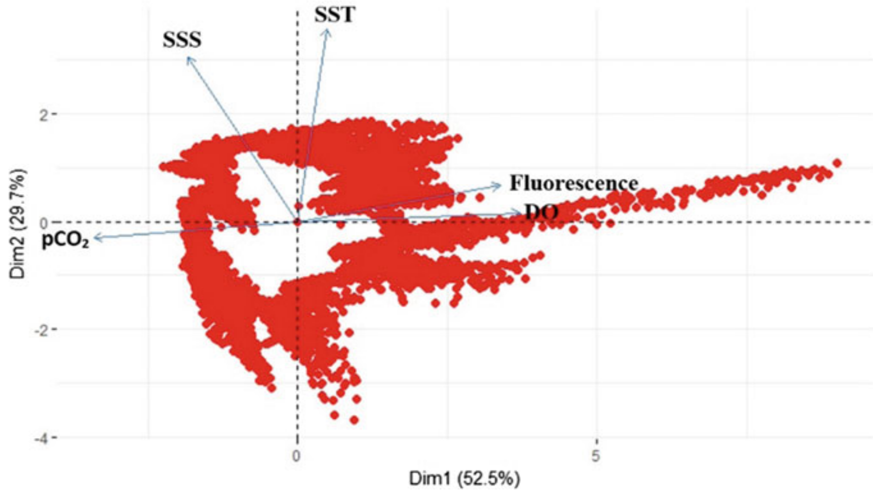


**Fig. 3** Principal component analysis of Sea Surface Temperature (SST), Sea Surface Salinity (SSS), Dissolved Oxygen (DO), Fluorescence and $pCO_2$ during the year 2016

b). It has been shown that this difference is due to the light availability that differs inter-annually.

### 3.1.3 Dynamic of $CO_2$ Air-Sea Fluxes

In Fig. 2e, the $CO_2$ air-sea fluxes show three distinct regimes. From January to April, fluxes were positives and range from 0 to 10 mmol C $m^{-2}$ $d^{-1}$. The environment behaved like a source of $CO_2$. During that period, the physical processes were the main drivers with low SST and SSS, non-existent primary production, strong wind and $CO_2$ in seawater above atmospheric equilibrium (Marrec et al. 2014a, b). The fluxes became negative from April to September. They reached a minimum on 19 May 2015, with −22.05 mmol C $m^{-2}$ $d^{-1}$. During this period, primary production was very important, favouring the reduction of $CO_2$ stock in seawater. From September to the end of the year, fluxes were again positive, but less important than at the beginning of the year. They reached values higher than 11 mmol C $m^{-2}$ $d^{-1}$, but remained on average around 2 mmol C $m^{-2}$ $d^{-1}$. This $CO_2$ source was explained by the increased occurrence of respiratory species, remineralization processes, more influent than the decrease in temperature and salinity at the beginning of fall (Marrec et al. 2014a, b).

### 3.2 Characterization of Water Masses

Figure 4 shows the daily variations of SST, SSS, $\%O_2$ and $pCO_2$ for representative periods. The winter season (Fig. 4a, c) showed correlated variations of SST and SSS (low tide, 10 °C, and 35.0, respectively; high tide, 11 °C, and 35.2, respectively), and correlated variations of $\%O_2$ and $pCO_2$ (low tide, 95%, 435 μatm; high tide, 102%, 440 μatm). These two trends were reversed during the productive summer period (Fig. 4b, d). These figures show the importance of the tidal range in the movement of water masses, which imply a significant daily variation of the physicochemical parameters at the ASTAN buoy. Similar observations have been done by Bozec et al. (2012) in the Loire estuary and by Ribas-Ribas et al. (2013) in the Cadiz Bay.

As mentioned above, the physical parameters SST and SSS showed significant variations depending on the water level, with SST and SSS lower at low tide during winter and lower at high tide in summer. These physical properties allowed the identification of two distinct water masses: a very Coastal Water Mass (CWM) and an Offshore Water Mass (OWM). To further investigate these two water masses, Fig. 5 represents data of SST, SSS, $\%O_2$, fluorescence and $pCO_2$ during 2016 as a function of time for each water masses: OWM for the high tidal level (>7 m) and CWM for the low tidal level (<3 m). This makes it possible to highlight the physicochemical characteristics of each water masses. The CWM was characterized by a lower temperature than the OWN from October to March and higher the rest of the year (0.1 °C of difference). In addition, the CWM showed lower salinities throughout the year, especially due to rainwater runoff (0.1–0.4 PSU of difference). Finally, it was characterized by a larger biological activity: the phytoplankton activity was more significant, highlighted by higher fluorescence and $O_2$ saturation (1–10% of difference), and a lower $pCO_2$ (1–5 μatm of difference) values. The tide signal thus made it

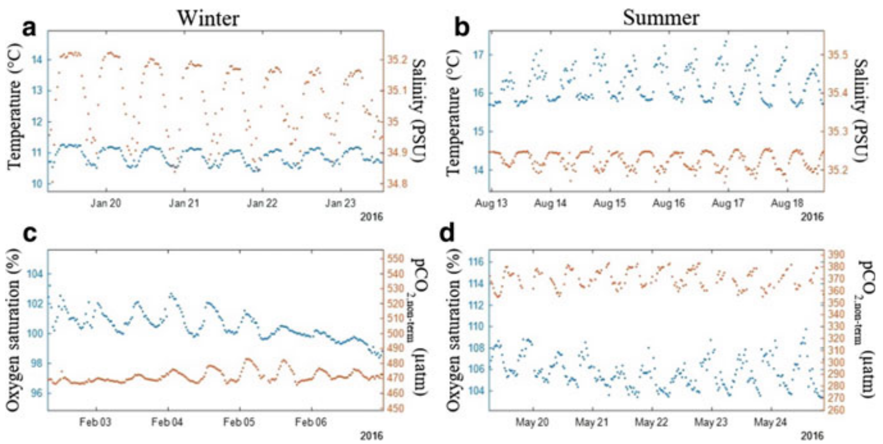


**Fig. 4** SST and SSS during time for **a** winter and **b** summer and $\%O_2$ and $pCO_{2,non\text{-}term}$ during **c** a low-productive period and **d** a productive period

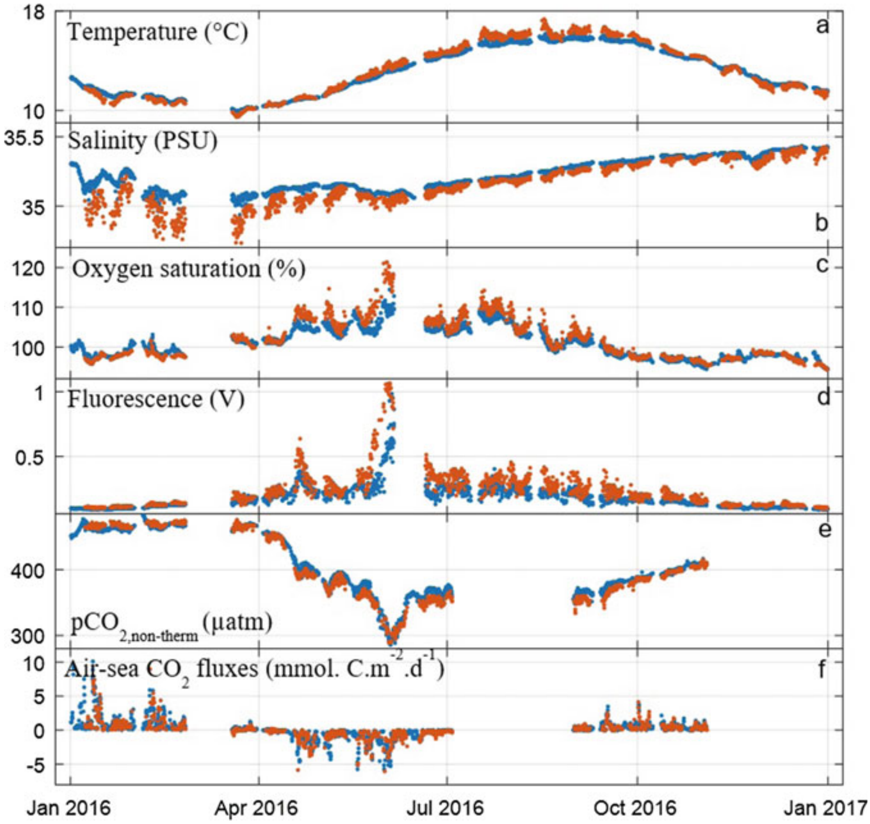


**Fig. 5** **a** SST (°C), **b** SSS (PSU), %$O_2$ (%), **d** fluorescence (V), **e** $pCO_{2,non\text{-}therm}$ (µatm) and **f** air-sea $CO_2$ fluxes (mmol $m^{-2}$ $d^{-1}$) for the OWM (tidal level >7 m, blue) and the CWM (tidal level <3 m, red) during 2016

possible to separate the water masses and to follow their physicochemical properties. In order to understand other factors influencing these properties, additional tools can be used (see Sect. 3.3).

### 3.3 *Frequency Analysis of $CO_2$ Air-Sea Fluxes*

The separation of signals by tidal level for all the parameters measured by the sensors showed significant differences, proving the presence of two distinct water masses, with very different physicochemical and biological parameters. However, it was difficult to observe other phenomena affecting the signal except for the strong tidal signal. Frequency analysis is therefore necessary. However, the time component is lost when using analyses such as Fourier transformation. We thus chose to perform a wavelet analysis (Torrence and Compo 1998). The wavelet transform makes it possible to characterize the periodicities of parameter fluctuations as a function of time. Santos et al. (2003) described wavelet analysis as an analysis that allows temporal and frequency localization in a signal analysis by decomposition or transformation of a one-dimensional time-series into a diffuse time–frequency image simultaneously. It is possible to obtain information on the amplitude of all the periodic signals in the series and how this amplitude varies with time. We used the Morlet wavelets; they offer a better resolution for this case study (De Moortel et al. 2004).

### 3.3.1 Physical Parameters Frequency Analysis

When we applied the wavelets to the SST data (Fig. 6a), we clearly observed a 12-h cycle throughout the year, more important during the summer period. However, it remained unclear whether this frequency was related to the day/night cycle or tidal cycle. For SSS (Fig. 6b), we observed the same phenomenon, more marked during winter caused by the introduction of more freshwater with lower SSS at the coast. By applying the crossed wavelets of SST and SSS (Fig. 6c), the same periodicity of 0.5 days was observed. The advantage of this representation lies in the fact that it can reveal whether the signals are in phase or not. This is represented by the arrows. If the arrow is pointing to the right, the signal is in phase for the given frequency; to the left, the signals are shifted by $\pi$, they are out of phases. At the frequency of 12 h, we observed precisely this alternation, with a signal in phase from October to April, and shifted the rest of the year as visible from snapshots observations (Fig. 4). The statistical analysis revealed that these phase changes were very sharp and allowed to precisely pinpoint the different physical regimes at the ASTAN site. For example, in 2016, we located a first inversion on April 10 and the second on November 9.

### 3.3.2 Biological Parameters Frequency Analysis

Wavelet analysis for $\%O_2$ and $pCO_{2,\text{non-therm}}$ (Fig. 6d, e) still revealed two characteristics frequencies: 0.5 and 1 days. These frequencies seemed more marked during summer compared to the winter. This could be directly related to phytoplankton production from April, more important on the coast than offshore, inducing a higher variability of the signal during a tide revolution. These two frequencies were related to the tidal range and the day/night cycle. The cross-wavelet analysis (Fig. 6f) revealed that these two frequencies were identical for both parameters. However, the phases were more difficult to understand. For the 12-h signal, the phase made a revolution throughout the year: we did not observe distinct regimes similar to the ones of SST and SSS. In winter, there seemed to be a phase shift of $\pi$, and when the $\%O_2$ is at maximum, the $pCO_{2,\text{non-therm}}$ decreases. Thus, the statistical analysis was less efficient on the biological parameters.

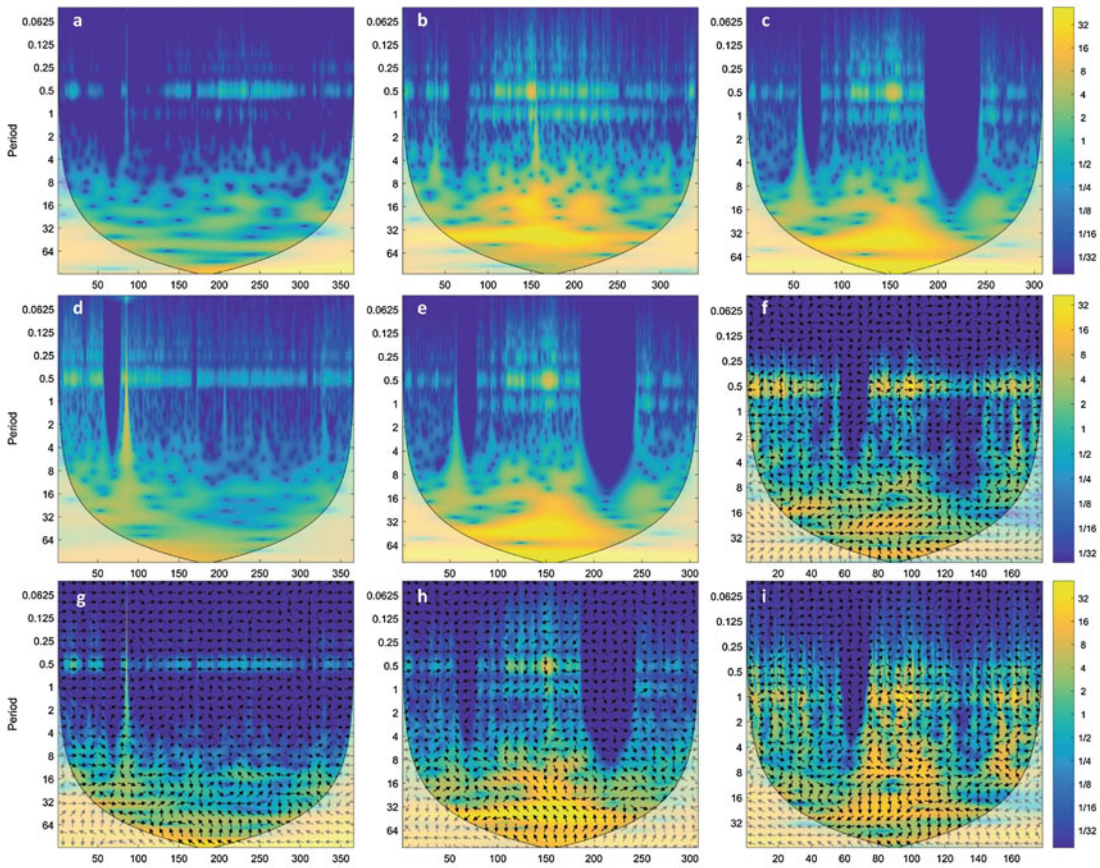


**Fig. 6** Wavelet analysis: period (in day) during the year 2016 for **a** SST, **b** SSS, **d** $\%O_2$, **e** $pCO_{2,non\text{-}therm}$ and **g** air-sea $CO_2$ fluxes. Cross-wavelet analysis between **c** SST and SSS, **f** $\%O_2$ and $pCO_{2,non\text{-}therm}$, **h** air-sea $CO_2$ fluxes and tides and between (i) air-sea $CO_2$ fluxes and PAR

### 3.3.3 Flux Frequency Analysis

Fluxes were obtained from $pCO_2$, SST and SSS, which are dependent on the movements of the water masses. Atmospheric $pCO_2$ and wind speed values were very significant for the $CO_2$ air-sea flux calculations and are not influenced by the movement of the water. As a result, no differentiation could be made by separating the fluxes by water level contrary to the other parameters (Fig. 5). Figure 6g shows the wavelet diagram applied to the fluxes. In this diagram, we did not observe frequencies detached from the noise. Cross-wavelets will be important for detecting $CO_2$ air-sea fluxes frequencies in relation to important parameters. We have seen previously that the two main frequencies influencing the study parameters were the day/night and tidal signal. By crossing the tide and the fluxes (Fig. 6h), we observed the same characteristic frequency observed for all the parameters at 0.5 day. By crossing the PAR (data from biological station of Roscoff) with the fluxes signal (Fig. 6i), we observed the same characteristic frequency observed for the biological parameters at 0.5 day and 1 day. This analysis showed that although we did not observed differences between water masses for the fluxes, it does exist and is related to the day/night and tide signals.

## 4 Conclusion

The study of the sWEC based on high-frequency measurements showed that the location of the sensors in a tidal environment allowed investigating coastal waters with different physical and biological regimes from a single measuring point. From this high-frequency database, we were able to separate the signal according to the tide to determine the physicochemical and biological characteristics of two water masses: the coastal water mass (CWM) and the offshore water mass (OWM). In order to overcome the marked seasonality and the strong tideal signal, a wavelet frequency analysis made it possible to extract additional signals. The daily signal was detected from the biological parameters, and the different shift in physical parameters of the two waters masses were precisely located. However, this study did not allow the extraction of characteristic frequencies of the air-sea $CO_2$ fluxes, because they were largely influenced by atmospheric parameters.

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# Spatial Variation in $pCO_2$ Based on 16 Years of In Situ Measurements in the Seto Inland Sea, Japan

**Mitsuru Hayashi and Eiji Yamashita**

**Abstract** It is important to understand the behavior of carbon dioxide ($CO_2$) in the sea, especially in terms of its relation to climate change in coastal seas, blue carbon, ocean acidification, etc. Spatial variations in the partial pressure of $CO_2$ in the seawater ($pCO_2$) in the Seto Inland Sea and adjacent regions were studied based on 16 years of historical in situ data. $pCO_2$ was lower than the partial pressure of $CO_2$ in the atmosphere ($PCO_2$) throughout the Seto Inland Sea in spring. The same tendency was found in the open sea regions (the Pacific Ocean and Kii and Bungo Channels) and Osaka Bay in summer. In Osaka Bay, $CO_2$ influx into the water ($pCO_2 < PCO_2$) in spring is due to very high primary productivity. That is also due, in all the basin, to low water temperatures (leading to high solubility). Conversely, $CO_2$ efflux to the atmosphere ($pCO_2 > PCO_2$) in summer in the Seto Inland Sea, excluding Osaka Bay, is due to low primary production (causing high $pCO_2$) and high-water temperature (leading to low solubility). Vertical mixing dominates at Bisan-Seto; therefore, it was presumed that increased $pCO_2$ due to the decomposition of organic matter in the bottom layer was supplied to the surface layer in Bisan-Seto, and spread throughout the basin. Bisan-Seto may thus cause large $pCO_2$ in fall.

**Keywords** $CO_2$ · $pCO_2$ · Seto Inland Sea · In situ measurement

## 1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) has estimated a global carbon budget in relation to global warming. In previous decades, the "missing sink" for anthropogenic carbon was a conundrum. Therefore, the carbon dioxide ($CO_2$) flux between air and sea was actively studied to find this missing sink. Most $CO_2$ was absorbed by the open ocean. Current thinking holds that the ocean is expected as "Blue Carbon" (United Nations Environment Programme 2019), while

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ocean acidification is suspected to cause damage to ecosystems. Both matters are closely related to coastal seas, wherein biological production is active. Thus, it is important to understand the behavior of $CO_2$ in coastal seas. The Seto Inland Sea is a sea characterized by highly active primary production. However, only a few measurements and estimates of the partial pressure of $CO_2$ in sea water ($pCO_2$) have been reported in the Seto Inland Sea (Harashima 1997; Fujii et al. 2013). We have measured $pCO_2$ as well as the partial pressure of $CO_2$ in the atmosphere ($PCO_2$) in the Seto Inland Sea and adjacent regions since the 1990s. In this study, the spatial variations in $pCO_2$ in the Seto Inland Sea are studied based on historical in situ data obtained over a 16-year period.

## 2 Methods

The in situ data were obtained during research cruises on TS *Fukae Maru* of the Graduate School of Maritime Science, Kobe University. Twelve cruises occurred in spring (March), and eleven in summer (July, August, or September) during 1994–2010, as shown in Table 1. The cruise tracks are shown in Fig. 1.

**Table 1** List of cruises

| Year | Periods | |
|---|---|---|
| | Spring | Summer |
| 1994 | 16–18 March | – |
| 1995 | – | 24–31 July |
| 1 996 | 18–21 March | – |
| 1997 | 18–21 March | 26–29 September |
| 1998 | – | – |
| 1999 | – | – |
| 2000 | 7–10 March | 6–14 September |
| 2001 | 12–16 March | 2–10 August |
| 2002 | 18–22 March | 1–8 August |
| 2003 | – | 1–8 August |
| 2004 | 18–22 March | – |
| 2005 | 14–18 March | 10–16 September |
| 2006 | – | 9–15 September |
| 2007 | 8–13 March | 4–10 September |
| 2008 | 3–11 March | 4–10 September |
| 2009 | 6–11 March | 3–9 September |
| 2010 | 5–10 March | – |

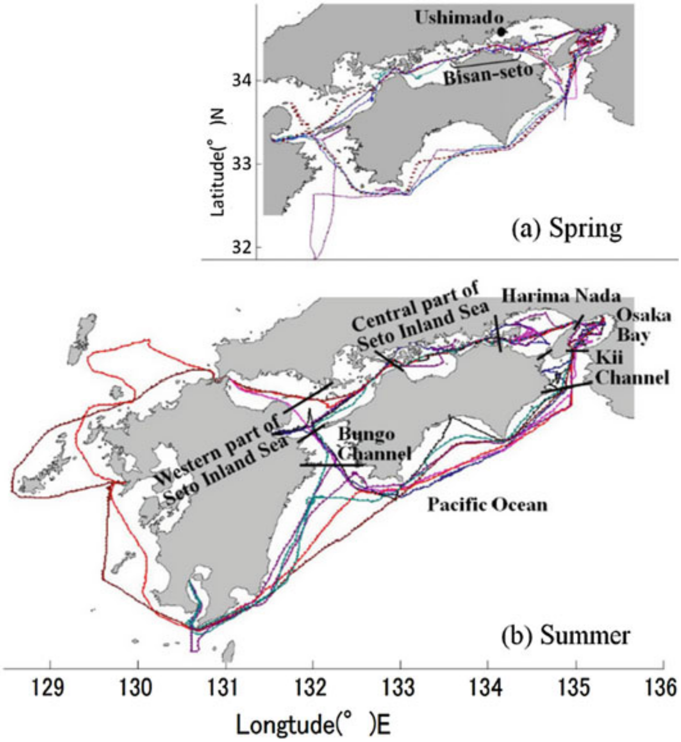


**Fig. 1** Research cruise tracks of TS *Fukae Maru* in spring (**a**) and summer (**b**) during 1994–2010. Black bold lines indicate boundaries between regions

The length of TS *Fukae Maru* is 49.95 m, the gross tonnage is 449 tons, and the draft is around 3 m. The navigation speed is 12.5 km. But the actual speed was reduced.

The air samples were collected from an inlet located on the main mast at a height of about 12 m, and were then transferred to the laboratory. $PCO_2$ was measured every minute using a non-dispersive infrared analyzer (NDIR) (LI6242; LI-COR). $pCO_2$ was determined using an automatic $CO_2$ measurement system of the Okayama type (Yamashita et al. 1993), as shown in Fig. 2.

$N_2$ gas (no $CO_2$) and a high $CO_2$ concentration gas are blended in the carrier gas unit to generate carrier gases of known $CO_2$ concentration. Seawater is pumped from the sea chest at the ship's bottom during cruises, and then transferred into the equilibration cylinder. The carrier gas also enters the equilibration cylinder, and then it bubbles, and $CO_2$ gas is exchanged between the carrier gas and the sample seawater. After the gas exchange, the $CO_2$ concentration is monitored using a second NDIR, and the maximum difference (*Y*-axis in Fig. 3) in concentration between the carrier gas and the exchanged gas is detected. This is repeated with carrier gases of five different $CO_2$ concentrations (*X*-axis in Fig. 3). $pCO_2$ is determined as the $CO_2$ concentration

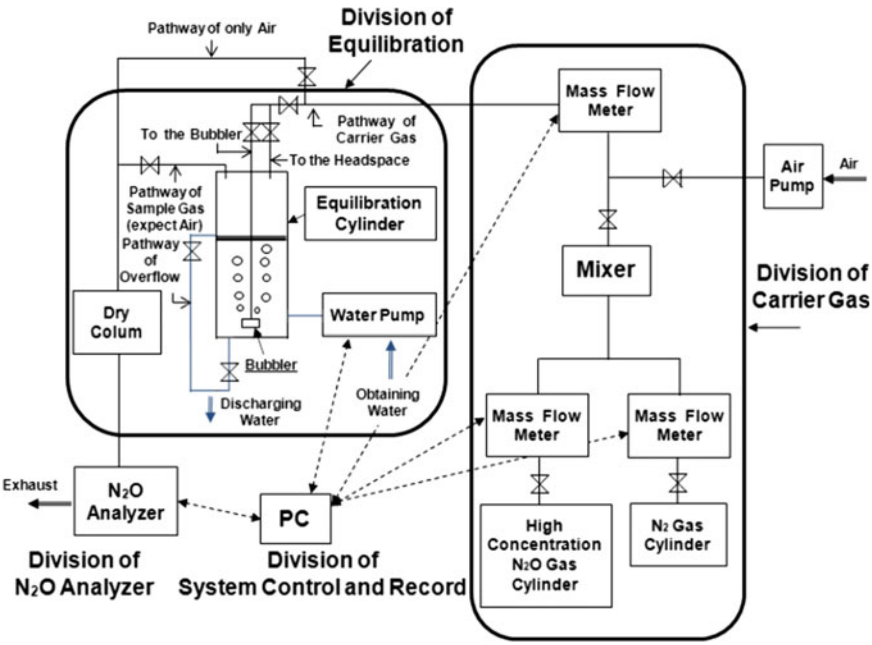


**Fig. 2** Schematic of the automatic $CO_2$ measurement system of the Okayama type

at "difference = 0" on the calibration line shown in Fig. 3, by plotting the differences against $CO_2$ concentrations in carrier gas every 15 mn (approximately 3 miles or 5.5 km). The entire system is controlled by a computer. Water temperature, salinity, and pH were measured every 5 mn using a conductivity meter (DS-15; HORIBA) and pH meter (F-52; HORIBA) in the seawater scale. Dissolved oxygen concentration (DO) was measured every minute using a DO meter (DO-25A; TOA). These data were averaged over 15 mn.

Data from each cruise were averaged for each region shown in Fig. 1b, namely, Harima Nada, the central part of the Seto Inland Sea (Bisan-Seto, Bingo Nada, and Hiuchi Nada), the western part of the Seto Inland Sea (Aki Nada and Iyo Nada), the Bungo Channel, the Pacific Ocean (landward of the mainstream of the Kuroshio Current), the Kii Channel, and Osaka Bay. The data from each region were averaged for each season (spring and summer). The difference between $pCO_2$ and $PCO_2$ ($\Delta pCO_2 = pCO_2 - PCO_2$) is considered an index of $CO_2$ emission (+) or absorption (−) by the sea.

We also used $pCO_2$ and $PCO_2$ data observed using the same system during 1993–2009 at Ushimado in the central Seto Inland Sea shown in Fig. 1a, to discuss annual variations in $pCO_2$ and $PCO_2$. Field observations were conducted for 1–3 days of a given month, while the month varied from year to year. Mean values for each observation period were calculated and were averaged on a monthly basis.

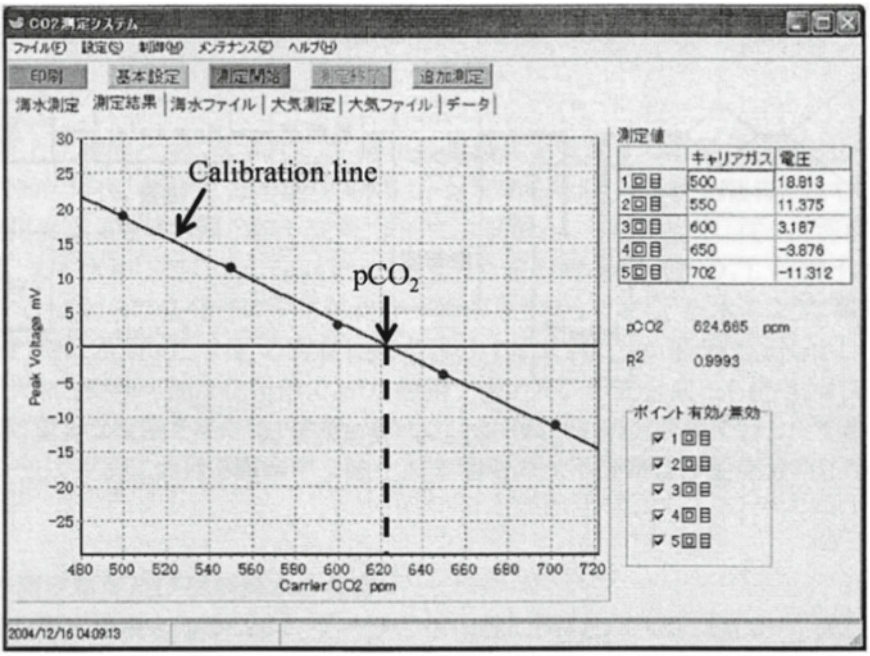


**Fig. 3** Display screen of calibration line (solid line) on software of the system. *Y*-axis is difference between output signals of NDIR with and without bubbling of carrier gas through seawater sample. *X*-axis is the $CO_2$ concentration of carrier gas

## 3 Results

Figure 4 shows spatial variations in $pCO_2$ and $PCO_2$ in spring (a) and summer (b). The minimum and maximum values of $pCO_2$ and $PCO_2$ are shown in Table 2. $PCO_2$ was slightly higher in spring compared to summer, and spatial variations were small in both seasons. $pCO_2$ was lower in spring, and the spatial variation was larger in summer. Minimum $pCO_2$ was observed in Osaka Bay in both seasons. The maximum $pCO_2$ was found in the Pacific Ocean in spring, and in the central part of the Seto Inland Sea in summer. The seasonal difference in $pCO_2$ in the Seto Inland Sea, except Osaka Bay (130–230 μatm), was larger than that in open sea regions (40–90 μatm).

Figure 5 shows the spatial variations in $\Delta pCO_2$ in both seasons. $\Delta pCO_2$ in spring was negative ($PCO_2 > pCO_2$; absorption tendency) in all regions.

The same tendency was found in the open sea regions and Osaka Bay in summer. However, $\Delta pCO_2$ in the Seto Inland Sea, excluding Osaka Bay, is positive ($PCO_2 < pCO_2$; emission tendency) in summer and showed a large seasonal variation.

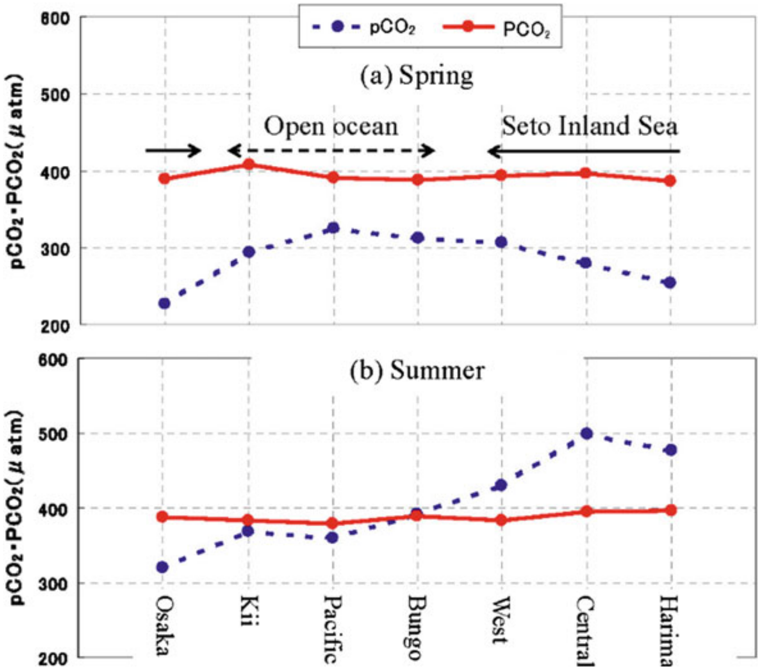


**Fig. 4** Spatial variations of $pCO_2$ and $PCO_2$ in spring (**a**) and summer (**b**)

Figure 6 shows the spatial variations in water temperature (a), salinity (b), DO (c), and pH (d) in both seasons. The minimum and maximum values are shown in Table 2. Water temperature was higher in summer, but their spatial variation was larger in spring. Salinity was higher and showed a larger spatial variation in spring. DO was higher in spring, while its spatial variation was slightly larger in summer. pH was also higher in spring, with larger spatial variation in summer.

## 4 Discussion

Here, we discuss the observed variations in $pCO_2$ and $\Delta pCO_2$. The higher DO in spring was likely due to higher primary production than in summer. There was a strong negative correlation between $pCO_2$ and DO as shown in Fig. 7, and this was stronger in spring (a) ($R = 0.92$) than in summer (b) ($R = 0.88$).

**Table 2** Range of data

| Season | Aria | $PCO_2$ (μatm) | | $pCO_2$ (μatm) | | Temp. (°C) | | Salinity | | DO (mg/l) | | pH | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. |
| Spring | Osaka Bay | 361 | 428 | 186 | 284 | 9.5 | 13.5 | 24.4 | 34.4 | 8.2 | 8.5 | 6.3 | 11.1 |
| | Kii Channel | 363 | 423 | 264 | 343 | 11.2 | 18.5 | 28.4 | 35.5 | 8.2 | 8.4 | 5.7 | 10.7 |
| | Pacific Ocean | 354 | 422 | 255 | 354 | 11.2 | 25.2 | 28.8 | 36.2 | 8.2 | 8.4 | 5.5 | 10.4 |
| | Bungo Channel | 362 | 426 | 306 | 376 | 13.4 | 27.6 | 32.7 | 35.9 | 8.1 | 8.4 | 5 2 | 8.7 |
| | Western part of the Seto Inland Sea | 379 | 425 | 286 | 334 | 12.0 | 15.4 | 32.4 | 35.6 | 8.2 | 8.4 | 7.4 | 8.9 |
| | Central part of the Seto Inland Sea | 383 | 430 | 256 | 315 | 9.8 | 12.9 | 32.3 | 34.7 | 8.2 | 8.3 | 6.3 | 9.2 |
| | Harima Nada | 371 | 431 | 217 | 312 | 9.6 | 12.2 | 30.0 | 34.2 | 8.2 | 8.4 | 6.4 | 11.3 |
| Summer | Osaka Bay | 366 | 477 | 134 | 494 | 25.0 | 28.0 | 26.0 | 32.1 | 8.1 | 8.4 | 6.2 | 12.6 |
| | Kii Channel | 361 | 434 | 348 | 538 | 25.3 | 28.2 | 28.1 | 33.2 | 7.9 | 8.3 | 4.7 | 9.6 |
| | Pacific Ocean | 354 | 424 | 323 | 537 | 16.5 | 30.4 | 28.2 | 34.5 | 7.9 | 8.3 | 5.6 | 9.2 |
| | Bugo Channel | 361 | 417 | 324 | 395 | 25.8 | 30.3 | 29.0 | 33.8 | 8.2 | 8.3 | 5.6 | 8.0 |
| | Western part of the Seto Inland Sea | 363 | 434 | 361 | 456 | 23.9 | 27.4 | 31.4 | 33.8 | 8.0 | 8.2 | 6.1 | 8.2 |
| | Central part of the Seto Inland Sea | 372 | 464 | 355 | 673 | 14.3 | 28.7 | 31.6 | 33.4 | 7.9 | 8.3 | 5.1 | 7.6 |
| | Harima Nada | 375 | 432 | 427 | 612 | 25.0 | 28.8 | 29.9 | 32.9 | 8.0 | 8.2 | 5.3 | 8.4 |

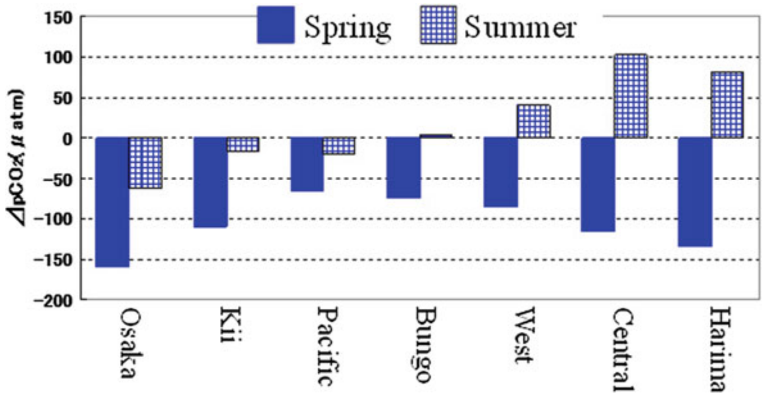


**Fig. 5** Spatial variations of $\Delta pCO_2$ in both seasons

This means that primary production affects $pCO_2$ via $CO_2$ consumption through photosynthesis, and this tendency appears stronger in spring. Osaka Bay has very high DO in both seasons, due to very high primary productivity in this region (Hashimoto et al. 1997). Primary production in Osaka Bay is highest in October, and accordingly, $pCO_2$ in Osaka Bay may be low from spring to early fall. In addition, when water temperature decreases, $CO_2$ solubility (capacity to dissolve) in seawater increases. Therefore, it is likely that the negative $\Delta pCO_2$ in spring in all basins is due to high primary production (causing low $pCO_2$) and low water temperatures (leading to high solubility).

Conversely, primary production is lower, and water temperature is higher in summer. DO and pH in the Seto Inland Sea excluding Osaka Bay drop significantly from spring to summer (Fig. 6). Therefore, it is likely that the positive $\Delta pCO_2$ in summer in the Seto Inland Sea excluding Osaka Bay is due to low primary production (causing high $pCO_2$) and high-water temperature (leading to low solubility). Figure 8 shows the correlation between $pCO_2$ and pH in spring (a) and summer (b).

They are negatively correlated especially in summer ($R = 0.99$). The tendency towards higher $pCO_2$ and lower pH was also observed by Harashima (1997) in Bisan-Seto in July 1994, as shown in Fig. 9a, b and was referred to as a "pH hole".

Because Bisan-Seto is included in the central region in this study, Harashima (1997) supports our results. Based on observations of the whole Seto Inland Sea, Kobayashi and Fujiwara (2006) described the cross-section of the Seto Inland Sea, as shown in Fig. 9c. Vertical mixing dominates at straits and at Bisan-Seto in the Seto Inland Sea (Yanagi 1997), although stratification generally develops in summer. It was presumed that $CO_2$ was supplied from the bottom layer to the surface layer in Bisan-Seto by vertical mixing, which was increased due to the decomposition of organic matter in the bottom layer, and was spread around basin. This is another reason for the positive $\Delta pCO_2$ in summer in the Seto Inland Sea, excluding Osaka Bay.

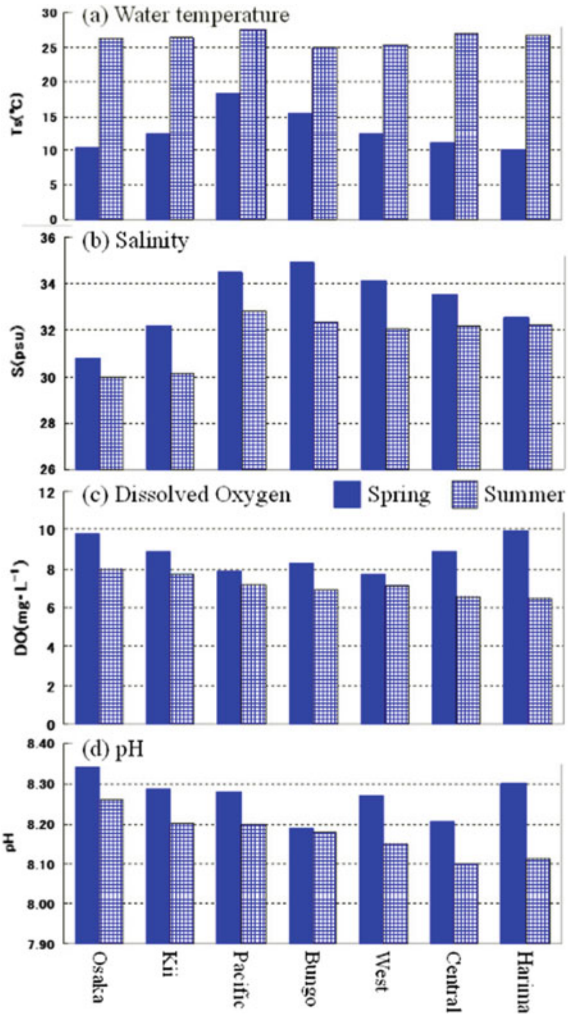


**Fig. 6** Spatial variations of water temperature (**a**), salinity (**b**), DO (**c**) and pH (**d**) in both seasons

$PCO_2$ and $pCO_2$ in Ushimado are shown in Fig. 10. $\Delta pCO_2$ was positive from January to April and negative from June to November. $\Delta pCO_2$ was highest in the fall, and the positive period is longer than the negative period. Therefore, Bisan-Seto may have larger $\Delta pCO_2$ in the fall than in summer.

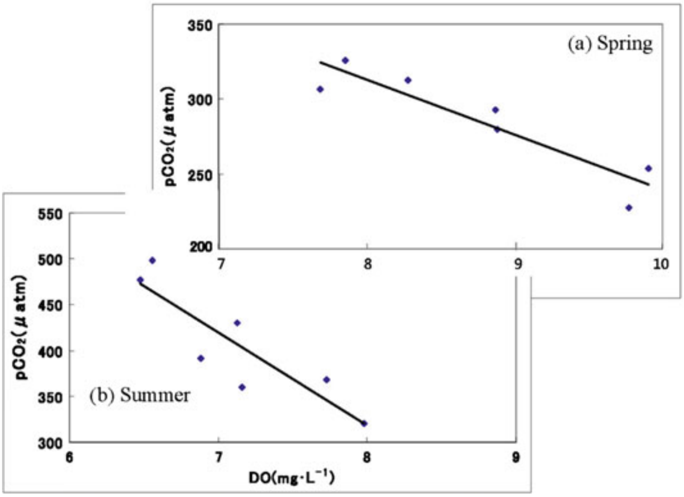


**Fig. 7** Correlation between $pCO_2$ and DO in spring (**a**) and summer (**b**)

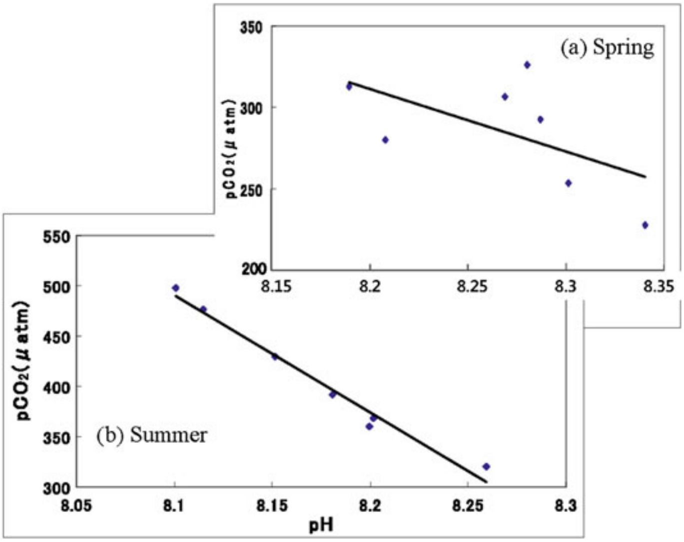


**Fig. 8** Correlation between $pCO_2$ and pH in spring (**a**) and summer (**b**)

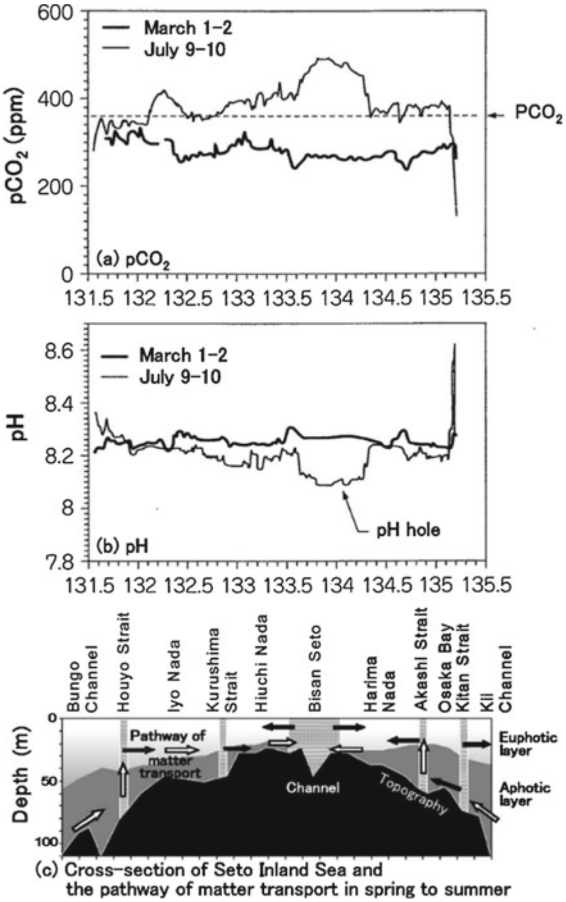


**Fig. 9** Spatial variations of $pCO_2$ (**a**) and pH (**b**) observed using intake water on ferry boat in 1994, and the cross-section of the Seto Inland Sea (**c**). (**a**) and (**b**) were modified from Harashima (1997). (**c**) was modified from Kobayashi and Fujiwara (2006). Arrows in (**c**) show the mean pathways of matter transport in spring to summer based on in situ observations

## 5 Conclusions

Spatial variations in $pCO_2$ in the Seto Inland Sea were studied based on our 16 years of historical in situ data. It is suggested that primary production influences $pCO_2$ in the Seto Inland Sea. A significant net sink for $CO_2$ was also reported in Tokyo Bay (Kubo et al. 2017). Osaka Bay, with its particularly high primary productivity, may also behave as a sink region. Conversely, Bisan-Seto may be a high $pCO_2$ region not only in summer, and provide $CO_2$ to the adjacent basin.

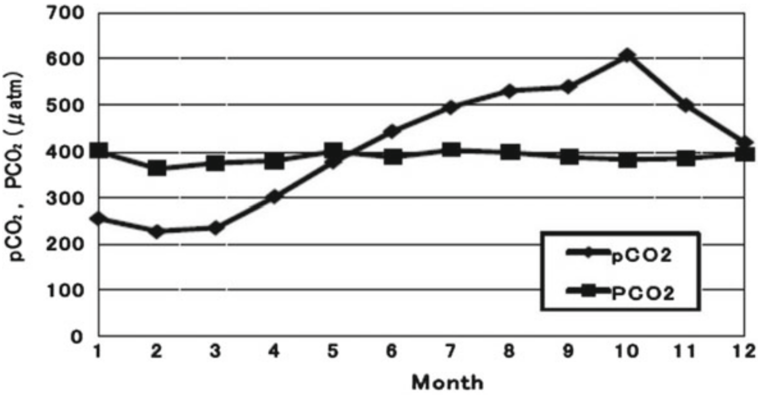


**Fig. 10** Annual variation of $\Delta pCO_2$ in Ushimado indicated in Fig. 1a

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# The Bay of Seine: A Resilient Socio-Eco-System Under Cumulative Pressures

**Jean-Claude Dauvin, Aurore Raoux, Jean-Philippe Pezy, Noémie Baux, and Nathalie Niquil**

**Abstract** The Bay of Seine (Normandy coast of the English Channel) is a highly impacted ecosystem concerned by numerous human activities. It is subjected to heavy historic anthropogenic pressures and the emergence of new human activities: fishing, harbour extension, aggregate extraction, deposition of dredged sediment, and offshore wind farms. By contrast, this area shows a high level of protection of its natural heritage, mainly owing to the Natural Reserve and Natura 2000 sites. Moreover, an accumulation of research projects has ensured the acquisition of a high level of scientific knowledge and high-quality ecological data in this area. However, there is a lack of a systematic approach taking into account the available data. By building maps of benthic habitats, food-web modelling and calculating ecological indicators, we are able to take the first steps towards an ecosystem-based management. These integrative approaches allow us to assess the ecological quality status of the Bay of Seine and the Seine estuary. Trophic models based on the quantification of energy and matter fluxes in ecosystems, as well as indices derived from ecological network analysis, are used to describe the interaction between species across all trophic levels. When applied to spatial models, ecological functioning and ecosystem health can be assessed in different areas of the ecosystem. In the Bay of Seine, benthic habitats display high resilience while pelagic, fish and bird compartments have been shown to be highly modified, due to hydrological and climatic changes. The North Channel and the Navigation Channel of the Seine estuary appear to be far more intensely stressed, while the South Channel and marine areas of the Bay show a more mature functioning. Our conclusions reveal the need to consider the influence of human pressures on the functioning of complex ecosystems, thus providing an integrated approach that can be used to study a social-ecological system affected by global changes and investigate the cumulative impacts of human activities.

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**Keywords** Bay of Seine · Cumulative pressures · Resilience · Climatic change · Trophic models

# 1 Introduction

The Bay of Seine, located on the Normandy coast of France in the eastern part of the English Channel, covers an approximately quadrilateral area of ~5000 km$^2$. The Bay is largely open in the north to the influence of Atlantic waters, while the south-eastern part is affected by the input of freshwater from the Seine (Fig. 1). The Seine River has a mean annual discharge of ~410 m$^3$ s$^{-1}$, with peak flows exceeding 2200 m$^3$ s$^{-1}$. The mean annual transport of suspended particulate matter is estimated at ~6 $\times$ 10$^5$ t year$^{-1}$. The water depth in the Bay does not exceed 30 m, and a macrotidal regime (tidal range of up to 7.5 m at Le Havre) generates tidal currents averaging between 1 and 2 knots in its southern sector (Salomon and Breton 1991, 1993). These currents play an essential role in the distribution of superficial sediments (Larsonneur et al. 1982) as well as benthic communities (Gentil and Cabioch 1997; Dauvin 2015). Lesourd et al. (2001, 2016) mapped sedimentary facies in the eastern part of the bay, before and after the construction of Port 2000 (2002–2005) in the North Channel of the Seine estuary. There is a sedimentary gradient from offshore gravel and coarse sand to inshore fine sands and silty/muddy fine sands in the estuary. Since the mid-nineteenth century, sediment distribution has changed from a sand/gravel system to

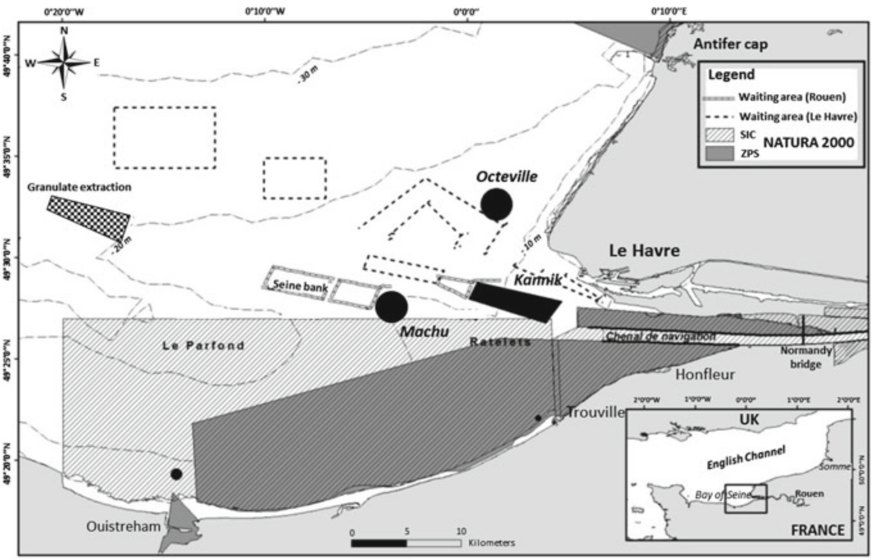


**Fig. 1** Map of the eastern Bay of Seine with bathymetry, showing locations of existing and future human activities as well as limits of the Natura 2000 sites, Natural Reserve of the Seine estuary and marine harbour waiting areas

the muddy depositional system prevalent at the beginning of the twenty-first century (Lesourd et al. 2016). Recent morpho-sedimentary changes have been observed in the North Channel in relation to the building of the extension of Le Havre harbour (Port 2000), leading to the increased abundance of heterometric sediment and a patchy distribution of several facies covering very small areas (Cuvilliez et al. 2009; Lesourd et al. 2016).

The construction of Port 2000 and the dredging of the Rouen navigational channel (2010 to present) represent the most recent management developments of the Seine estuary, which began in 1850, by the construction of the first dykes. The successive phases of management to facilitate maritime transport up to Rouen, which is located 120 km upstream from the mouth of the Seine, together with the increase in vessel size and fishing activities over the whole Bay of Seine, have contributed to the decline in Dover sole and brown shrimp fisheries in the eastern part of the bay. New human activities are also being developed, such as the current granulate extraction and the future implementation of the Courseulles-sur-Mer offshore wind farm that could also contribute to the degradation of the ecological status of the Bay of Seine.

In their review, Halpern et al. (2008) pointed out that the North Sea and English Channel, especially its eastern Basin (Dauvin and Lozachmeur 2006; Dauvin 2012), is among the coastal marine zones where cumulative human impacts have the greatest influence, at the scale of the worldwide ocean. Thus, the Bay of Seine is one of the areas in the North-Eastern Atlantic and European seas that is most impacted by human activities. However, in spite of the accumulation of human pressures, this area remains important [for the natural environment] due to its ecological functions, such as providing major flatfish and sea bass nurseries, and its role in the foraging of birds leading to a high biodiversity (Dauvin and Desroy 2005).

## 2 One Hundred Seventy Years of Anthropogenic Pressures

Anthropogenic influence in the Seine estuary began in the mid-nineteenth century and continues to the present day. The successive construction of embankments and dykes from Rouen to the sea, as well as in Le Havre Harbour and including Port 2000, in addition to permanent dredging, has led to an extreme compartmentalization of biological units in the estuary ecosystem and a drastic reduction of the intertidal zones downstream, with a loss of more than 100 km$^2$ between 1850 and the present day (Hamm et al. 2001; Dauvin 2006; Cuvilliez et al. 2009).

Due to the regular maintenance and permanent dredging of the Navigation Channel, mainly in the lower part of the Seine estuary between the Normandy Bridge and the open sea, as well as in the harbour basins of Le Havre, the port authorities of both Rouen and Le Havre are obliged to deposit dredged fine sediment (mainly sand and mud) in dumping zones offshore. Until 2016, Rouen dredged between 4 and 4.5 million m$^3$ of sediment spoil per year, which was dumped on the disposal site called Kannik, commissioned in 1977 in the North Channel of the Seine estuary. At present, this spoil is dumped in the offshore Machu area (Fig. 1) (Marmin et al. 2014, 2016). Moreover, the authorities dredge between 2 and 2.5 million $m^3$ of sediment each year in the harbour basins of Le Havre and deposits this material in an offshore dumping zone named Octeville (Fig. 1) (Marmin et al. 2014).

During the twentieth century, the physico-chemical conditions have steadily deteriorated. By the 1980s, the estuary was highly contaminated: levels of contamination in metals (e.g. Cd and Hg), hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) were among the highest in the world, and insufficient/inadequate water treatment facilities created oxygen deficits downstream of Rouen (Fisson 2014). However, the recent reduction in discharges, developments in the treatment capacities of effluents and changes of agricultural and industrial practices have begun to lead to some improvement. There has been a decrease in contamination by micro-pollutants, mainly metals, organochlorine compounds, PCBs and several nutrients such as phosphorus and ammonia, and microbiological contamination has also declined (Fisson 2014). Nevertheless, the most significant hazard nowadays arises from chemical and microbiological sources, such as pharmaceutical products and antibiotic-resistant bacteria in the water, and from contamination stored in sediments, which is mainly represented by metals and PCBs (Fisson 2014; Petit et al. 2014).

Another anthropogenic constraint in the Bay of Seine is a granulate extraction, not only offshore (>40 m depth), but also in shallow-water areas (<20 m) in the eastern part of the Bay of Seine near the navigational channels of Le Havre harbour (Fig. 1). All the concession zones are located in the Seine paleo-valley consisting of a mixture of medium to coarse siliceous sands, with gravel and some reworked siliceous pebbles; the authorized duration of extraction is 25–30 years for 25–30 million $m^3$ per concession (Duclos 2012).

Maritime transport (and its associated practice of ballast water release) and aquaculture, mainly concerning the oyster *Crassostrea gigas* in the south-western of Bay of Seine, play a role in the introduction of non-native species (NNS). Baffreau et al. (2018) reported a total of 139 NNS along the Normandy coast, most of them being recorded in the Bay of Seine, with first sightings in the Le Havre harbour basins. Among these NNS, 54 species come from the seas off Japan and are now present in 48 established populations (Dauvin et al. 2019). The crabs, *Hemigrapsus sanguineus* and *H. takanoi* originating from the north-western Pacific, have changed the dynamics and functioning of the rocky shore ecosystems. In these habitats, both of these crab species make up abundant populations and could be a problem for the development of oyster and mussel aquaculture since they are known to be predators of young bivalves.

## 3 An Accumulation of Scientific Programmes and Data Over 50 Years

In the estuary and the Bay of Seine, there has been an accumulation of data acquired by successive scientific programmes since the first *Schéma d'Aptitude et d'Utilisation* *de la Mer* (SAUM) programme at the beginning of the 1970s. Then, during the two decades from 1980 to 2000, French national programmes led to an integration of research at the scale of the whole Bay of Seine: *the Baie de Seine programme* (Cabioch 1986), the *Programme National d'Océanographie Côtière* (PNOC), the *Programme National d'Environnement Côtier* (PNEC), the *Programme National d'Ecotoxicologie* (PNETOX) and the *Programme National des Zones Humides* (PNZH) (Guézennec et al. 1999; Dauvin and Desroy 2005; Dauvin 2006, 2011; Dauvin et al. 2009). In 1995, the scientific programme "Seine Aval" was set up to increase our knowledge of the Seine estuary, from the Poses dam in the upstream part of the estuary to the eastern part of the Bay of Seine, and propose a plan for management of the estuary for the main stakeholders in the region (Dauvin 2006; Dauvin et al. 2009). The *Groupement d'Intérêt Public Seine-Aval* (GIP SA) was created several years later as an intermediary structure between the scientific teams and the stakeholders, with the aim of applying scientific results to the management of the Seine estuary (Dauvin et al. 2009). The GIP SA also has a mission to archive all the data acquired in the Seine estuary. However, in spite of these programmes and structures, there is currently no global management plan for the Seine estuary (Dauvin 2011).

## 4 A Resistant and Resilient Ecosystem

Despite the diverse environmental problems encountered in the Seine estuary, it is nevertheless still a highly favourable habitat for the juveniles of numerous fish species, and the ornithological richness is one of the major positive aspects of the estuary's natural heritage (Dauvin and Desroy 2005; Dauvin 2011). The Seine estuary plays an important trophic role as a nursery for young fish, especially for sea bass and flat fish (Le Pape et al. 2003, 2007), and offers feeding areas for birds, especially on the tidal mud flats (Dauvin and Desroy 2005). Various Natura 2000 sites border the Seine estuary, and this network has recently been extended outside the estuary along the Calvados coast (Fig. 1). The richness of this natural heritage can be judged by the profusion of regulatory measures and inventories that have sprung up over the years (Alard 2002). The different fish communities, as well as their spatial distribution, appear to be persistent over time, reflecting the relative stability of environmental conditions in this area. However, species diversity in the eastern sector of the EC appears to have increased over the last two decades (Vaz et al. 2007). In the Bay of Seine, there is an important fishery of the scallop *Pecten maximus*, based on stocks that are managed in partnership between fishermen and the French research institute IFREMER. Fishing for brown shrimp (*Crangon crangon*) is a traditional activity carried out with small-meshed trawling nets, taking place in the estuary in summer and along the coast of Calvados in winter and spring. Although stocks have been decreasing dramatically with time, this fishery remains active for the ports of Le Havre, Honfleur and Trouville (Dauvin 2006).

## 5 The Need to Synthesize the Overload in Information

The accumulation of data in the estuary and Bay of Seine appears very useful for the application of European Directives, such as through the Natura 2000 network, as well as in the context of the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD), to assess the ecological status of coastal and estuarine water masses and the ecological quality status of the Bay of Seine.

### *5.1 Mapping of Benthic Habitats*

First of all, the establishment of benthic marine habitat maps plays an important role in the conservation and management of coastal ecosystems faced with increasing human activities. In the framework of French government action, an inventory of 'Natural Zones of Interest for Ecology in terms of Flora and Fauna' (ZNIEFF) was set up in the 1980s and applied to the marine areas of Normandy in the 2010s (Baffreau et al. 2017). This action consisted of identifying marine areas with heritage interest, which were delimited based on scientific knowledge and the available data on fauna and flora. For the Bay of Seine, the benthic community maps (Bay of Seine, with particular attention paid to the south-eastern and south-western parts of the bay) were based on the European EUNIS habitat classification system (Baffreau et al. 2017). While the ZNIEFFs are not part of the legal management tools, they identify zones with high natural heritage potential, species richness and crucial importance for ecosystem functioning.

### *5.2 Modelling of Trophic Networks*

Another integrative approach involves the modelling of trophic networks. Various modelling studies related to the Seine estuary and the Bay of Seine have been implemented during the two last two decades for different periods and spatial compartments (Fig. 2). Rybarczyk and Elkaïm (2003) used the Ecopath model to make a first estimation of trophic flows for the whole Seine estuary over the years 1996–1999. Their results show a highly productive ecosystem under stress, but which is more dependent than other estuaries on external sources of organic matter such as river discharge.

Subsequently, Tecchio et al. (2015) applied ecological network analysis (ENA) to the Seine estuary by incorporating ecological data from the years 1996 to 2002. The same Ecopath approach was used to model the trophic flows in six spatial compartments leading to six distinct models: the Navigation Channel, the North and South Channels and three marine habitats in the eastern part of the Bay of Seine (Fig. 2). Results show that the North and Central Navigation Channels show a

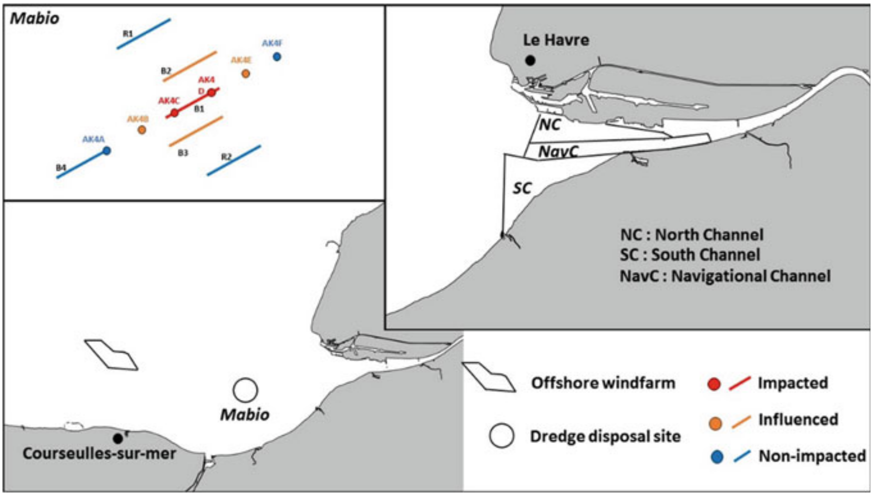


**Fig. 2** Map of the eastern Bay of Seine and the Seine estuary, northern France, showing the zones and subdivisions of the Ecopath modelling application

functioning related to a high level of stress, in areas where the construction of Port 2000 and the constant dredging are considered as major anthropogenic stressors. In the inner estuary, the South Channel shows the highest system activity (high value of total system throughput), high trophic specialization (with low system omnivory) and the lowest indication of stress (low cycling and relative redundancy). Marine habitats yield higher transfer efficiencies per trophic level than the estuarine habitats.

Tecchio et al. (2016) modelled the trophic web before and after Port 2000 construction for the North Channel (2002–2005), analysing the dynamics of the three inner estuarine habitats of the Seine estuary (North, South and Navigation Channels; Fig. 2). These authors used a Linear Inverse Modelling technique (LIM-MCMC) to estimate flows in the food web, together with their range of uncertainty. ENA indices were also calculated, summarizing ecosystem functioning traits and giving indications about the health status of the three habitats. Again, results show that the South Channel is the least stressed habitat of the estuary: the system activity and functional specialization of flows remain stable between periods, while ecosystem recycling processes and detrital dynamics are also stable; the only change is an increase in trophic specialization (decrease in system omnivory), confirming a general ecological succession. The North Channel has a food web reflecting the increased importance of lower trophic levels (increased detritivory and carbon recycling), increased stability and flow efficiency, but shows a possible regression to a previous stage in the ecological succession. Finally, the functioning of the Seine estuary has been modified by the combination of harbour construction and related mitigation measures (Hamm et al. 2001). ENA appears to be an interesting approach to describe the functioning of ecosystems in the Seine estuary and distinguish stressed from unstressed situations in transition water masses. However, the use of ENA has not been unequivocally demonstrated as able to discriminate natural from anthropogenic stresses, which would allow us to address the Estuarine Quality Paradox (Dauvin 2007, Niquil et al. 2012). Since estuaries are naturally stressed systems, the relationships between functioning and stress, which are mainly based on marine ecosystems, need to be redefined in this particular context (Tecchio et al. 2016).

Raoux et al. (2017, 2018) have applied an Ecopath with Ecosim (EwE) approach to trophic web modelling of the future Courseulles-sur-Mer offshore wind farm. Special attention was paid to commercial species by assigning them to monospecific compartments. This is because one of the main challenges of wind farm implementation will be the possibility of continuing fishery activities in the surrounding area. Three scenarios were simulated: (1) a reef effect due to the installation of a hard substratum on coarse sands and gravels habitats, established from observations on existing wind farms, (2) a reserve effect associated with the local optimized strategy of authorizing fisheries along the turbine alignments as well as fishing restrictions on 15% of the surface area of the farm and (3) a combination of both effects. For each model (before offshore wind Farm and the three future scenarios), energetic flows were quantified before and 30 years after the offshore wind farm construction using EwE, and then the food web was characterized based on the ENA indices. The main conclusion of this multi-modelling study is that the food web is controlled by an intermediate trophic level dominated by the keystone species: the pouting (*Trisopterus luscus*). Furthermore, analysis of the three model scenarios reveals that the dominant influence of the offshore wind farm would be the reef effect, due to the massive arrival of blue mussels and associated species on the hard substrate (Raoux et al. 2017). This anticipated increase in mussel biomass after the offshore wind farm construction is predicted to lead to a detritivory-dominated food web and an increase in benthic invertebrate and benthos-feeding fish biomasses in response to the reef effect (Raoux et al. 2017, 2018).

Assuming that dumping operations represent a stress for a given ecosystem, the ENA approach is used here on the Machu experimental deposition zone in the eastern part of the Bay of Seine (Figs. 1 and 2), to test the efficiency of modelling to detect functional changes of benthic habitats subject to dredge spoil deposition (Pezy et al. 2017). In 2012–2013, experimental dumping operations were carried out at the Machu site, followed by a before-after-control impact approach (Marmin et al. 2014, 2016) to improve our understanding of the impact of the dumping of sediments dredged from the Navigation Channel on the morpho-sedimentary seabed and medium sand benthic habitats. Trophic flows are modelled for two periods: before (2010–2011) and after (2013–2014) the experimental operations. Results show that the fish biomass increases after the dumping operations, while invertebrate biomass remained relatively stable through time. Nevertheless, some increases are observed in the biomasses of benthic invertebrates, omnivores/scavengers and predators, while non-selective deposit feeders and filter feeders show a decline. At the ecosystem level, the results from trophic network modelling indicate that the total ecosystem activity, the ascendency and the overall omnivorous character of the food-web structure increased after dumping operations, whereas recycling subsequently decreased. Finally, the Machu zone, which undergoes regular natural physical perturbations, shows a high resilience after a short dumping phase. In a second step, Pezy et al. (2018) modelled trophic flows using Ecopath for the 2012–2013 deposition phase and distinguishing impacted and influenced zones from the non-impacted zone. Moreover, a combination of indices (BO2A, AMBI benthic indices) and modelling tools was also applied to study the impact of dredge spoil dumping over one year (1 million $m^3$ dumped in four deposition phases of 250,000 $m^3$, each lasting three months). Results show that indices, including the Finn's cycling index (FCI), can be used to detect the effects of dumping operations which lead to an increase in cycling (Table 1). In addition, indices reveal that the system exhibits a high resilience after a short dumping phase. Lastly, the macrofauna and demersal fishes appear to be stimulated in the influenced zone during the dumping phase, thus supporting the intermediate disturbance hypothesis (Pezy et al. 2018).

As an example of ENA, showing the observed effects of the different impacts studied, Table 1 gives the FCI values which correspond to the percentage of all flows generated by cycling. We find that high values of FCI would be obtained after the offshore wind farm construction (reef effect) as well as in the Navigation Channel and in the North Channel of the Seine estuary, which are known as highly impacted areas (Dauvin and Desroy 2005; Marmin et al. 2014; Tecchio et al. 2015) where ecosystem functioning is related to a stressed state (Tecchio et al. 2015). In addition, a high FCI value is also observed in the influenced zone of the Mabio clumping site, in the area undergoing the most change after sediment deposition (Pezy et al. 2018). Thus, this increase in FCI can be interpreted as the response to stress after either the installation of offshore wind farms or dumping operations. In fact, under conditions of stress, cycling can act as a buffer during the perturbation and thus increase the ability of the system to resist changes (Saint-Béat et al. 2015).

**Table 1** Finn's cycling index values, giving percentage of flows generated by cycling as an indicator of stress (an increase in carbon recycling can be interpreted as a response to stress) for different models constructed in the eastern Bay of Seine and Seine estuary (From Tecchio et al. 2015; Raoux et al. 2017, 2018; Pezy et al. 2018)

| Ecosystems | | FCI (%) | Stress Gradient | References |
|---|---|---|---|---|
| Seine estuary | South Channel | 4 | ▲ | Tecchio et al. (2015) |
| | Navigation Channel | 9 | | |
| | North Channel | 19 | | |
| Mabio Dumping experiment | Control area | 9 | ▲ | Pezy et al. (2018) |
| | Impacted area | 9 | | |
| | Influenced area | 13 | | |
| Bay of Seine Project of offshore wind farm | Before oWF construction | 9 | ▲ | Raoux et al. (2017, 2018) |
| | Reef effect | 13 | | |

One of the scientific challenges to understanding human pressures in coastal ecosystems is to take into account the cumulative impacts of such activities including socio-ecological factors. Raoux et al. (2018) proposed a first approach in the Bay of Seine based on a qualitative modelling technique using oriented di-graphs (Levins 1966, 1998; Puccia and Levins 1985). This approach constructs networks of ecosystem and human variables, as well as their positive and negative interactions, without attempting to quantify the strength of these interactions (Dambacher et al. 2015). Raoux et al. (2019) use this approach to model the cumulative impacts of fisheries, climate change and the future offshore wind farm at Courseulles-sur-Mer. This type of combined model is a promising tool to elucidate the direct or indirect effects on local populations or actors and help overcome residual environmental concerns and social conflicts while increasing acceptance.

## *5.3 Development of Indicators of Ecosystem Health Based on Functioning of the Trophic Network*

Another major challenge in coastal management is to find simple methods to evaluate the health of complex ecosystems, i.e. their ecological quality status. The development of appropriate indicators and evaluation tools has mainly occurred in response to WFD and MSFD implementation or for the OSPAR convention (Rombouts et al. 2013a; Niquil et al. 2014; Arroyo et al. 2017). By combining the structural and functional attributes of the system, along with modelling outputs integrating the biological and physical environments, we can illustrate the usefulness and complementarity of methods for assessing ecosystem health (Rombouts et al. 2013b). Nevertheless, the choice of relevant indicators depends on the ecological questions raised as well as the biological and habitat components considered, which can range from a single level (individual or population) to multiple levels (community or ecosystem-based indicators) in the ecosystem (Rombouts et al. 2013b). The combination of ecological attributes and tools should be used to improve our knowledge and assessment of marine ecosystems for better management and conservation in future (Niquil et al. 2018).

Nevertheless, most benthic indicators were developed to assess the impact of increasing organic matter on species placed together in ecological groups (Borja et al. 2000; Dauvin et al. 2012, 2016). Nowadays, research in benthic ecology is focused on developing specific indices corresponding to a particular human activity. In this context, a Dredge Spoil Disposal (DSD) Index based on the selection and scoring of species between impacted and unimpacted stations has been developed and tested on the Machu site in the eastern part of the Bay of Seine (Fig. 1) (Dauvin et al. 2018). Based on a BACI approach (before, after, control and impact), the DSD index responds rapidly to a succession of periods with or without dumping. Some macrofauna species appear adapted to survive after a given disposal phase, while others colonize rapidly by adult drifting. Still others are sensitive and remain absent on soft-bottom habitats throughout the dumping period. The relevance of the DSD index is being tested on two other spoil disposal sites (Octeville and Kannik) in the eastern part of the Bay of Seine (Fig. 1), before seeking a wider application.

## 6 Towards an Ecosystem-Based Management

In 1992, during the United Nations Conference on the Environment and Development held in Rio de Janeiro, the international community established the concept of 'Integrated Coastal Zone Management (ICZM)' (http://www.un.org/Depts/los/consultative_process/documents/A21-Ch17.htm). This concept is based on six principles, which could be applied in the implementation of an integrative ecosystem vision of the global management plan for the Seine and Bay of Seine (Dauvin, 2011). (1) Spatial integration of the management of the continuum from freshwater to seawater. (2) Administrative and institutional integration with adapted governance. (3) Integration of all human activities those are located in the territory, in order to assess the cumulative effects of such human pressures. (4) Temporal integration of management objectives, not only in the short term but also in the long term: aggregate concessions, offshore wind farms being installed for a long duration (25–30 years) and ecosystem modifications due to climate change on the same long-timescale (30–50 year). (5) Environmental integration, which covers various sectoral policies (agriculture, waste, water, natural heritage, industry, tourism, physical planning, maritime transport, etc.). (6) Integration between science and management, as well as between the various scientific disciplines.

The global ecosystem-based management of a large territory would not aim to take the place of politics in sectoral projects, but rather provides a framework for coordinating these actions in the perspective of sustainable development with a single governance and project holder.

Several drawbacks may explain the absence of any unified vision of the Seine Bay-estuary system (Desroy et al. 2004; Dauvin 2011). There are multiple actors involved with various different laws and procedures on the European, National and Regional levels, and a single authority is lacking (Glegg et al. 2015). As a result, the vision for an ecosystem-based management of both the estuary and the Bay of Seine, and not simply juxtaposition, is more established at the regional and European level than at the national level. Nevertheless, to face the challenges for the sustainable development of this territory, a common vision between all the authorities may be required to adapt the future management of this estuarine and marine space impacted by climate change and increasing human pressures (e.g. granulate extraction and new offshore energies, such as wind farms and hydraulic systems). In future, studies of the cumulative effects of human pressures (Halpern et al. 2008) should be promoted to cover both the Bay of Seine and the Seine estuary. This subdivision of the territory appears to be a coherent level of ecosystem-based management, which would be sufficiently efficient to establish a degree of independence between the western and eastern systems. Suitable monitoring programmes need to be established, not only to respond to the obligatory laws and procedures, but also useful for the scientific understanding of the impact of particular activities in the context of global change (Pezy et al. 2019). «*Mieux on observe, mieux on comprend et… mieux on gère*». «The better we observe, the better we understand and the better we manage». This slogan is highly relevant in the context of the global management of this complex and strongly anthropized ecosystem, where new human activities will emerge over the next few decades.

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# Effect of Bacterial Infection on the Expression of Stress Proteins and Antioxidative Enzymes in Japanese Flounder

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**Abstract** Stress induced by environmental stimuli, such as pollutants and infection, in fish is thought to influence their fitness. Bacterium *Edwardsiella tarda* is a virulent intracellular pathogen of commercial fish species. Edwardsiellosis caused by *E. tarda* is one of the most severe diseases in Japanese flounder *Paralichthys olivaceus*. However, little is known about the effect of bacterial (such as *E. tarda*) infectious-induced stress on the expression of stress proteins and antioxidative enzymes in fish. In the present study, we examined the expression of heat shock protein (HSP) 70 and superoxide dismutases (SODs) in the hepatopancreas of Japanese flounder in response to *E. tarda* infection. HSP70 expression was rapidly increased and was significantly higher in fish 48 h after being infected with *E. tarda*, compared to that in control fish. The expression level of Cu, Zn–SOD in infected fish increased from 24 to 48 h and peaked at 48 h post-infection. On the other hand, the expression level of Mn–SOD in infected fish gradually increased from 12 h post-infection and remained high between 24 and 48 h post-infections. The changes in expression levels of HSP70 and SODs are suggestive of reactive oxygen species-induced oxidative stress in Japanese flounder. The results also suggest that both HSP70 and SODs play roles in mediating immune response upon *E. tarda* infection in Japanese flounder. We hypothesize that these proteins are important factors that protect cells against oxidative stress.

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**Keywords** Bacterial infection · *Edwardsiella tarda* · Oxidative stress · Japanese flounder

## 1 Introduction

Farmed fishes are often exposed to various local and global environmental stressors, such as pollutants and acute changes in temperature, and the chances of succumbing to infectious diseases may be increased as a result (Barton and Iwama 1991; Iwama et al. 2006; Nakano 2011, 2016, 2020). Therefore, the stress induced by environmental stimuli in fish is thought to influence their fitness. *Edwardsiella tarda* is a gram-negative, motile, facultatively anaerobic, non-spore forming, virulent, and intracellular bacterial pathogen that can infect multiple cell types. *E. tarda* has been isolated from many organisms such as fishes, turtles, frogs, birds, and mammals. However, fish appears to be most susceptible to *E. tarda* infection compared to other animals. Edwardsiellosis caused by *E. tarda* is one of the most severe diseases in Japanese flounder *Paralichthys olivaceus*, red sea bream *Pagrus major*, and Japanese eel *Anguilla japonica*, and is characterized by skin lesions, formation of abscesses and granulomas in internal tissues such as liver and kidney (Aoki et al. 1996; Kanai et al. 1988; Kusuda and Salati 1993; Sakai et al. 2004; Xu and Zhang 2014). Japanese flounder is an important species for aquaculture in Japan and highly valued fish for consumption. *E. tarda* infection causes huge economic loss in Japanese flounder farming. Although Edwardsiellosis has been studied for many years, effective treatments to cure fish infected with *E. tarda* are limited (Xu and Zhang 2014), as most antibiotics are not effective against *E. tarda*. Research is underway to establish effective procedures and methods to protect Japanese flounder against *E. tarda* infection in aquaculture.

Reactive oxygen species (ROS) are some of the strong oxidants that are produced in the bodies of fish. ROS is important for immunity in both mammals and fish, and are involved in the killing of invading pathogens (Nakano 2007, 2011, 2016, 2020; Nakano and Takeuchi 1997; Takeshige and Mizukami 1987). However, excessive ROS generation attacks almost all host-cell components such as proteins, lipids, and membranes, and hence is undesirable. Aerobic organisms have developed both chemical and enzymatic defence systems to protect against the toxicity caused by ROS. Antioxidative enzymes such as superoxide dismutases (SODs), glutathione peroxidase, and catalase scavenge free radicals, and contribute to the antioxidative defence system. SODs play a key role in the first step of enzymatic antioxidative defence response. SODs are classified into three main types depending upon the metals found in their active site-copper and zinc (Cu, Zn–SOD), manganese (Mn–SOD), and iron (Fe–SOD). Cu, Zn–SOD is predominantly found in the cytosolic fraction in eukaryotes. Mn–SOD is associated with mitochondria and prokaryotes, while Fe–SOD is found exclusively in prokaryotes (Nakano 1987; Nakano et al. 1993, 1995; Nakano and Takeuchi 1997; Oyanagui 1989; Wang et al. 2011; Zelko et al. 2002).

Organisms often respond to stress by exhibiting biochemical and physiological changes. Stress responses have been classified into three categories—primary, secondary and tertiary responses (Barton and Iwama 1991; Iwama et al. 2006). The primary response represents the perception of an altered state and initiation of a neuroendocrine response. This response includes the rapid release of stress-related hormones such as cortisol and catecholamines into blood. The secondary stress response is composed of the various biochemical and physiological changes associated with stress, and is mediated by several stress hormones. Conversion of glycogen to glucose in response to stress assists the animal by providing energy substrates to tissues, to cope with the increased energy demand. The tertiary stress response represents whole-organismal and population-level changes associated with stress. The characteristic feature of cellular stress response is the induction of a family of stress proteins known as heat shock proteins (HSPs), which are highly conserved in all animals and plants. Extensive studies on model organisms have revealed three major families of HSPs such as HSP90, HSP70, and low molecular weight HSPs. In the unstressed cell, there is constitutive production of heat shock cognate (HSC) proteins. Exposure to stress can often affect organismal performance parameters such as growth, immune response, resistance to diseases, liver function, and reproductive success (Basu et al. 2001, 2002; Bonga 1997; Charmandari et al. 2005; Hochachka and Somero 2002; Iwama et al. 1998, 1999, 2006; Mitani 1997; Nakano 2011, 2016, 2020; Nakano et al. 1999a, 2013, 2014, 2018; Roberts et al. 2010; Tort 2011; Yamashita et al. 2010). However, little is known about the effect of bacterial infection-induced stress on the expression of stress-related functional proteins, such as stress proteins and antioxidative enzymes, in fish. Understanding of stress-related functional proteins and their expression pattern in the course of disease is important to determine strategies for disease control (disease resistance) of fish in aquaculture.

In the present study, we examined the expression of HSP70 and SODs in the hepatopancreas of Japanese flounder, where *E. tarda* grows vigorously after infection (Osatomi et al. 2002; Xu and Zhang 2014). We directly measured the expression of these proteins in fish with immunoblotting following bacterial challenge. This is because measurement of mRNA expression might not accurately reflect expression of proteins. On the other hand, proteomic analysis should identify actual protein expression level. We have discussed the relationships between infection-induced stress and the physiological states in fish in the context of our findings.

## 2 Materials and Methods

### *2.1 Fish*

Japanese flounder were raised in tanks supplied with running seawater at 28 °C in Nagasaki Prefectural Marine Station's Aquarium Facility. The fishes were fed into apparent satiation twice a day with commercial feed (Higashimaru, Japan). Healthy, mixed sex, fishes were randomly divided into two groups in circular 200-L polycarbonate tanks and allowed to acclimatize for at least one week before experimental treatment. All the protocols of fish treatment were performed according to the Regulation of Animal Experimentation of Nagasaki University.

### 2.2 Bacterial Challenge and Tissue Sampling

Bacterial challenge experiment was conducted according to the method described previously (Osatomi et al. 2002). *E. tarda* NUF251 isolated from diseased Japanese flounder (Kanai et al. 1988; Osatomi et al. 2002) was incubated with agar medium at 27 °C for 24 h. NUF251 culture was diluted in phosphate-buffered saline (PBS, pH 7.2) and the final concentration was set to $1.5 \times 10^4$ colony-forming units (cfu) $mL^{-1}$. Before injection, fishes weighing approximately 111.5 g were anaesthetized with 100 mg/L tricane methane sulfonate (MS-222). Fishes were infected by intramuscular injection with 0.2 mL bacterial suspension per 100 g body weight for the challenge experiment. For the controls, fishes were injected only with PBS. All fishes were maintained under quiet and suitable natural photoperiod conditions. Food was withheld during bacterial challenge. At 0, 6, 12, 24, and 48 h post-infections, four fishes were randomly anaesthetized with MS-222 from each of two groups and rapidly team-sampled for tissues. All tissues were stored at −80 °C until further analyses.

Bacterial concentration was confirmed by determining the cfu per mL by plating 0.1 mL of serial tenfold dilutions onto agar plates (Nissui, Japan) (Osatomi et al. 2002).

### 2.3 Measurements of HSP70 and SODs Levels

Levels of HSP70 and SODs were measured using SDS-polyacrylamide gel electrophoresis (SDS-PAGE) and immunoblotting (western blot) as described previously (Basu et al. 2001; Nakano et al. 2014, 2018). Molecular weight markers (Bio-Rad Laboratories, Hercules, CA, USA) and tissue protein samples from control fish taken at 0 h post-injection were added to every gel to normalize the data. Equal amount of protein were loaded on the gels enabling direct comparison between different protein samples in the gel. Following electrophoretic separation, the proteins were transferred onto nitrocellulose membranes for immunoblotting. Primary antibodies used were mouse anti-bovine HSP70 monoclonal (Sigma-Aldrich, St. Louis, MO, USA), rabbit anti-human Cu, Zn–SOD polyclonal (StressMarq Biosciences, Victoria, BC, Canada), and rabbit anti-human Mn–SOD polyclonal (StressMarq Biosciences, Victoria, BC, Canada). Secondary antibodies used were affinity-purified goat anti-mouse IgG (H + L) alkaline phosphatase conjugated (SouthernBiotech, Birmingham, AL, USA) and goat anti-rabbit IgG (H + L) peroxidase conjugated

(FUJIFILM Wako Pure Chemical, Osaka, Japan). Monoclonal antibody for HSP70 used in this study was confirmed to recognize both constitutive type (HSC70) and inducible type (HSP70), by western blotting (data not shown). Accordingly, total levels of HSC70 and HSP70 were considered as HSP70 levels in this study.

Sample protein content was determined by DC Protein Assay Reagents Kit (Bio-Rad Laboratories, Hercules, CA, USA) using bovine serum albumin as a standard.

### *2.4 Statistical Analysis*

Results are reported as mean ± SEM. All data were subjected to one-way analysis of variance (ANOVA). Multiple comparisons between groups were made by the Tukey-Kramer test and results were determined statistically significant at $p < 0.05$.

## 3 Results

### *3.1 Bacterial Challenge*

Edwardsiellosis was developed in the infected fish in a manner similar to our previous report (Osatomi et al. 2002). *E. tarda*-injected fish showed clinical signs of disease and *E. tarda* was detected in hepatopancreas 48 h post-infection. Total number of bacterial population in the hepatopancreas of infected fish was significantly higher at 48 h post-injection compared to the sample obtained at 24 h post-injection. No mortality was observed in either control fish injected only with PBS or infected fish during the experiment.

### *3.2 HSP70 Expression Level*

Western blot analysis indicated that HSP70 (total HSP70 and HSC70) was ubiquitously expressed in multiple tissues of uninfected healthy Japanese flounder. The highest level of HSP70 expression was observed in the brain, followed by hepatopancreas, stomach, gill, heart, spleen, kidney, and muscle (data not shown).

The effect of *E. tarda* infection on HSP70 expression in hepatopancreas of Japanese flounder is shown in Fig. 1.

The expression level of HSP70 in infected fish remained unchanged between 0 and 12 h, and then increased at 24 and 48 h post-infections. At 48 h post-infection, rapid elevation of HSP70 expression was observed in infected fish. The expression level of HSP70 in infected fish at 48 h post-infection was significantly higher than that in infected fish at 0, 6, and 12 h post-infections.

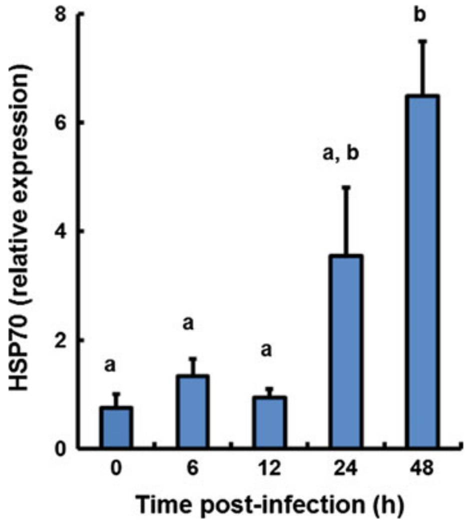


**Fig. 1** Effect of bacterial infection on HSP70 level in the hepatopancreas of Japanese flounder *Paralichthys olivaceus*. Data represent means ± SEM ($n = 3$). Statistical relationships between groups are indicated by letters where significant differences were detected ($p < 0.05$)

## *3.3 Cu, Zn– and Mn–SOD Expression Levels*

The effect of *E. tarda* infection on the expression of SODs in hepatopancreas of Japanese flounder is shown in Figs. 2 and 3.

The expression level of Cu, Zn–SOD in infected fish was stable between 0 and 12 h, and then increased between 24 and 48 h post-infections. The expression level of Cu, Zn–SOD in infected fish peaked at 48 h post-infection (Fig. 2). The administration of live *E. tarda* caused approximately twofold increase in Cu, Zn–SOD levels at 48 h

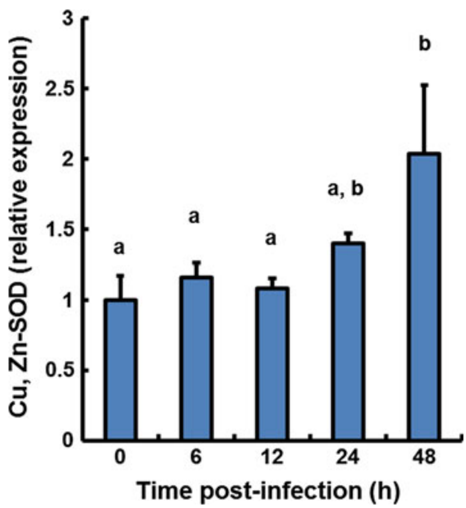


**Fig. 2** Effect of bacterial infection on Cu, Zn–SOD level in the hepatopancreas of Japanese flounder *Paralichthys olivaceus*. Data represent means ± SEM ($n = 4$). Statistical relationships between groups are indicated by letters where significant differences were detected ($p < 0.05$)

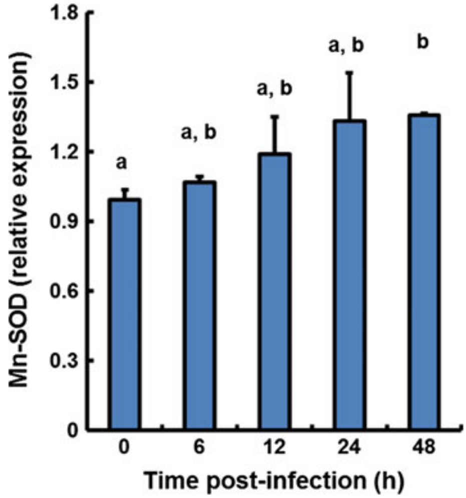


**Fig. 3** Effect of bacterial infection on Mn–SOD level in the hepatopancreas of Japanese flounder *Paralichthys olivaceus*. Data represent means ± SEM ($n = 4$). Statistical relationships between groups are indicated by letters where significant differences were detected ($p < 0.05$)

post-infection, compared with the infected fish at 0, 6, and 12 post-infections. On the other hand, a clear time-dependent expression pattern of Mn–SOD was observed in fish infected with *E. tarda* (Fig. 3).

The expression level of Mn–SOD in infected fish gradually increased post-infection. High levels of Mn–SOD expression were observed between 24 and 48 h post-infections. The expression level of Mn–SOD in infected fish reached a maximum at 48 h post-infection. The Mn–SOD expression level in infected fish at 48 h was significantly higher than that in infected fish at 0 h.

## 4 Discussion

In the present study, we have investigated the changes in expression of antioxidative enzymes and stress proteins in the hepatopancreas of Japanese flounder, in response to bacterial infection. Our results revealed that the expression of HSP70 and the antioxidative enzymes, such as Cu, Zn–SOD and Mn–SOD, was up-regulated in fish infected with *E. tarda*, between 24 and 48 h of infection. HSP70 was particularly up-regulated at 48 h post-infection.

Most organisms living in the aquatic environment face environmental and physiological stressors, such as heat, pollutants, heavy metals, bacterial, and viral infections. Cultured fishes are particularly exposed to both abiotic and biotic stressors such as stock density, confinement, quality of water, and diseases. Exposure of organisms to stressors results in a series of biochemical and physiological changes. At the organismal level, these changes are mediated by the neuroendocrine system (Barton and Iwama 1991; Charmandari et al. 2005; Iwama et al. 2006; Nakano 2011, 2016, 2020; Pickering and Pottinger 1995; Prunet et al. 2012; Roberts et al. 2010;

Wu et al. 2015, 2019). In addition to the neuroendocrine stress response, there is a cellular response following exposure to stressful situations. The induction of various HSPs by environmental stressors has been reported in many tissues of fish (Basu et al. 2001, 2002; Deane and Woo 2011; Feder and Hofmann 1999; Hochachka and Somero 2002; Iwama et al. 1998; 2006; Nakano 2016; Nakano et al. 2014, 2018; Roberts et al. 2010; Yamashita et al. 2010). HSPs are indicators of a generalized stress response at the cellular level (Iwama et al. 1998, 2004). HSP70 is particularly responsive to a wide variety of physiological and environmental stimuli, and hence is one of the most widely researched stress proteins in fish (Deane and Woo 2011; Iwama et al. 1998, 1999, 2006; Roberts et al. 2010). However, most studies on HSPs in fish have been conducted in laboratory environment in vitro. Many of these studies have reported the induction of HSPs following exposure to abiotic stress. On the other hand, information about the effects of biotic factors on HSP expression in fish is limited (Basu et al. 2002; Deane and Woo 2011; Iwama et al. 1998, 2004, 2006; Nakano 2011, 2016, 2020; Nakano et al. 2018; Yamashita et al. 2010). Fish display both innate (non-specific) and acquired forms of immunity (Iwama et al. 2006; Kaattari and Piganelli 1996; Kiron 2012; Manning and Nakanishi 1996; Secombes 1996; Yano 1996). During infection, the host-immune system is stimulated to produce and activate enzymes such as myeloperoxidase, NADPH oxidase, and inducible nitric oxide synthase (iNOS). These enzymes generate NO and ROS such as superoxide anion ($O_2^{\cdot-}$), hydroxyl radical (·OH), and hypochlorous acid (HOCl). ROS can react with each other to form new ROS. Though ROS play an important role in signaling processes and the host defence system owing to its bacteria-killing abilities, ROS can also react with various biological molecules and damage host tissues (Asada 1987; Lambeth 2004; Lushchak 2011; Maeda and Akaike 2000; Nakano 1987, 2016, 2020; Nakano et al. 2012; Nakano and Takeuchi 1997; Nathan and Cunningham-Bussel 2013; Ohshima et al. 2005; Oyanagui 1993; Sasada 1988; Secombes 1996; Sumimoto 2000; Takeshige and Mizukami 1987). HSP70 assists the folding of nascent polypeptides, mediates the repair of denatured proteins and turnover of irreparable proteins (Basu et al. 2002; Hochachka and Somero 2002; Iwama et al. 1998, 2006; Mitani 1997; Nakano 2016, 2020; Yamashita et al. 2010). In this study, the upregulation of hepatic HSP70 in fish following bacterial stress is indicative of protein damage caused due to excessive ROS production, in response to the infection. A redox state has been reported to modulate the synthesis of HSP in both mammalian and fish tissues (Nakano et al. 2014, 2018; Peng et al. 2000). Furthermore, HSP70 expression was observed in various tissues in uninfected healthy Japanese flounder in this study. Ubiquitous presence of HSP70 transcripts has been previously demonstrated in many tissues including the major immune tissues such as head kidney, spleen, intestine, and thymus in fish (Han et al. 2017; Li et al. 2015; Zhang et al. 2011a). Infection with bacteria, such as *Edwardsiella* sp., *Renibacterium* sp., *Vibrio* sp., *Streptococcus* sp. and *Aeromonas* sp., has been shown to induce HSPs in several fish species (Ackerman and Iwama 2001; Cha et al. 2013; Deane et al. 2004; Deane and Woo 2011; Forsyth et al. 1997; Han et al. 2017; Liu et al. 2013; Ming et al. 2010; Roberts et al. 2010; Xu et al. 2011). Additionally, the mRNA expression level of HSP in fish has also been reported to increase following infection with pathogenic bacteria

(Cha et al. 2013; Cui et al. 2011; Deane et al. 2004; Ming et al. 2010; Song et al. 2016; Xie et al. 2015; Xu et al. 2011). These findings suggest that HSP70 may be involved in immune response and have a role in organismal survival in Japanese flounder (Breloer et al. 2001; Pockley et al. 2008; Robert 2003; Srivastava 2002; Sun and MacRae 2005). Under unstressed normal conditions, HSP70 is expressed at a very low level, whereas HSC70 is constitutively expressed in all cells. Under stressed conditions, HSC70 levels remain unchanged, while expression of HSP70 is induced. Recently, differences in expression patterns of HSC70 and HSP70, in response to infection-induced stress, have been reported (Han et al. 2017; Li et al. 2015; Yuan et al. 2017). In this study, however, the level of HSC70 expression in response to bacterial infection could not be distinguished from that of HSP70. We surmise that both HSC70 and HSP70 could play important roles in immune response of fish. Hence, expression of HSC70 of Japanese flounder in response to *E. tarda* infection should be investigated.

SODs are the most important antioxidative defence enzymes that function against ROS-induced damage (Lesser 2006; Lushchak 2011; Martinez-Alvarez et al. 2005; Nakano 2016; Nakano and Takeuchi 1997; Oyanagui 1989; Taniguchi and Endo 2000; Zelko et al. 2002). In this study, both Cu, Zn–SOD and Mn–SOD expression levels were increased in the hepatopancreas of Japanese flounder by *E. tarda* infection. Infectious bacteria such as *E. tarda* have been shown to induce ROS production in Japanese flounder, NO production in mouse macrophages and zebrafish, and iNOS in channel catfish and rohu carp, respectively (Ishibe et al. 2008; Kole et al. 2017; Schoor and Plumb 1994; Wang et al. 2010). In addition, levels of oxidative stress-related biomarkers such as lipid peroxidation and oxidative protein (protein carbonylation) increase in response to bacterial infection (Adeyemi 2014; Liu et al. 2012). Hence, the present results regarding the elevated expressions of HSP70 and SODs caused by bacterial-mediated ROS production due to phagocytosis, suggest that bacterial infection induces oxidative stress in Japanese flounder, which may result in imbalance of redox state and damage of host tissues (Nakano et al. 2014, 2018; Nathan and Cunningham-Bussel 2013). Under oxidative stress conditions, therefore, the levels of stress-related proteins such as HSP and SOD may increase due to their de novo synthesis to mediate redox homeostasis and protect tissues against oxidative damage (Adeyemi 2014; Cha et al. 2013; Nakano et al. 2014; Osatomi et al. 2002). HSP is particularly induced to eliminate and help refolding of denatured proteins which were produced by oxidative stress.

Though Cu, Zn–SOD is more stably expressed than Mn–SOD; Mn–SOD is often induced in response to both abiotic and biotic stresses in mammals (Oyanagui 1989; Taniguchi and Endo 2000; Yamakura 1988; Zelko et al. 2002). Induction of Cu, Zn–SOD expression has also been observed in fish and shellfish in response to stresses derived from bacterial or viral infections, lipopolysaccharide (LPS) challenge, thermal treatment, hypoxia, and metal exposure (Anju et al. 2013; Bao et al. 2009; Cha et al. 2013; Chakravarthy et al. 2012; Cho et al. 2006; Craig et al. 2007; Kim et al. 2007, 2010; Meng et al. 2013; Poly 1997; Zhang et al. 2011b). Although SODs were induced by *E. tarda* infection in hepatopancreas of Japanese flounder, the modulation of SODs expressions by bacterial infection is still unknown in fish. Cu, Zn– and

Mn–SODs showed significant increase and peaked at 48 h post *E. tarda* infection. We surmise that ROS accumulate in the tissues before 48 h of infection. Accumulated ROS potentially activate signaling cascades including transcription factors such as activator protein-1 (AP-1) and nuclear factor κB (NF-κB), and induce the expression of both Cu, Zn– and Mn–SODs, that for to neutralize the harmful effects of ROS (Bao et al. 2009; Brady et al. 1997; Droge 2002; Lushchak 2011; Maehara et al. 1999; Nakano et al. 2014; Osatomi et al. 2002; Schwarz 1996; Suzuki et al. 1997; Takahashi et al. 1988). ROS-induced oxidative stress has been reported to activate several kinases, such as mitogen-activated protein kinase (MAPK), c-Jun N-terminal kinase (JNK) and extracellular signal-regulated kinase (ERK), and the transcription factor AP-1, leading to increased SOD antioxidative response in virus-infected mammalian cells (Qadri et al. 2004).

Induction of SOD proteins in response to the enhanced ROS production during bacterial infection, including *E. tarda* infection, has been observed in several fish species (Cha et al. 2013; Cho et al. 2009; Osatomi et al. 2002; Rieger and Barreda 2011; Rodriguez et al. 2008; Villamil et al. 2003). Intercellular signaling is also affected by ROS or a pro-oxidative shift in the redox state resulting in the up- or down-regulation of several genes and proteins (Allen and Tresini 2000; Arrigo 1999; Droge 2002; Espinosa-Diez et al. 2015; Ho et al. 2013; Lesser 2006; Lushchak 2011; Nathan and Cunningham-Bussel 2013; Valavanidis et al. 2006). The expression of both Cu, Zn– and Mn–SODs mRNA is reported in fish following infection with pathogenic bacteria (Cho et al. 2009; Perera et al. 2016, 2017; Umasuthan et al. 2013, 2014). In practice, previous studies observe significant upregulation of SODs genes in response to *E. tarda* infection. Although the differences in the levels of Mn–SOD expression after infection could not be regarded as significant, the mean expression levels increased gradually. These phenomena suggest that the susceptibility of Mn–SOD to infection-induced oxidative stress might be higher than that of Cu, Zn–SOD. Accordingly, the elevation of SODs expression levels upon *E. tarda* infection is likely to be a part of antioxidative response to scavenge ROS. An antioxidative supplement, such as astaxanthin, dramatically reduces oxidative stress-induced damage in fish (Nakano 2007, 2016, 2018, 2020; Nakano et al. 1999a, b, 2004). Antioxidants can improve the redox state and enhance tolerance against oxidative stress in organisms. Accordingly, the possible beneficial effects of antioxidants on oxidative stress and redox state should be determined in Japanese flounder (Espinosa-Diez et al. 2015; Nakano 2016; Nakano et al. 2014, 2018; Penglas et al. 2015).

In conclusion, the results of this study suggest that both hepatic HSP and SODs play roles in mediating the immune responses upon *E. tarda* infection in Japanese flounder. These proteins potentially function to protect cells against bacterial infection-induced oxidative stress. HSPs are involved in cross-protection, which is the ability of one stressor to increase resistance to a subsequent stressor such as bacterial and viral infections (Roberts et al. 2010; Ryckaert et al. 2010; Sung et al. 2007, 2012; Todgham et al. 2005; Yuan et al. 2017). Therefore, functional proteins, such as stress proteins and antioxidative enzymes, may be possible candidates for the development of novel preventive methods to protect against infectious disease, and should be investigated from the perspective of cross-protection in fish. In addition, HSP70 and SODs could be used as bacterial infection-related biomarkers to evaluate stress states of infected fish. Further studies are required to reveal the relationships between bacterial infection, oxidative stress, stress management, functional proteins, and their contribution to fitness in fish.

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# Impacts on Socio-Eco-Systems and Biological Resources

# A Review of the Effects of Global Warming and Current Trends on Fisheries and Its Impact on Important Commercial Species in Japan

**Kazufumi Takayanagi**

**Abstract** Global warming can alter the spatial and temporal distribution of fish stocks, which often has an impact in commercial fisheries. Better anticipation and preparations for the effects of global warming on fisheries are necessary. In this review paper, we examined and summarized the past predictions of the effects of global warming on commercially important fishes around Japan and contrasted with recent information

**Keywords** Global warming · Migratory fish species · Japan fisheries management

## 1 Introduction

Japan extends over 3000 km from north to south along the western edge of the Pacific Ocean in the temperate region. This area is characterized by two dominant currents: Kuroshio, a subtropical current which transports warm and oligotrophic water, and the Oyashio, a subarctic current which transports cold and nutrient-rich subarctic water (Fig. 1).

These two currents meet off the east coast of Japan in the Kuroshio–Oyashio interfrontal zone (K/O zone), a mixing area supplying nutrient-rich waters to the surface which promotes primary production. This oceanographic feature brings a rich fisheries production to Japan, whose people can enjoy a variety of fishes each season. However, this enjoyable lifestyle might be in danger because of global warming. A better anticipation for rising issues and preparation for the effects of global warming on fisheries are necessary.

It is not an easy task to illustrate the effect of global warming on fish stocks and their distributions. Because global warming affects all trophic levels of marine ecosystems, it is necessary not only to comprehensively analyze the target fish species but also to examine the changes in the physical and chemical environment surrounding target fish species, its preys, competitors and predators.

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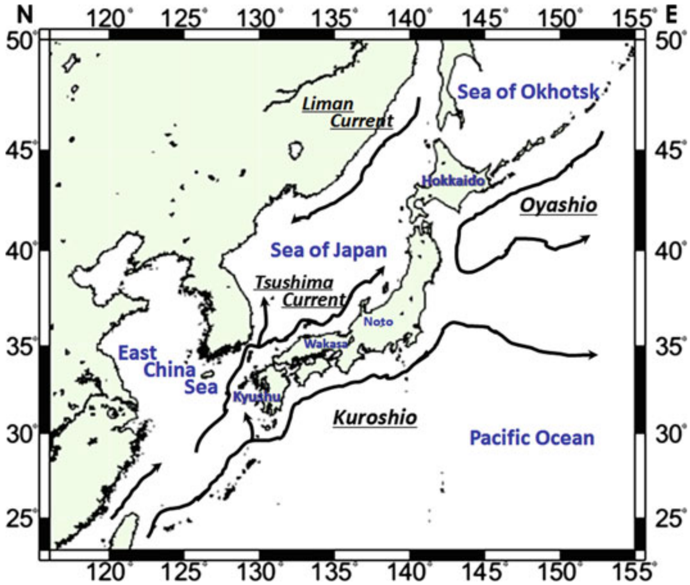


**Fig. 1** Oceanographic feature around Japan

In order to take appropriate measures against the possible effects of global warming, it is important to review the current situation and anticipate how the stock and distribution of commercially important fish species will respond to changes in the future. Some reviews have examined the effects of global warming on marine ecosystems around Japan (Tadokoro et al. 2008; Takayanagi 2009; Fisheries Research Agency 2019), and predicted possible distribution changes around Japan (Kuwahara et al. 2006; Fisheries Research Agency 2009). In this review, we contrast some of the past predictions with ongoing trends to achieve an advanced prediction and improved fisheries management.

## 2 Current Situation

### *2.1 Sea Surface Temperature*

In the waters around Japan, the annual average sea surface temperature has increased +1.11 °C over the last 100 years (JMA 2018a). This increment is larger than the world's average sea surface temperature increase rate (+0.54 °C/100 years) and is about the same value as the air temperature increase rate in Japan (+1.1 °C/100 years). The increment is particularly large in the central part of the Sea of Japan, at 1.71 °C/100 years (JMA 2018a).

## 2.2 Sea Level

A clear rising trend of the sea level along the Japanese coast has not been observed in the past 100 years, but increasing values have been observed after the 1980s with a decadal-scale change (JMA 2018b).

## 2.3 Kuroshio

Climate models predicted that the Kuroshio Current would be strengthened by global warming (Sakamoto et al. 2005; Yang et al. 2016). However, in the results of the long-term oceanographic survey at 137° E in the North Pacific by the Meteorological Agency of Japan over the past 50 years (JMA 2018c), no noticeable trend was observed, although periodic fluctuations in the flow rate of the Kuroshio Current were recorded.

## 2.4 Sea Surface Salinity

Global warming may increase freshwater inputs from land due to melting of glaciers and changes in rainfall patterns. In fact, a decreasing trend of surface salinity has been observed in precipitation-dominated areas, such as high-latitude waters of the Atlantic Ocean and the Pacific Ocean (Boyer et al. 2005). In the East China Sea, a decrease in salinity was also reported during the summer (Siswanto et al. 2008).

## 2.5 Marine Organisms

Poloczanska et al. (2013) reported that, on average, marine organisms have expanded their distributions by 72.0 ± 13.5 km per decade (generally poleward) based on a metadatabase of 1735 species around worldwide. This result suggests an order of magnitude faster than expected rates for terrestrial species (Poloczanska et al. 2013).

In the case of intertidal organisms and zooplankton in the English Channel, a distribution shift of 192 km north in the 70 years since the 1920s was observed, when an average water temperature rise of 0.5 °C was recorded (Helmuth et al. 2006). Additionally, a steady appearance of warm-water toxic phytoplankton (Nagai et al. 2003), a northward expansion of the distribution area of warm-water species of Sargassum (Yoshimura 2007; Kiriyama 2009; Tanaka et al. 2012) and scleractinian corals (Nojima and Okamaoto 2008) have also been reported.

## 2.6 Fish

Perry et al. (2005) reported that two-thirds of the fish species in the North Sea had shifted their distribution in mean latitude and/or depth over the last 25 years, a fact especially noticeable for fishes with fast life cycles and smaller body sizes.

In Maizuru Bay, facing the Sea of Japan, warm-water fish has consistently increased during the last 30 years. By comparing the mean latitude of the distribution area of each fish species, an average northward movement of 270 km over the last 30 years can be noticed, while the average sea surface temperature has increased 0.4 °C (Masuda 2008).

## 2.7 Fisheries

The western North Pacific Ocean around Japan is a very productive area. Many migratory fish and small pelagic species gather in this region for food, creating one of the richest fishing grounds in the world. However, decadal-scale fluctuations of fish stocks and commercial catches are well known. Catch records in the last 100 years of sardine (*Sardinops melanostictus*), anchovy (*Engraulis japonicus*), chub mackerel (*Scomber japonicus*) and jack mackerel (*Trachurus japonicus*) in Japanese waters show huge fluctuations which cannot be explained only by advances in fishing technology (Fig. 2).

These fluctuations appear to be linked to the Pacific Decadal Oscillation (PDO), a decadal alternation of a warm period and a cold period (Mantua and Hare 2002; Yatsu et al. 2008; Takasuka et al. 2008). This climate phenomenon and the corresponding changes in fish stocks were evident well before the effects of global warming became

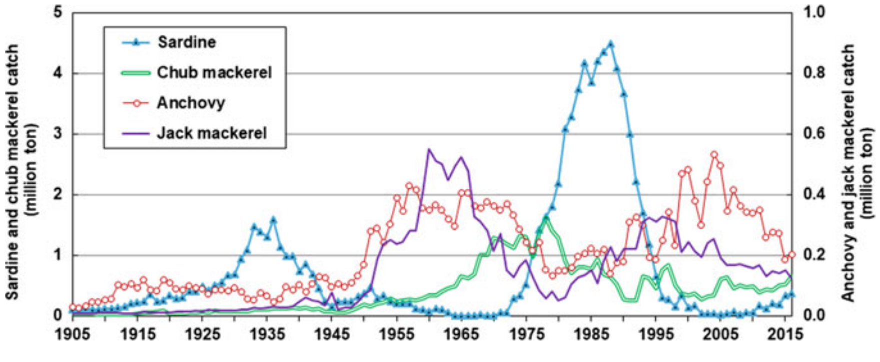


**Fig. 2** Hundred-year trends of commercial catch of sardine *(S. melanostictus*), Japanese anchovy (*E. japonicus*), chub mackerel (*S. japonicus*) and jack mackerel (*T. japonicus*) in Japan. New data added to the figure from FRA (2009) by Dr. Akihiko Yatsu

noticeable. For these fishes, it may be difficult to extract the environmental cause of stock fluctuations and differentiate the effects of global warming and regional climate forcing.

## 3 Japanese Common Squid, *Todarodes pacificus*

Japanese common squid, *T. pacificus*, is widely distributed around Japan. Major spawning areas of this species are located in the continental shelf and adjacent slope of the East China Sea and the Sea of Japan at depths of 100–500 m. The main spawning season occurs between fall and winter. The optimum temperatures are 18–23 °C (Sakurai et al. 1996). Newborn juveniles migrate north to reach their feeding grounds, and matured adults return to the spawning areas (Fig. 3). The life span of this species is approximately one year, with faster growth and faster sexual maturation at higher temperature observed in laboratory experiments (Takahara et al. 2017).

Juvenile squids at length sizes below 5 cm feed mostly on plankton, and at larger sizes, they feed on variety of fishes (Uchikawa and Kidokoro 2014). Young individuals, around 100 days after hatching, have been reported to feed on each other (Kidokoro and Uji 1999), and squids are frequently predated by large fishes and marine mammals.

In the past, a large fluctuation of the stock size was observed. During a cold period (from late 1970s to early 1980s), the stock decreased and the spawning areas in the East China Sea shrank. On the other hand, during warm periods (before 1970s and 1990s), the stock increased and the spawning area extended to the Sea of Japan (Sakurai et al. 2000; Kidokoro 2011; Rosa et al. 2011). In addition, tagging and recapture experiments revealed changes in the migration route (Kidokoro et al. 2010).

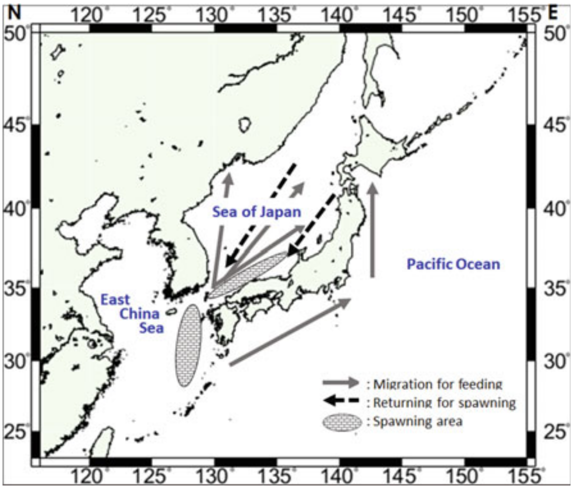


**Fig. 3** Migration pattern and spawning area of Japanese common squid, *T. pacificus*. Modified from FA & FRA (2018a)

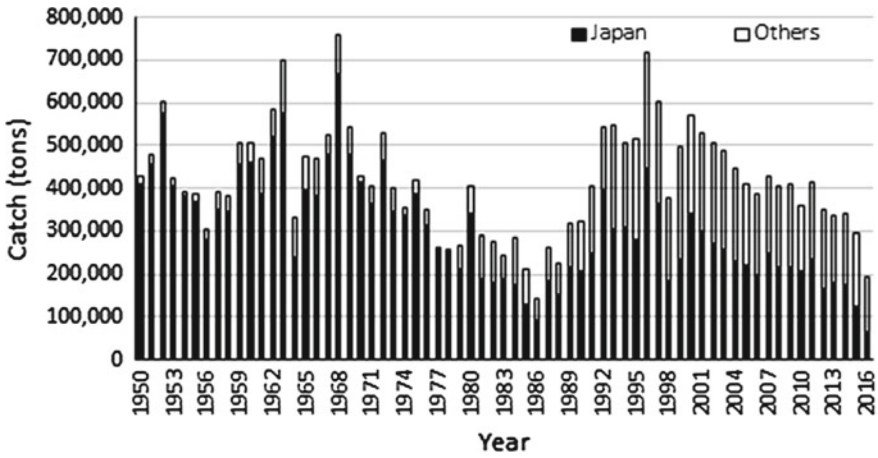


**Fig. 4** Commercial catch of Japanese common squid, *T. pacificus,* since 1950. Data obtained from FAO (2019) and FA & FRA (2018a)

Based on these observations, predictions of the effects of global warming on Japanese common squid were (1) an expansion of the spawning area to the north with some delays in the spawning season and (2) improved fishing grounds toward the north (FRA 2009).

Recent Japanese catch data in the Sea of Japan shows a large decline (Fig. 4), although foreign catch remains almost to the level in the previous years. The main distribution area and richer fishing grounds may have displaced northward outside the Japanese EEZ; hence, it is possible that the total stock may not be reflected in the Japanese catch.

## 4 Pacific Saury, *Cololabis saira*

Pacific saury, *C. saira*, is widely distributed from the subtropical waters of the North Pacific to the subarctic waters of the Sea of Okhotsk including the Sea of Japan (Fig. 5).

Surface water temperature within the distribution area of this species ranges from 7 to 25 °C. Among the different populations of this species, Japanese fisheries rely mostly in the one mainly distributed in the western and central part of the North Pacific, a population known to migrate near the coast of Japan in fall (Suyama et al. 2006). Spawning starts in fall in the K/O zone, and the spawning area progressively moves to the subtropical region of the Kuroshio area in winter and returns north in spring (Watanabe et al. 1997; Iwahashi et al. 2006; Suyama et al. 2012). The life span of this species is approximately two years (Suyama et al. 2006) and feeds mainly on copepods (Odate 1977). Whales such as minke whales (*Balaenoptera*

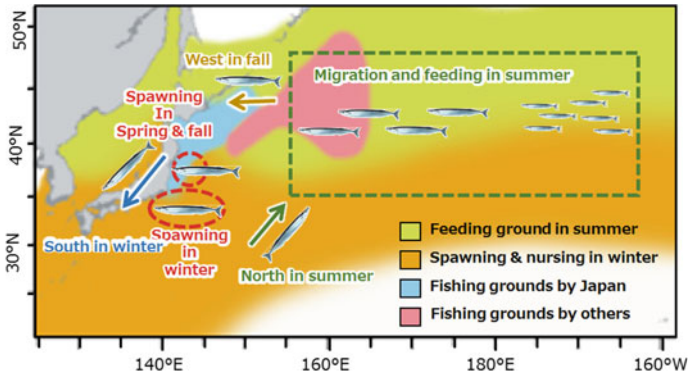


**Fig. 5** Migration pattern and spawning area of Pacific saury, *C. saira*. Modified from FA & FRA (2018b)

*acutorostrata*), sea birds and large fish like coho salmons (*Oncorhynchus kisutch*) or albacores (*Thunnus alalunga*) are known predators to Pacific saury (FA & FRA 2018b).

Predictions on the effect of global warming on Pacific saury were (1) a shift of fishing grounds to the north (Kuwahara et al. 2006) and (2) a decrease in body size with an increase in population numbers and a change in the migration patterns, all based on the NEMURO FISH model calculations (Ito et al. 2007; FRA 2009; Ito et al. 2010).

Although the total catch of Pacific saury in the North Pacific remains more or less steady, the Japanese contribution to the total has drastically decreased in the recent years (Fig. 6). This implies that, despite the fact that the stock size likely remains

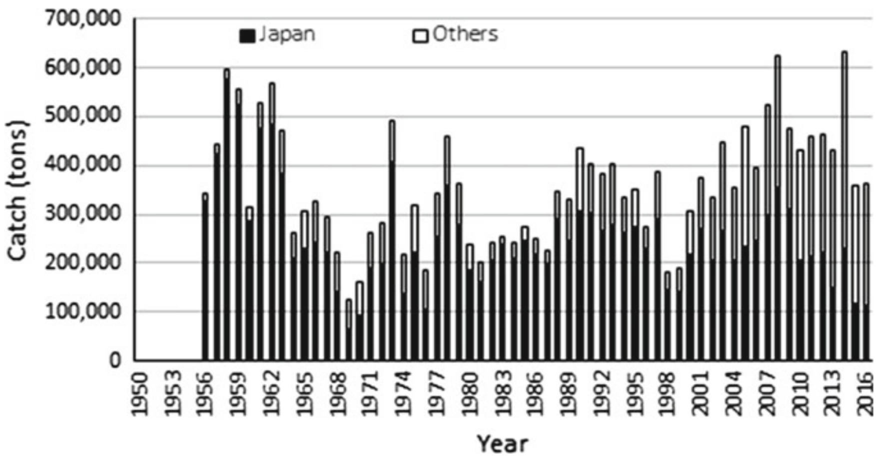


**Fig. 6** Commercial catch of Pacific saury, *C. saira*, since 1956. Data obtained from FAO (2019) and FA & FRA (2018b)

near the same level, migration routes may have changed. There are still too many uncertainties to construct an ecological model for Pacific saury, as, for example, a lower-trophic level interaction, fish growth and fish migration (Ito et al. 2013). For migratory pelagic fish, interspecies interactions (e.g., resource competition or prey-predator relationships) may be critical to predict responses to future climate changes.

## 5 Yellowtail, *Seriola quinqueradiata*

Yellowtail, *S. quinqueradiata*, is a coastal migratory fish widely distributed along Japan, from the southern coast of Kyushu to the coastal areas in northern Japan (Fig. 7).

The life span of this species is about 7 years, reaching maturity at age 2 (50%) or age 3 (100%). The spawning season starts in the Pacific Ocean from January and ends in the Sea of Japan side near July. Spawning areas are located west of the Noto Peninsula on the continental shelf of East China Sea around Kyushu in the Sea of Japan and west of the Izu Islands in the Pacific coast. Adult fish migrate south for spawning from winter to spring (Ino et al. 2008; Yamamoto et al. 2007; Sakaji et al. 2010). Larvae feed on zooplankton, like copepods, at early stages, feeding on small fish such as anchovy as they grow, consuming preys over 13 cm at adult (Anraku

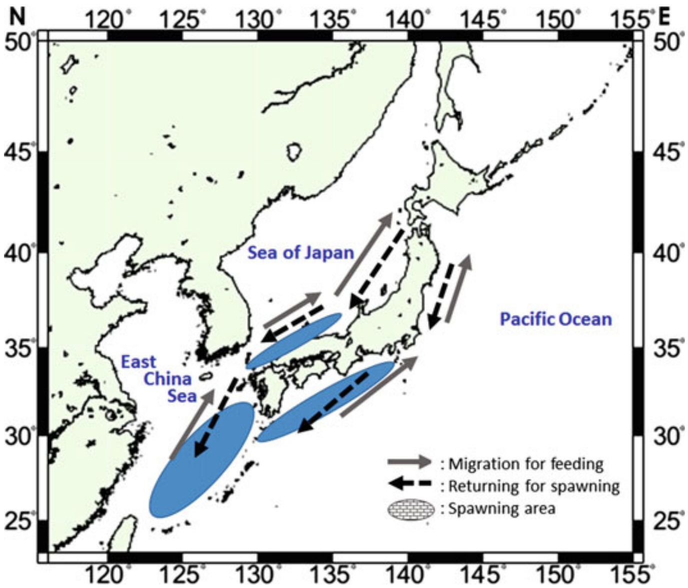


**Fig. 7** Migration pattern and spawning area of yellowtail, *S. quinqueradiata*. Modified from FA & FRA (2018a)

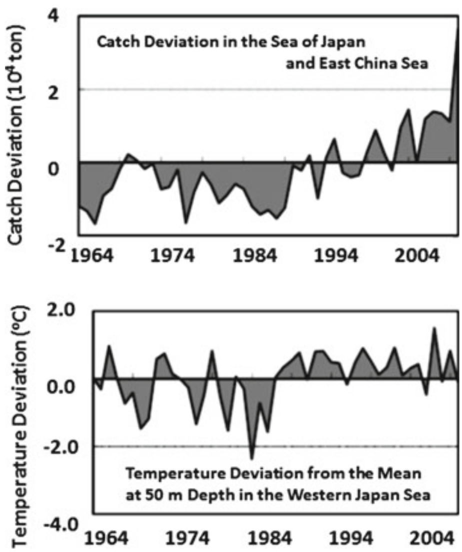


**Fig. 8** Catch deviation of yellowtail, *S. quinqueradiata*, and seawater temperature deviation from the past 30 years mean in the Sea of Japan and East China Sea. Modified from FA & FRA (2018a)

and Azeta 1965). The optimum water temperature for this species is 20–29 °C (FA & FRA 2018a, b).

Historical records over the last century indicate a good correlation between sea surface temperature (SST) and yellowtail catch (Fig. 8).

An increment in SSTs has positive effects on yellowtail landings, with particularly good catches observed when both winter and summer water temperatures were over the mean (Hara 1990; Tian et al. 2012).

Predictions regarding the effects of global warming on yellowtail suggested a northward expansion of the distribution area in winter with an increased stock size around Japan (Tian et al. 2012). As predicted, recent Japanese catches of yellowtails have been steadily increasing and the number of landings has doubled from 1970s and 1980s (Fig. 9).

## 6 Japanese Chum Salmon, *Oncorhynchus keta*

Japanese chum salmon, *O. keta*, is an anadromous species spawning in freshwater and growing and maturing during long oceanic migrations that can last 3 to 5 years. This fish is widely distributed in the northern North Pacific (Fig. 10).

Juveniles migrate to the ocean in late spring, remaining near shore for a while before moving to the Sea of Okhotsk where they can remain up to several months feeding on zooplankton, mainly amphipoda, copepoda and krill. Afterward, juveniles migrate to the North Pacific, including the Bering Sea and the Gulf of Alaska, as well as part of the Arctic Ocean, feeding on micronekton and a variety of small fishes

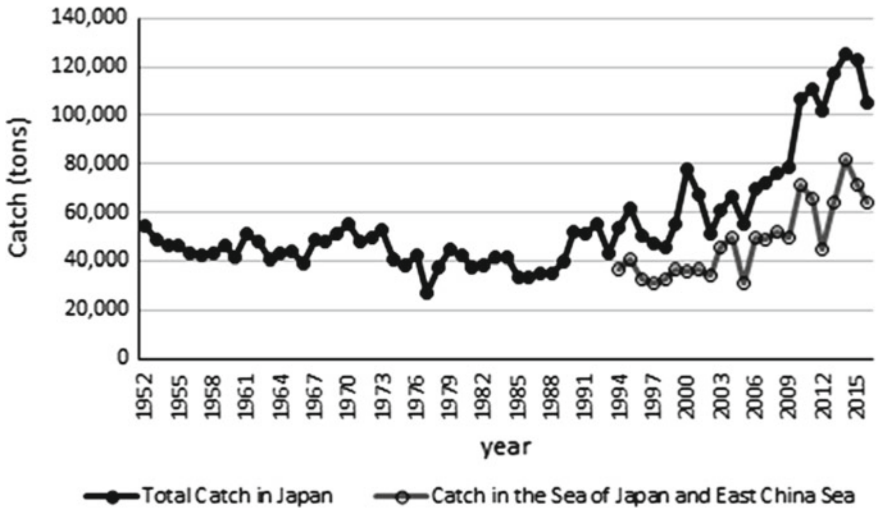


**Fig. 9** Commercial catch of yellowtail, *S. quinqueradiata*, since 1952. Data obtained from FAO (2019) and FA & FRA (2018a)

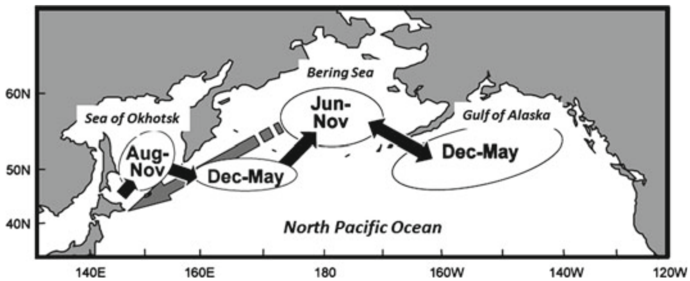


**Fig. 10** Seasonal migration pattern of Japanese chum salmon, *O. keta*, in the North Pacific Ocean and its adjacent Waters (after Urawa 2000, 2015)

(Urawa 2015). Optimum water temperature for this species is ranged from 4 to 13 °C (Kaeriyama et al. 2014).

It was suggested that a poleward displacement of the 10 °C sea surface temperature isotherm may be related to the changes in distribution of this species, which reportedly moved northward (Ishida et al. 2002). On the other hand, historical data indicates that the body size of Japanese chum salmon is positively correlated with sea surface temperature (SST) in the Okhotsk Sea during summer and fall (Ishida et al. 1993; Kaeriyama et al. 2007), implying that an increase in water temperature in the Okhotsk Sea favors the growth of young Japanese chum salmon. However, an increased body size and high survival rates may induce prey competition resulting in a decrease of the stock size (Kishi et al. 2010; Kaeriyama et al. 2014).

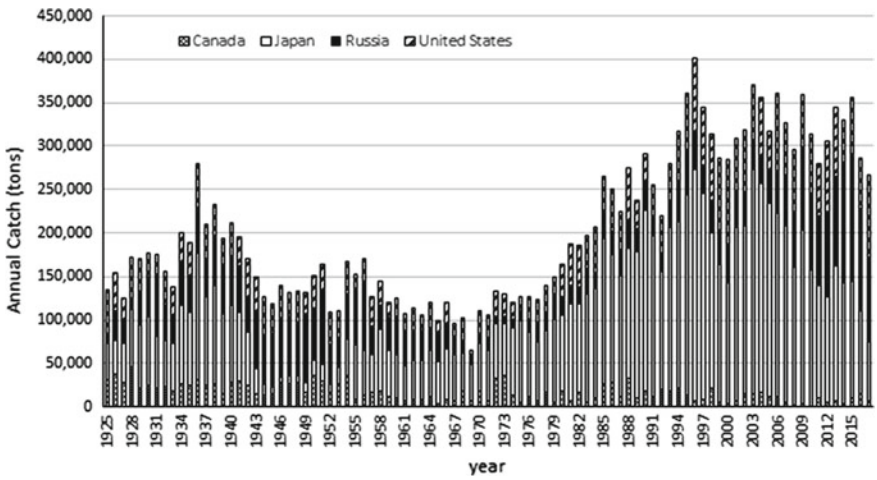


**Fig. 11** Commercial catch of Japanese chum salmon, *O. keta*, since 1925. Data obtained from FAO (2019) and FA & FRA (2018b)

Based on this knowledge and some model analyses, predictions on the effects of global warming on the chum salmon were (1) decrease in the carrying capacity and distribution area, (2) strong density-dependent effect and (3) loss of migration routes to the Sea of Okhotsk (Kishi et al. 2010; Kaeriyama et al. 2014).

An archeological approach was also used to predict global warming effects (Ishida et al 2001, 2016). Salmon bones found on archeological sites in Hokkaido (northern Japan), consisting in preserved fish bones and shells from the warmer period of early Jomon era (about 6000 years ago), when the mean seawater temperature was estimated to be about 5 °C higher than in the present, suggest that chum salmon may be able to migrate to Hokkaido even when the current global warming trend continues (FRA 2009).

Recent Japanese catches of chum salmon have been decreasing. The catch in 2017 had fallen to less than 100,000 tons, the lowest in the past 30 years (Fig. 11). This denotes that the stock size likely remains the same but migration routes may have changed.

## 7 Skipjack Tuna, *Katsuwonus pelamis*

Skipjack tuna, *K. pelamis*, is an epipelagic oceanic species that migrate in a wide range of the Pacific Ocean (Fig. 12).

Most adults distributed near the 15 °C isotherm (overall temperature range of recurrence is 14.7–30 °C) in the subtropical to tropical waters, while larvae are mostly restricted to waters with surface temperatures of at least 25 °C. This species feeds on fishes, cephalopods and crustaceans, spawning in batches throughout the

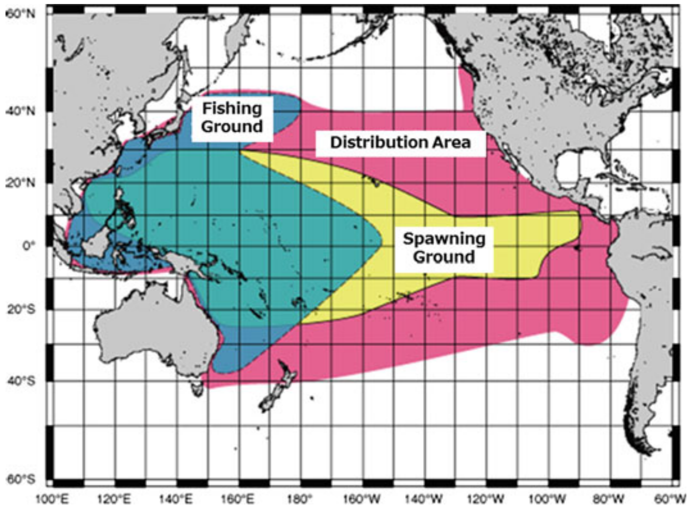


**Fig. 12** Distribution and spawning area of Skipjack tuna, *K. pelamis,* in the Pacific Ocean. Modified from FA & FRA (2018b)

year in equatorial waters, and from spring to early fall in subtropical waters, with the spawning season becoming shorter as distance from the equator increases (FA & FRA 2018b).

A model prediction indicated an overall extension of favorable habitats for skipjack throughout the tropical ocean (Loukos et al. 2003). The total catch of this species is steadily increasing, although the Japanese catch presents a slightly decreasing trend (Fig. 13). Brouwer et al. (2018) reported a period with high recruitments and increased spawning biomass in recent years. However, there is a concern that high catches in the equatorial region could result in a reduction in the latitudinal range of the stock toward the tropical area, thus reducing skipjack stock at higher latitudes (Harley et al. 2015).

## 8 Adaptive Management

The assessment of fisheries resources by FAO (2018) indicates that the percentage of stocks overfished increased from 10.0% in 1974 to 33.1% in 2015, when maximally sustainably fished stocks accounted for 59.9% and underfished stocks for 7.0% of the total of assessed stocks. Fish populations under intense fishing pressure tend to mature at younger and at smaller sizes, and they may become vulnerable to year-to-year environmental variability.

Our present ability to predict regional effects on fish stocks is lacking, particularly for long-distance migratory fish species, requiring swift improvement. Improved fisheries management measures need to be adaptive to new available information

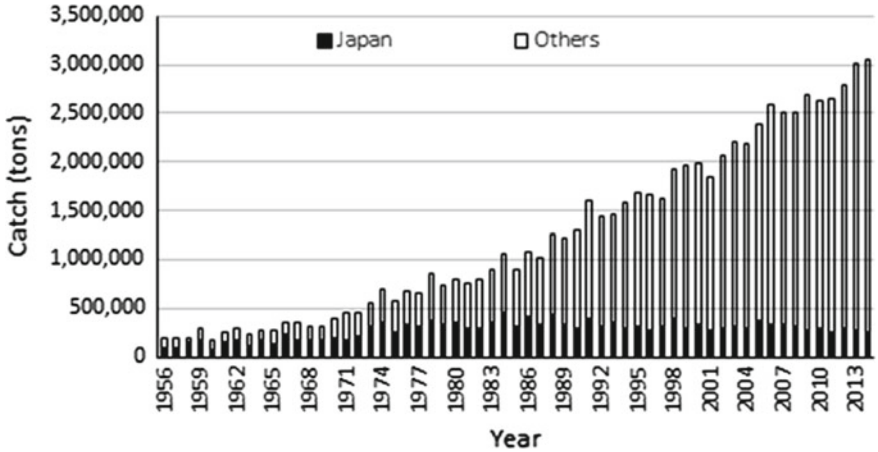


**Fig. 13** Commercial catch of Skipjack tuna, *K. pelamis,* in the Pacific Ocean. Data obtained from FAO (2019) and FA & FRA (2018b)

regarding the marine ecosystem, transparent and openness of the use of information, capable of evaluating the management results continuously and flexible to changes.

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# Physiology of Winter Coral Bleaching in Temperate Zone

**Tomihiko Higuchi, Ikuko Yuyama, and Sylvain Agostini**

**Abstract** With high-temperature stress due to climate change threatening corals in the tropics, cooler high latitudes may become a potential refuge. Already established high latitudes coral communities experience severe cold stress during winter, stress that would be fatal to most of the tropical coral species. Here we studied the physiological response of two high latitude coral species in Japan: *Alveopora japonica* and *Porites heronensis*, through field transplantation and in situ incubations. The specimens experienced 243 days at a temperature under 18 °C, which is the limit for the development of reefs and, and 110 days under 15 °C. While bleaching was observed for both species, none of the specimens died, highlighting the high resilience of temperate coral species to cold stress. The survival strategies to the cold temperature seem to differ among the species. *P. heronensis* exhibited decreased *Fv/Fm* and highly decreased metabolism (photosynthesis, calcification, respiration, ETSA) suggesting that this species could survive the winter by decreasing its basal metabolism. It also shows a mitotic index of more than 30% during the warmer period that could a prompt recovery from the stress experienced during winter. *A. japonica*, which showed several bleaching for around three months, also showed decreased metabolism but to a lesser extent suggesting that it was able to use an alternative source of energy. These kinds of adaptations to cold stress may not be widespread among tropical coral species, highlighting the need for better conservation of this future reservoir of biodiversity that represents marginal high latitude coral communities.

**Keywords** Hermatypic coral · Cold stress · Bleaching · High latitude · Marginal communities

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## 1 Introduction

Massive bleaching events, widespread disease outbreaks and high mortality of scleractinian corals have been reported in tropical zones during the last few decades (Bruno et al. 2007; Hoegh-Guldberg and Bruno 2010; Sato et al. 2009). These can be linked to the recent increase in temperature due to climate change, and the situation of corals and their ecosystems is critical to further warming in the future. Corals typically thrive in clear warm tropical and subtropical waters. However, it is not rare to find coral communities that occur out of the typical range of temperature for the development of reefs and the growth of corals, including higher latitudes with lower temperatures (Denis et al. 2013; Smith 1981; Veron and Minchin 1992). Such marginal communities could potentially represent a "refugia" that would allow the survival of corals in a warming climate (Beger et al. 2014; Makino et al. 2014).

Several parameters have been shown to determine the distribution of corals (Guinotte et al. 2003; Kleypas et al. 1999). Biogeographic studies showed a well-defined thermal envelope (Lough 2012). The higher temperature limit has been extensively studied due to its importance in the prediction of bleaching events and modelling of the impact of global warming on reef communities (Gang Liu et al. 2013; Hoegh-Guldberg et al. 2007). Although the maximum threshold is dependent on the biogeographic region and potential acclimatisation and/or adaptation, it has been defined as 31.1 °C for corals in the Indo-Pacific (Guinotte et al. 2003). A minimum yearly temperature of 18 °C is thought to be required for the development of coral reefs, but marginal coral communities have been observed in areas where surface seawater temperature regularly drops down to 10 °C (Denis et al. 2013; Dimond et al. 2013; Yamano et al. 2001, 2011; Yamano and Namizaki 2009), which therefore have led to consider 10°C as the minimum requirement for the distribution of corals in high latitudes (Yara et al. 2012). Other parameters, global one such as the saturation state in regards to aragonitic $CaCO_3$, which is a skeletal component of coral, and local ones such as light availability, nutrients levels, etc. were shown to also contribute to corals distribution, especially in the finer scale, and aragonite saturation state will surely be of importance in the future with saturation levels decreasing under ocean acidification (Guinotte et al. 2003; Kleypas et al. 1999; van Hooidonk et al. 2014; Yara et al. 2012).

The coastline of Japan stretches north–south over 1200 km ranging from tropical to subpolar areas. The northward flowing Kuroshio Current on the Pacific coast and Tsushima Current on the Japan Sea coast, warm up the waters around the Honshu Island. In addition, they bring high connectivity between the higher latitudes in Japan and the tropical and subtropical reefs of the Ryukyu Archipelago. Thus, oceanic circulation models showed that these currents can transport drifters such as larvae between those regions (Cho et al. 2009) and genetic studies confirmed the role of these current in shaping marine organisms' community around East Asia (Chan et al. 2007). For these reasons, Japan host some of the northernmost coral communities, with the world northernmost reefs in Iki Island, Japan Sea (Yamano et al. 2001), communities of Acroporid corals up to 35° N and the northernmost coral, *Oulastrea* *crispata*, can be observed in Sado Island (38° N) (Sugihara et al. 2009). The coast of the Izu peninsula, south of Tokyo (Fig. 1), is hosting a diverse community of corals (Nishihira and Veron 1995; Veron and Minchin 1992). Two dominant corals in temperate regions of Japan are *Alveopora japonic*a (Eguchi 1968) and *Porites heronensis* (Veron 1985). *A. japonica* is endemic to the temperate regions of Japan and Korea, and while *P. heronensis* can be found in more tropical areas, it is more commonly found in higher latitudes.

In recent years, poleward expansion of fauna and flora has been observed on land and in the sea. In the last hundred years, some coral species have expanded their range in Japan at tremendous speed, up to 14 km per year (Yamano et al. 2011). However, other species do not show such expansion which suggests some inherent physiological characteristics to allow survival in higher latitudes. Higuchi et al. (2015) highlight the importance of cold resilience and recovery from bleaching due to cold stress in determining the distribution of *Acropora* coral species. Bleaching is commonly defined as the loss of the symbiotic algae and/or its pigments. Severe and prolonged bleaching events can cause mass mortality of corals (Hughes et al. 2018; Kayanne et al. 2017; Sampayo et al. 2008). Numerous studies focused on the physiological mechanism of coral bleaching due to high-temperature stress (Ainsworth et al. 2008; Downs et al. 2002; Jones et al. 1998). In that case, the most accepted

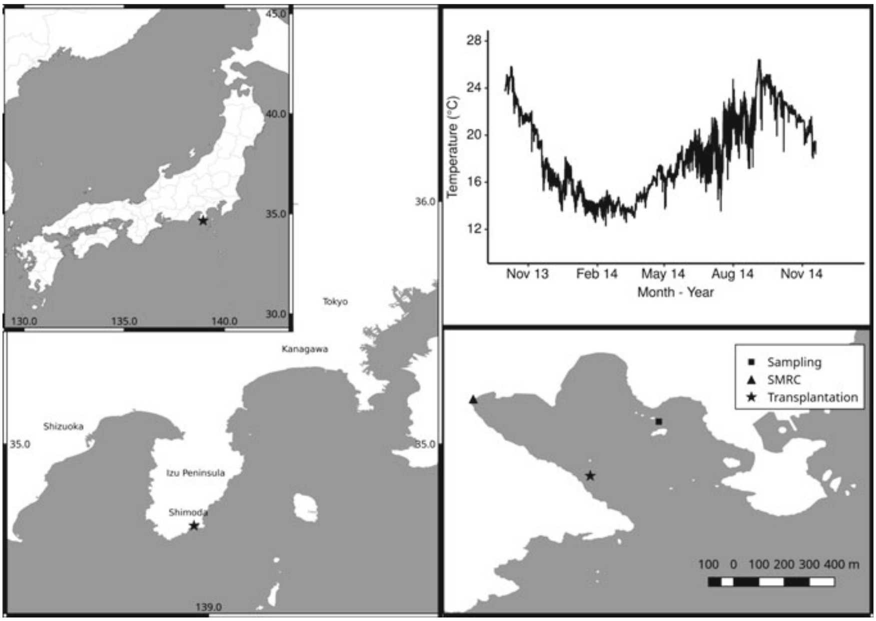


**Fig. 1** Map showing the transplantation and sampling sites in relation to the Shimoda Marine Research Center (SMRC) and temperature data at the transplantation site. The map was build based on geographic data freely available under the Open Database License © OpenStreetMap contributors (www.openstreetmap.org/copyright) using the QGIS software (QGIS Development Team 2009)

physiological mechanism is that bleaching starts with the impairment of the photosynthetic systems of the zooxanthellae, leading to high production of reactive oxygen species (ROS) (Downs et al. 2002; Higuchi et al. 2010; Jones et al. 1998) and, perhaps as a protective mechanism, the coral expulse or digest its own symbionts. While low-temperature stress bleaching has been also shown to cause high mortality, both in tropical and temperate zones (Colella et al. 2012; Hoegh-Guldberg et al. 2005; Yamano and Namizaki 2009; Zapata et al. 2011), its mechanism is less understood and the potential role of ROS remains uncertain (Higuchi et al. 2015).

Here, we studied the physiology of two dominant corals in Izu: *A. japonica* and *P. heronensis*, under natural conditions through field transplantation over a year and in situ chamber incubation. We hypothesised that these species are well adapted to the marginal environment that are high latitudes, and focused our study on the potential survival strategies during the winter period.

## 2 Materials and Methods

Coral sampling and further experiments were conducted in Oura Bay, Shimoda, Shizuoka, Japan (34° 66° N, 138° 93° E) (Fig. 1). Eighteen small fragments from individual colonies of each species *Alveopora japonica* (Eguchi 1968) and *Porites heronensis* (Veron 1985) were sample in July 2013 at a depth of around 3 m (recorded by the divers at the time of sampling). The fragments were fixed to stainless steel rods using epoxy glue and left to recover in outdoor aquariums with running seawater for a month at the Shimoda Marine Research Center, University of Tsukuba. A plastic lid was fixed on the rods under the coral colonies and the rods were transplanted on concrete blocks in Nabeta Bay which is adjacent to Oura Bay (Fig. 1) where the corals were sampled, at a depth of 8 m to minimize the risk from high wave energy and typhoons. The temperature was recorded by fixing a temperature logger (Hobo Pendant Temperature Logger, Onset USA) on the concrete block next to the chambers.

The transplantation system was designed so that the coral colonies could be enclosed within a plastic (polyethylene) transparent chamber in situ (Fig. 2a). Water was sampled from the chamber using two 50 ml syringes connected to two sampling ports on the side of the chamber. While injecting air through the upper port, water was sampled through the lower port (Fig. 2b). For metabolism measurements, SCUBA divers placed individual chambers on three randomly selected colonies of each species. Surrounding water was sampled to obtain the starting value for pH and total alkalinity (TA), with the chamber water sampled three hours after closing to obtain the final values. Each chamber was opened, and the procedure was repeated with the chambers then covered by aluminium foil. This provided a measurement of metabolic rates under both light and dark conditions. Field incubations were performed from 9:00 to 12:00 under light conditions, and from 13:00 to 16:00 under dark conditions. Metabolism measurements were conducted on 5th November 2013, 2nd February 2014, 8th May 2014, 16th July 2014 and 18th November 2014. Water

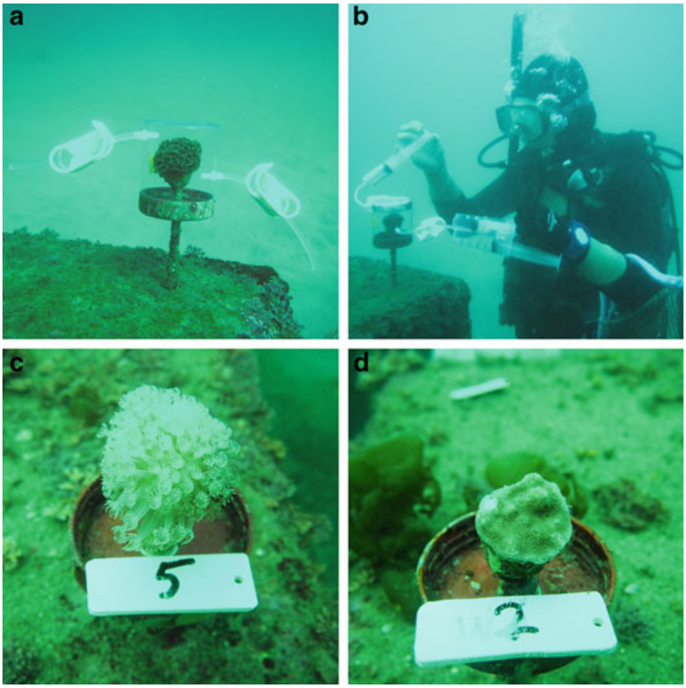


**Fig. 2** Transplantation setup in the field. **a** A closed chamber with a colony of *A. japonica* for in situ metabolism measurement in the light. **b** SCUBA diver sampling chamber water at the end of the light incubation for light metabolic rate measurements. **c**, **d** Bleached colonies of *A. japonica* and *P. heronensis* as observed in May 2014

samples were brought back to the laboratory and pH was measured using an Orion 4-Star pH equipped with a ROSS electrode (Thermo Scientific, USA) calibrated on the NBS pH scale. The remaining water sample was filtered through 0.45 μm cellulose acetate filter (Advantech, Japan) and stored in the dark at room temperature until they were measured. Total alkalinity was determined according to the protocol of the manufacturer using a TA titrator (ATT-05, Kimoto) in open cells. The titrations were cross-validated using a working standard and against certified reference material purchased from the A. G. Dickson laboratory. Total dissolved inorganic carbon (DIC) was calculated using the $CO_2$SYS software (Pierrot et al. 2006). Measured pH, TA, temperature and salinity were used as the input variables, alongside the dissociation constants from Mehrbach et al. (1973), as adjusted by Dickson and Millero (1987), $KSO_4$ using Dickson (1990), and total borate concentrations from Uppström (1974). The net photosynthesis rates were calculated from the difference in calculated DIC concentration between the start and the end of the incubation in the light, corrected for the changes in DIC due to calcification. Respiration rates under dark conditions were similarly calculated using the difference in DIC (Fujimura et al. 2001). The differences in total alkalinity were used to calculate calcification rates under both light and dark conditions (Smith and Key 1975).

The three colonies of each species used for metabolism measurements were then brought back to the laboratory for physiological measurements. The maximum quantum yield of photosystem II (*Fv/Fm*) was measured using a Junior PAM (Walz, Germany) following a 30 min dark adaptation period. The settings used were: measuring light 8, saturation light 8 and gain 1.

Colonies were washed with 0.7 M NaCl solution and tissue removed from the skeleton using an air jet filled with ice-cold phosphate buffer saline solution at pH 8.5 (100 mmol $l^{-1}$ phosphate buffer, 10 g $l^{-1}$ of NaCl). The tissue slurry was then homogenised using a Teflon potter homogeniser on ice. Two aliquots of the tissue slurry were taken for zooxanthellae density and phylogenetic genus determination. The remaining slurry was centrifuged at 1000 g for 10 min at 5 °C to separate the host fraction (supernatant) and the zooxanthellae fraction (pellet). The zooxanthellae pellet was resuspended in a phosphate buffer saline solution and centrifuged two additional times. The following parameters were measured in the host fraction: mitochondrial electron transport system activities (ETSA), catalase activities (CAT), total superoxide dismutase activities (SOD host) and total protein contents. ETS activities were determined following Agostini et al. (2013) using the reduction of 2-(4-iodophenyl)-3-(4-nitro-phenyl)-5-phenyl-2H-tetrazolium chloride (INT) after separation and homogenisation of the host mitochondria (expressed in mg $O^2$ $h^{-1}$ $mg^{-1}$ (host protein)). The activities of CAT in the host were measured spectrophotometrically by following the decrease in absorbance of added $H_2O_2$ at 240 nm (Beers and Sizer 1952). SOD host was assayed using the nitrite method which is based on the inhibition of nitrite formation from hydroxylamine under the presence of hypoxanthine as a generator for radical oxygen with modification from Elstner and Heupel (1976) and Higuchi et al. (2008). Protein concentrations were determined by the Bradford assay (Bradford 1976). In the zooxanthellae fraction, total superoxide dismutase activities (SOD zoox) and total protein contents were measured. In addition, for the zooxanthellae, their number and of those undergoing mitotic division (i.e. cell doublets linked by a cell wall) were counted in the homogenate using a Neubauer counting chamber in order to determine zooxanthellae density and mitotic index. The genus of zooxanthellae (*Symbiodiniaceae*) was determined by using restriction fragment length polymorphism (RFLP) analysis (Yuyama and Higuchi 2014). The SOD activities of the zooxanthellae fractions were determined using the same methods as the host with the difference that zooxanthellae were lysed before measurement by sonication with phosphate buffer in the presence of 0.025% Triton X100. Protein contents of zooxanthellae were also determined by the Bradford assay (Bradford 1976).

Metabolic rates (photosynthesis, respiration, and calcification) were normalised by the surface of the coral colonies, which was determined by the aluminium foil technique (Marsh and Marsh Jr. 1970). Physiological parameters were normalised by the amount of protein (host and zooxanthellae as required). The normality of the data was visually assessed by QQ plots and the homogeneity of variance was checked using the Levene test. As these two hypotheses could be verified the statistical significance of the difference across months of the different parameters measured was estimated using one-way ANOVA and the Tukey HSD test was used when relevant. All statistical analysis and production of the different plots were done using the R software (Team 2011) and a collection of packages (Fox et al. 2011; Kassambara 2018; Wickham 2016).

## 3 Results

The corals recovered well from the sampling and fixation on the rods with their tissue and skeleton growing over the exposed skeleton and epoxy during the recovery period at the Shimoda Marine Research Center, no paling or bleaching was observed following sampling and prior to transplantation. Once set up underwater, the corals kept a good colour and had their polyp extended each time they were checked before the measurement in November 2014. Small barnacles, coralline algae and other algae grew on the lid, rod and epoxy especially during the first months of the transplantation. These were removed as much as possible using wire brushes, being careful to not hurt the corals. Temperature at the transplantation location ranged between 12.3 °C (minimum temperature observed on the 12th of February 2014) and 26.4 °C (on both the 4th, 5th September 2013 and 16th September 2014), with a median of 17.8 °C. There were 110 days under 15 °C and 243 days under 18 °C (Fig. 1). Corals started to bleach in February 2014 and were fully bleached in May 2015 (Fig. 2c, d), so three months after the minimum temperature was reached but still with temperature under 15 °C. Bleaching was especially visible for *A. japonica* while *P. heronensis* showed mostly paling. No mortality was recorded. Analysis of the zooxanthellae genus was performed at the end of the experiment and revealed that *P. heronensis* hosted zooxanthellae from the *Cladocopium*, and *A. japonica* hosted mix genus, not only *Cladocopium* zooxanthellae but also *Fugacium*.

Measurements on the state of symbiosis such as zooxanthellae densities, photosynthetic yields and net photosynthesis rates, confirm the occurrence of bleaching during the coldest months (February and March 2014, where temperature was less than 15 °C), and its slow recovery during the following months (April, May and June 2014). Difference in the mechanisms of cold bleaching among both species was also highlighted (Fig. 3a, b, v, e–g).

In *A. japonica* all these parameters were significantly affected by temperature (ANOVA, df = 4, $p < 0.05$) while in *P. heronensis* only the maximum photosynthetic yield (*Fv/Fm*) (Fig. 3g) was affected (ANOVA, df = 4, $p < 0.05$). Post hoc tests, when significant, revealed that the minimum value for these parameters was mostly reached in May 2014, (i.e. *A. japonica* and *P. heronensis*, PAM (Fv/Fm): May, Tukey HSD, $p < 0.05$). Decreased mitotic index of the zooxanthellae (Fig. 3d, h) was also observed during May following the winter in both species (ANOVA, df = 4, $p < 0.05$ and Tukey HSD, $p < 0.05$) with very high rates during the favourable months for *P. heronensis* (i.e. 21.7 ± 3.9% in July 2014).

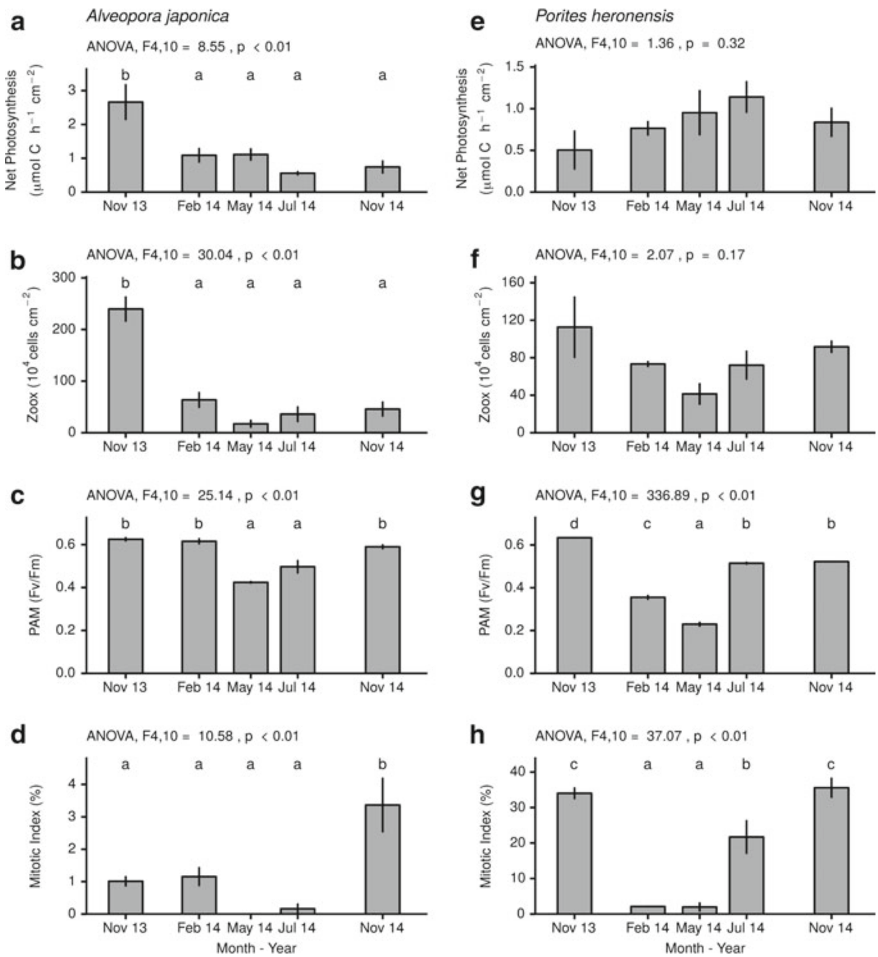


**Fig. 3** Net photosynthesis (**a**, **e**), zooxanthellae densities (**b**, **f**), maximum photosynthetic yield (**c**, **g**) and zooxanthellae mitotic index (**d**, **h**) for *A. japonica* (**a–d**) and *P. heronensis* (**e–h**). Letters indicate statistical groups as computed by Tukey HSD test at 95% interval of confidence. Error bars represent standard errors

Enzymatic activities associated with the removal of reactive oxygen species: SOD and CAT, were not affected by temperature (*A. japonica*: SOD.zoox and CAT Fig. 4b, c, *P. heronensis*: SOD.zoox Fig. 4f, ANOVA, df = 4, $p > 0.05$) or the effect was minor and post hoc test could not reveal a significant difference across measurements (*P. heronesis*: CAT, Tukey HSD, $p > 0.05$, Fig. 4g). The only exception was the host SOD activities (Fig. 4a,e) for which a maximum activity was recorded during November 2013 and minimum activities during the months of bleaching: February, May 2014 (Tukey HSD, $p < 0.05$).

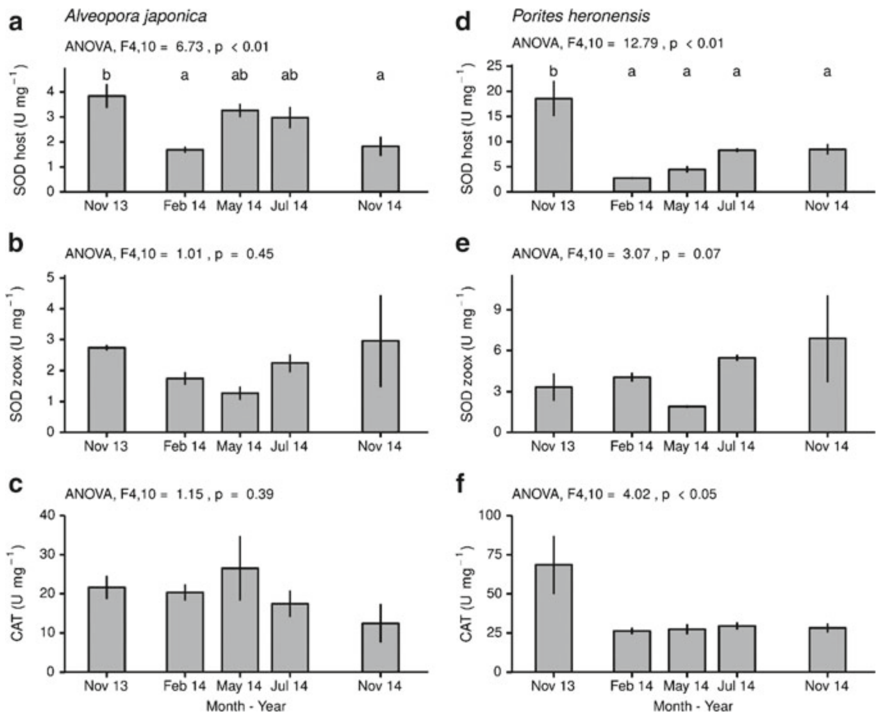


**Fig. 4** SOD activities of the host (**a**, **e**), SOD activities of the zooxanthellae (**b**, **f**) and catalase activities of the host (**c**, **g**) for *A. japonica* (**a**–**c**) and *P. heronensis* (**e**–**g**). Letters indicate statistical groups as computed by Tukey HSD test at 95% interval of confidence. Error bars represent standard errors

Growth of the corals was affected by temperature in both species (Light Calcification, ANOVA, df = 4, $p < 0.01$, Fig. 5a, e) with minimum light calcification rates observed in February 2014 for *P. heronensis* (Tukey HSD, $p < 0.05$) less than half of the rates observed in November 2013 (Fig. 5e, 0.36 ± 0.05 and 0.07 ± 0.02 μmol $CaCO_3$ $h^{-1}$ $cm^{-2}$ average ± SE, n = 3, in Nov 2013 and Feb 2014 respectively).

For *A. japonica*, calcification rates were low in February 2014 (Fig. 5a, 0.23 ± 0.05 μmol $CaCO_3$ $h^{-1}$ $cm^{-2}$), but the minimum was reached in July 2014 (0.14 ± 0.06 μmol $CaCO_3$ $h^{-1}$ $cm^{-2}$), and the maximum was reached in November 2013 with 0.45 ± 0.04 μmol $CaCO_3$ $h^{-1}$ $cm^{-2}$). Calcification rates in the dark (Fig. 5b, f) were lower than calcification in the light and while the temperature did not significantly affect it (ANOVA, df = 4, $p > 0.05$ for both species), negative net calcification, dissolution, was observed during some measurement (*A. japonica*: November 2014 and *P. heronensis*: Nov 2013 and February 2014). Respiration rates (Fig. 5c, g) were significantly affected by temperature for *P. heronensis* (ANOVA, df = 4, $p < 0.05$) with rates of 0.20 ± 0.05 μmol $CaCO_3$ $h^{-1}$ $cm^{-2}$ in February 2014 compared to 0.47 ± 0.09 μmol $CaCO_3$ $h^{-1}$ $cm^{-2}$ in November 2013 (Tukey HSD, $p < 0.05$). For *A. japonica*, while the respiration rate seems to follow a similar trend like in the case of

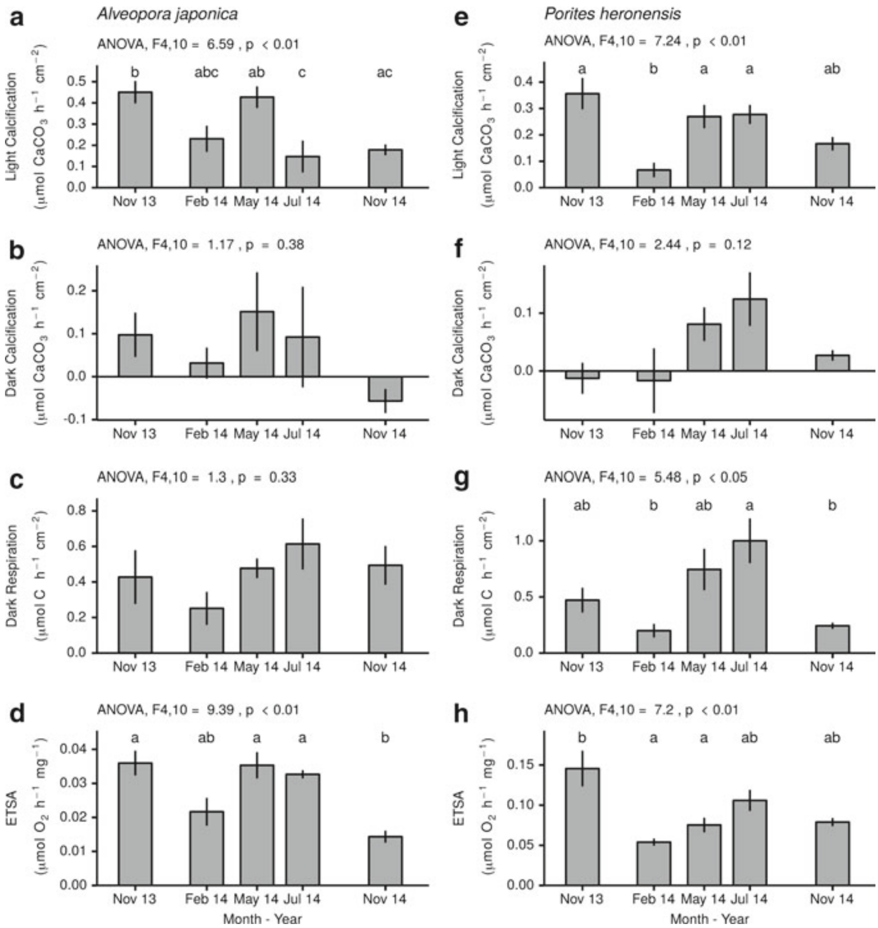


**Fig. 5** Light calcification (**a**, **e**), dark calcification (**b**, **f**), dark respiration (**c**, **g**) and ETSA (**d**, **h**) for *A. japonica* (**a**–**d**) and *P. heronensis* (**e**–**h**). Letters indicate statistical groups as computed by Tukey HSD test at 95% interval of confidence. Error bars represent standard errors

*P. heronensis*, the difference across month was not significant (ANOVA, df = 4, $p = 0.33$). ETS activities, a parameter related to the host maximum potential respiration, significantly differ over the year (both species ANOVA, df = 4, $p < 0.01$, Fig. 5d, h) with the lowest values observed for both species in February and November 2014 (Tukey HSD, $p < 0.05$).

## 4 Discussion

Cold bleaching is commonly observed in marginal high latitudes coral communities (Yamano and Namizaki 2009) and leads at times to high mortality rates of corals during winter. Such events highlight the marginality of these coral communities. Here, while both species showed bleaching during winter (Fig. 3), no mortality was recorded, even in the case of *A. japonica* which showed the most severe bleaching over several months. These results emphasise the importance of cold stress resilience for the survival of corals in high latitude areas (Higuchi et al. 2015). Both species are commonly found in the temperate regions of Japan and Asia (Nishihira and Veron, 1995). Tropical corals are under severe stresses at temperature under 18 °C (Colella et al. 2012; Kleypas et al. 1999), in comparison here these corals experienced 243 days under 18 °C and 110 days under 15 °C. This high resilience to cold stress allows them to survive in high latitudes and could be a common trait of corals found in high latitudes marginal coral communities (Chen et al. 2016; Howe and Marshall 2001; Ross et al. 2018). While the future increase in temperature under global warming may allow more species of corals to colonise higher latitudes, cold winter events will certainly occur and may cause extended mortalities of coral species less resilient to cold stress. This could severely limit the number of species that will be able to find refuges in higher latitudes. It is therefore important to understand in more detail the mechanisms of cold bleaching and of its resilience.

Several studies pointed out that cold stress can be as detrimental to coral health as hot stress on a short time scale (Roth et al. 2012). On the other hand, the decrease in zooxanthellae or its photosynthetic pigments (chlorophyll *a*) under low temperature was seen as an acclimation of marginal coral species to the low temperature in the form of thermal compensation that allows the maintenance of the symbiotic relation (Howe and Marshall 2001). The fact that coral in our experiment could survive several months bleached suggests that the cold bleaching observed here, which is due to a slow and natural decrease in temperature, may not be as detrimental as bleaching observed under laboratory conditions, where the decrease in temperature is much faster. Roth et al. (2012) showed that after a period of acclimation of two weeks the coral metabolism and zooxanthellae health under low temperature, while remaining low, stabilised. The pattern of bleaching observed in both species differed with *A. japonica* showing a decrease in zooxanthellae density while the bleaching in *P. heronensis* was mainly limited to a decrease in the photosystem's efficiency (Fig. 3). Nevertheless, a common trend was a lack of increase in SOD or CAT during the most severe bleaching periods, and on the reverse an increase during the warmer period of the year (Fig. 4). This lack or SOD response during cold bleaching has been observed earlier (Higuchi et al. 2015) and as stated there, this results can be interpreted under two different aspects: cold bleaching is not associated with the production of ROS and antioxidant enzymes activities decrease with the abundance of photosymbiont (Dykens et al. 1992), or the low metabolism of the corals under low temperature does not allow them to produce the enzymes. Under a slow natural decrease of temperature, it is, therefore, possible that these coral species are able to acclimate to the low-temperature conditions by reducing their metabolism and zooxanthellae density. While this acclimation leads to a strong reduction in growth rate (Fig. 5), it may limit the production of ROS and oxygen limitations (Pörtner 2002), and allow them to survive the winter.

Whether or not cold bleaching is associated with cellular damages due to ROS, do not remove the fact that the energetic input from photosynthesis is highly reduced during bleaching that extends for several months (Fig. 3). Under hot stress, such long bleaching period would certainly lead to a high mortality (Hughes et al. 2018; Kayanne et al. 2017). Resilient coral species to bleaching, under high-temperature stress, have been shown to use lipids reserve to compensate for the loss of energetic input (Rodrigues and Grottoli 2007). The low respiration and growth rates of the corals observed during winter (Fig. 5), suggest that the corals may be able to survive on very few energetic inputs. ETSA, which is equivalent to the potential for respiration, was also reduced during winter (Fig. 5), especially for *P. heronensis*, suggesting that the basal metabolism of the corals was reduced (Agostini et al. 2013). Reduction of metabolism, thermal compensation, during the minimum temperature periods is common in cold water marine ectotherms (see Pörtner 2002 for review). Decreased ETSA and respiration rates were less marked for *A. japonica* which was the species that experienced the most severe bleaching (Figs. 3 and 5). This suggests that *A. japonica* was still able to maintain a relatively high basal metabolism even under severe bleaching. A possible explanation of how this species was able to maintain its basal metabolism could be a shift from autotrophy to heterotrophy during winter as it has been observed for other high latitudes corals (Ferrier-Pagès et al. 2011; Hoogenboom et al. 2010; Rodolfo-Metalpa et al. 2007). To support this hypothesis big polyps corals, such as *A. japonica*, are thought to be more reliant on heterotrophy than smaller polyp species (Porter 1978). Heterotrophy may, therefore, be an alternative source of energy for *A. japonica* during winter allowing for its survival. More data including gastrovascular cavity contents (DNA and microscopic observation) and grazing rates or coral tissue isotopic compositions will be required to confirm this hypothesis.

Adaptation to the low winter temperature experienced in high latitudes could be provided by the zooxanthellae symbiont. *P. heronensis* exhibited during the warm months some extremely high mitotic index, more than 30% (Fig. 3), while in the literature the highest mitotic index reported was 14.1% for a Caribbean coral (Wilkerson et al. 1988). This indicates a very high activity of the zooxanthellae during the warm period and could allow this species to recover promptly from winter low-temperature damages once the temperature becomes favourable. Zooxanthellae associated with *P. heronsensis* were from *Cladocopium*, which is widespread across the Indo-Pacific (van Oppen et al. 2001), while *A. japonica* exhibited the uncommon *Fugacium* in addition to *Cladocopium*. The association of *Fugacium* zooxanthellae with *A. japonica* was already reported in Japan (Lien et al. 2013) and in Korea (Rodriguez-Lanetty et al. 2003), suggesting that this species has a strong relationship with *Fugacium*. Whether this specific *Fugacium* provides an advantage in terms of cold resilience is not known and was not reflected in our study as *A. japonica* showed the most severe bleaching. On the other hand, *P. heronensis* exhibited zooxanthellae from the common *Cladocopium*, and while thermal resilience of certain clades of zooxanthellae has been suggested in the past (Berkelmans and van Oppen 2006), *Cladocopium* was not one of them. Our results, therefore, highlight the insufficiency of the classification to conclude on physiological traits of zooxanthellae (LaJeunesse et al. 2018).

The two species studied here showed great resilience to cold stress through perhaps specific adaptations allowing their survival in the marginal high latitudes. The results of our studies suggest that these two species have different strategies: reduction in basal metabolism during winter and a possible shift to an alternative source of energy during the bleaching period. The length of exposure to cold temperature described here would be fatal to most coral species (Hoegh-Guldberg, et al. 2005; Colella et al. 2012). Moreover, as the level of cold stress resilience observed here may not be widespread among corals, it is important to take into account the occurrence of sporadic cold events in the higher latitudes such as those caused by sudden shifts in the position of the great meander of the Kuroshio Current (Murazaki et al. 2015), for the prediction of the future poleward shift of coral species. Thus, cold events could lead to high mortality of coral species which recently shifted towards higher latitude and that do show the high resilience to cold stress of the two species studied here which are already established at these latitudes. Because of their endemicity and potential adpation not common in scleractinian corals, already established high latitude marginal coral communities represent a reservoir of biodiversity (Veron 1992) that could play a determinant role as a refuge for coral diversity under climate change (Makino et al. 2014).

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# Preliminary Report of Impacts of the 2011 Earthquake and Tsunami and Subsequent Events on Macrobenthic Community in a Shallow Brackish Lagoon in Sendai Bay, Japan

**Tomohiko Kondoh, Gai Nakayama, and Waka Sato-Okoshi**

**Abstract** We have been monitoring the spatio-temporal change of macrobenthic community inhabiting soft sediment in Gamo Lagoon which is located on the north side of the Nanakita River Estuary in Sendai Bay, Japan since 2011 earthquake and tsunami disturbance. Unstable condition of estuary topography has been observed to continue until 2017. Just after the disturbance, topography was catastrophically damaged, and macrobenthic community was almost all disappeared by flowing outward and/or being buried in soft sediments caused by tsunami. Soon after that, some opportunistic polychaetes and amphipods were observed to appear, and they sharply increased their population. The secondary series of disturbance, namely river mouth closing and typhoon-derived floods occurred, the area lasted completely in freshwater condition, and that following drastic decline in density again. Adding to these initial sudden changes within a year, successive events and serious diurnal hypoxia in summer were observed every year from 2012 on. Dominant species consisted of firstly small polychaetes and amphipods and later adding bivalves repeatedly appear and disappear during the period. Furthermore, the extraordinary intense deluge occurred in 2015 and the second tsunami arrived in the estuary following Fukushima Earthquake in 2016. The collapse of the balance of the sediment dynamics is suggested to be the worst and major cause which drove the estuary to an unstable environment and macrobenthos community continued to be vulnerable until 2017. Not only natural disturbances but continuous anthropogenic disturbances such as reconstruction of seawalls and dikes have been carried out around the estuary since 2011.

**Keywords** Tsunami · Disturbance · Lagoon · Topography · Macrobenthos · Community structure · Great East Japan Earthquake

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# 1 Introduction

Macrobenthos shows a high biodiversity, abundance and biomass. Many species of macrobenthos inhabit soft sediment in an estuary and lagoon worldwide. For its high productivity, it plays an important role in marine food webs especially for the food for the upper producers such as fish and birds. It also functions as facilitating water purification by filter feeders such as bivalves, decomposition of bottom organic materials by polychaetes and crustaceans and materials circulation through its bioturbation. Accordingly, the macrobenthos contributes to the stability of the marine ecosystem and that estuary and lagoon environments provide essential ecosystem functions (Levin et al. 2001; Ortega-Cisneros and Scharler 2014).

On the other hand, macrobenthos, especially in faunal macrobenthos, usually have limited mobility, and thus, the adults have limited abilities to immigrate to open patches for recolonisation following a disturbance. Moreover, they are tightly associated with physical and chemical condition of bottom sediments. Considering these characteristics, the successional dynamics of macrobenthic community is a useful indicator for evaluating the impacts of disturbances in the benthic environment (Gray 1974; Rhoads 1974; Dean 2008).

A megathrust earthquake, the Great East Japan Earthquake and huge tsunamis occurred in March 2011 (Ide et al. 2011; Ozawa et al. 2011). Although great natural disturbances such as earthquakes and tsunamis have repeatedly occurred since the beginning of the natural history of earth, less study and research have done on long-term monitoring after the disturbance, only some have reported on short/medium-term monitoring (Hunsigi et al. 2006; Chavanich et al. 2008; Whanpetch et al. 2010; Kanaya et al. 2014, 2015, 2017; Abe et al. 2015, 2016; Kondoh and Sato-Okoshi 2016; Kondoh 2017; Nakayama 2017; Seike et al. 2017). The aim of our study is to evaluate the long-term impacts of the 2011 earthquake and tsunami on macrobenthic community and to examine the response of the community to a large-scale disturbance and subsequent events, and this is a preliminary report of the ongoing monitoring study. This also may be an important issue to understand the mechanisms that determine and control the community structure.

# 2 Materials and Methods

## 2.1 Study Site

Nanakita River flows in Sendai Bay, north-east mainland of Japan and Gamo Lagoon (0.1 $km^2$, mean water depth 0.8 m) is located on the north side of the estuary (Fig. 1).

The lagoon is separated from the estuary by a stone levee with three water gates and from Sendai Bay by a 150 m wide sand dune. The bottom sediment of river side and inner part of the lagoon is sandy and muddy, respectively, and high reduction condition was observed in the innermost part of the lagoon. Topographical change

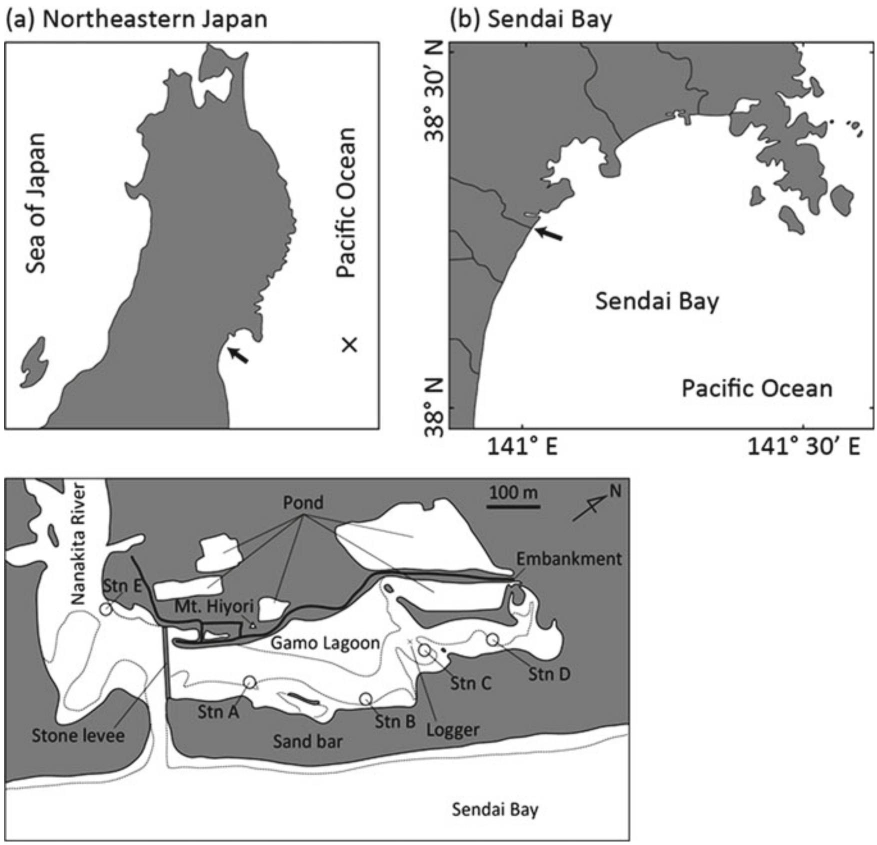


**Fig. 1** Map of Gamo Lagoon and Nanakita River mouth, Miyagi Prefecture, northeastern Japan. Each arrow points the Gamo Lagoon. X is the epicentre of the 2011 Earthquake

was monitored by direct observation and using aerial photography (Google earth https://www.google.co.jp/intl/ja/earth/).

## *2.2 Environmental Analyses*

Water temperature, salinity, dissolved oxygen (DO) concentration for the bottom layer and water depth were measured every 30 min using a data-logger (YSI, 600OMS) set in the lagoon and digital water quality meter (DKK-TOA, CM-21P; YSI, proODO) for temporal use from 2012 summer. Redox potential was measured by ORP meter (DKK-TOA, RM-30P) from 2014, and sediment grain size composition was analysed as silt-clay %, monthly from 2012 summer.

### 2.3 Samplings of Macrobenthos

Samplings were conducted at river side (Stn A), middle (Stns B and C) and innermost part (Stn D) of the Gamo Lagoon from May 2011 on and at extra station in Nanakita River (Station E) irregularly. Sampling was temporarily and repeatedly ceased by topographical changes. Samples were collected once a month using an Ekman-Birge grab (240 mm (W) × 210 mm (D) × 350 mm (H)) and sieved through a 0.5 mm mesh, and all organisms remaining on the sieve were fixed with 10% neutralised formalin. Each organism was sorted, identified and counted under a stereomicroscope.

## 3 Results and Discussion

### 3.1 Topographical Change

Before the earthquake and tsunami, the topography around the estuary was relatively constant for many years (Fig. 2a). Just after the disturbance, liquefaction and subsidence were observed, and the topography around the estuary was catastrophically damaged (Kanaya et al. 2016; Kondoh 2017). Sand dune was disappeared completely, and there was no boundary differentiation between ocean and lagoon (Fig. 2b). River mouth was widely opened. Afterwards, sand dune was rapidly reformed through the deposition of drifting sand (Fig. 2c), and also river mouth was completely closed in June and continued its condition (Fig. 2d). This two-month estuary closing induced estuary and lagoon to last completely in freshwater environment. A typhoon-induced flood hit the area in September, and this resulted in forming a new opening mouth at the central lagoon (Fig. 2d). The excavation of the river mouth was conducted at its original location in March 2012, and shortly after that, the new river opening was closed by drifting sea sand (Fig. 2e).

After the intense deluge happened in September 2015, the environment of the estuary was affected greatly again, and topography kept changing every month since then. Moreover, in November 2016, the second tsunami followed by Fukushima Earthquake hit this estuary, and the water level and bottom sediments have repeatedly and greatly fluctuated.

As shown above, the balance of the sediment dynamics—sedimentation and outflow of sand—continued to collapse, and this unfavourable condition lasted until 2017. Especially at river mouth, the water depth and sediment granulometry have commonly fluctuated and continued unstable since the disturbance. During these years, temporal reconstructions have intermittently been conducted around this area. From April 2018, a large-scale of reconstruction of the dike will be planning to begin at the mouth of the Gamo Lagoon.


**Fig. 2** Topographical changes of Gamo Lagoon before and after the 2011 earthquake and tsunami using Google Earth (https://www.google.co.jp/intl/ja/earth/). **a** Before the earthquake and tsunami. **b** Just after the earthquake and tsunami. **c** Sand deposits were quickly observed. **d** River mouth was closed and a new water mouth was formed inside the Lagoon. **e** River mouth was constructed at the previous position. **f** Present Gamo Lagoon and Nanakita River mouth

## *3.2 Environmental Data*

In Gamo Lagoon, water temperature showed a clear seasonal change annually ranged from the lowest value of ca −2 °C in January to the highest value of ca 37 °C in August. It did not show so much difference among the stations for successive years.

The salinity ranged relatively in high level from 20 to 30 for successive years since 2013 (Kondoh 2017). Diurnal variation in salinity did not largely fluctuate compared to that reported before the 2011 disturbance (ca 0–30) (Kanaya et al. 2016). There were several groundwater veins and water flows from the nearby aquaculture farms before the disturbance, and they adjusted the salinity of the lagoon downward (Miyagi Prefecture, personal communication). After the great earthquake, these veins seemed to disappear, and farms were destroyed. The period when some specific events happened, i.e., during the typhoon-derived floods in the initial sudden change, the salinity drastically dropped and lasted below 5.

Oxygen deficient water occurred in inner part of the lagoon every summer season. DO concentration drastically fluctuated diurnally from 0 at night to ca 20 mg/L at daytime in inner part every day in summer season after 2012. The seasonal change showed relatively high DO concentration in winter and low concentration in summer, and spatially relatively high in river side and low in innermost part for successive years.

High value Eh in the river side and low value in the inner part of the lagoon were recorded throughout the year. The severe reduction condition was observed especially in the innermost part of the lagoon.

Silt-clay composition varied and it seemed lower than that before the disturbance (Kanaya et al. 2016). There was a gradient of the composition from low at river side to high % at innermost part of the lagoon.

Changes in the water level were observed from 0 to 1.7 m at the inner part of the lagoon with the maximum value of 1.5 m in a day.

## *3.3 Dynamics of Macrobenthic Community*

### 3.3.1 Macrobenthic Community in Gamo Lagoon

Just after the disturbance, in May 2011, number of species, abundance and biomass of macrobenthos were very low. However, one month later in June, a small opportunistic polychaete *Capitella* aff. *teleta* (Fig. 3) was observed to appear and sharply increased in density.

After a small and opportunistic polychaete increase, it rapidly declined in number following salinity drop caused by the typhoon-derived flood into the lagoon. There are no data during the period of freshwater environment in the middle part of the lagoon. Spionid polychaete *Pseudopolydora* cf. *kempi* (Fig. 3) dominated with two

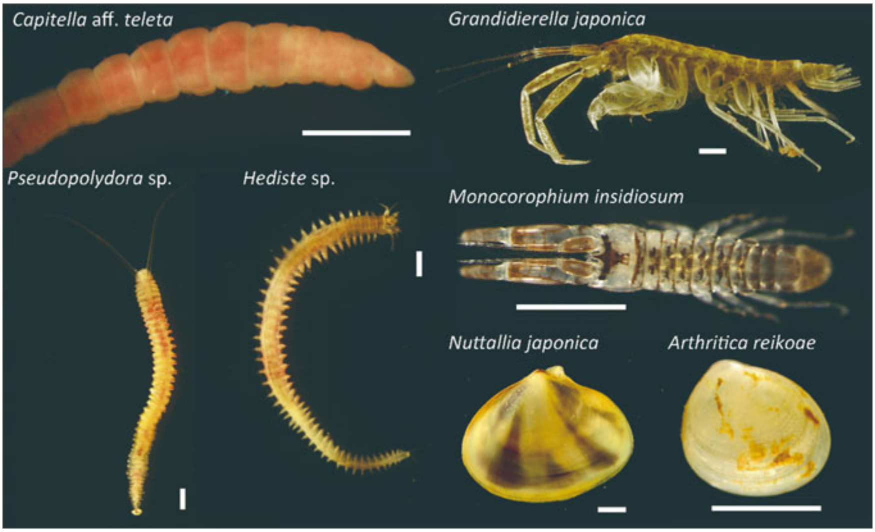


**Fig. 3** Dominant macrobenthic species inhabiting Gamo Lagoon. Each bar indicates 1 mm

**Table 1** Dominant macrobenthos species before and after each summer season in inner part of Gamo Lagoon from 2012 to 2016

| Year | Dominant species | |
|---|---|---|
| | Before summer | After summer |
| 2012 | *Hediste* spp. | *Monocorophium insidiosum* |
| 2013 | Tubificidae, *Capitella* aff. *teleta* | *Grandidierella japonica, Hediste* spp. |
| 2014 | *Grandidierella japonica, Monocorophium insidiosum* | *Arthritica reikoae, Hediste* spp. |
| 2015 | *Arthritica reikoae, Hediste* spp. | *Hediste* spp., Tubificidae |
| 2016 | *Pseudopolydora* cf. *kempi, Hediste* spp., Tubificidae | *Arthritica reikoae* |

amphipods *Grandidierella japonica* and *Monocorophium insidiosum* (Fig. 3) in the innermost part of the lagoon at the same time.

After April 2012, when the river mouth was excavated at the previous position, Tubificidae appeared firstly and after a month, *Hediste* spp. which is composed of two species, namely *H. atoka* and *H. diadroma* (Fig. 3) increased in the lagoon. From August, *Grandidierella japonica* and *Monocorophium insidiosum* dominated until December. The recruitment of the bivalve species was not observed in 2011 but appeared in 2012. This recruitment delay in bivalves seemed to be the result of the freshwater floods in summer which is the recruitment season for the dominant bivalve species *Nuttallia japonica* (Fig. 3). During 2013, the community was unique with low density of Tubificidae and *Capitella* aff. *teleta* dominant at the river side of the lagoon.

The structure of macrobenthic community began to change before and after every summer season from 2012 (Table 1) and this tendency continued until 2017. This is thought to be the effect of serious diurnal hypoxia which occurs every summer from 2012. Bivalve *Arthritica reikoae* (Fig. 3) frequently dominated before or after the summer season for a short period. Also, *Capitella* aff. *teleta, Hediste* spp., *Pseudopolydora* cf. *kempi*, *Grandidierella japonica* were observed to be the dominant species before or after the summer hypoxia, the species was alternative each year. The reason of which species/group dominates after each summer hypoxia is unclear; it may be expected to demonstrate after determining the ecological characteristics of each species including its life history.

After the 2016 Fukushima Earthquake, tsunami arrived once more into the lagoon, and the sharp decline of the density of the macrobenthic community was observed. Soon after that, *Capitella* aff. *teleta* quickly increased its population in the inner part of the lagoon.

The phenomenon that the amphipod *Grandidierella japonica* seemed to migrate seasonally between river and inner side of the lagoon was observed every year, and this suggests the adaptation of the estuary species to avoid summer hypoxia which occurs in the inner part of the lagoon.

Although almost all the macrobenthos species which inhabited the lagoon before the 2011 disturbance were observed to appear within two years (Kanaya et al. 2016), their populations were unstable both in abundance and biomass. The macrobenthic community still shows fluctuation under unstable condition.

### 3.3.2 Macrobenthic Community in Nanakita River: Additional Samplings

After August 2012, polychaetes *Hediste* spp. and *Prionospio japonica* dominated at river side. Abundant of the amphipod *Grandidierella japonica* appeared every summer, and it became a dominant species temporarily, but the species tended to decrease and disappear quickly afterwards. Species diversity kept low throughout the survey in river side. After the intense deluge happened in September 2015, the water level and grain size composition of sediments have largely fluctuated and have become unstable since then. Simultaneously, the number of species and the density of the macrobenthic community continued in the lowest level. The structure of the macrobenthic community in the river seemed to continue unstable for successive years.

## 4 Conclusions and Perspectives

The results of our monitoring showed that macrobenthic community inhabiting vulnerable soft sand/mud sediments around estuary has fluctuated drastically since the great earthquake and tsunami disturbance. The results indicate that the macrobenthos suffered impacts not only directly by the earthquake and tsunami but also by several subsequent events occurred in relation to the earthquake and tsunami and so on.

Firstly, the collapse in sand sedimentation balance forced the soft sand/mud sediments constantly unstable, and this seemed to be the crucial cause that induced the macrobenthic community unstable for seven years. The loss of sedimentation balance also leads fluctuation in water level and grain size composition of sediments, which are the most important factors to determine the species habitat condition. Tsunami destroyed the salt marsh formation, and a typhoon-induced flood washed out the vegetation, and thus, these also seemed to affect the soft sediments as vulnerable. Although the energy level of the disturbance and environmental condition are different in each site, once the soft bottoms lose the balance in sedimentation by disturbance, it can be hypothesised that it needs long time, at least more than seven years, to recover to the previous state in the estuary.

And secondly, a serious diurnal hypoxia occurring every summer seemed to prevent the chance to increase the more species to recruit and survive in the lagoon. So, as a result, the estuary has continued being vulnerable only permitting the small and opportunistic species to survive and dominate for seven years.

Some of the unstable conditions described above may not be necessarily to be attributed to a series of disturbances, but they may be within the range of normal condition in Gamo Lagoon. There has been not enough research on monitoring macrobenthos community before the disturbance; community was investigated once a year or so usually in summer season for several discontinuous years (cited in Kanaya et al. 2016). Also, Kanaya et al. (2016) succeeded to monitor the community structure of just after every main event occurred in early stage after the 2011 disturbance and the results showed the short-term and direct influence of each event, there is no information of the community between each event. Therefore, it is difficult to discuss whether the unstable conditions especially a serious diurnal hypoxia observed in summer season and alternation of the dominant species after every summer are the results of the impacts of a series of the 2011 disturbance or just the common fluctuation within the range of condition here. The more data is necessary to understand the characteristics of Gamo Lagoon and clarify the impacts of the disturbance.

Not only these natural disturbances but a series of anthropogenic disturbances such as various reconstructions have been ongoing continuously and the effects of them are yet unknown. We need to continue to conduct monitoring of macrobenthic community to understand the long-term impacts of a series of great natural disturbances including subsequent events on the benthic environment, and we also need to pay close attention to the impacts of a series of anthropogenic disturbances on macrobenthic community and estuary ecosystem which might be on their way to recover.

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# Post-tsunami Oyster Feeding Environment in Nagatsuraura Bay for Three Years

**Yutaka Okumura and Motoyuki Hara**

**Abstract** We investigated water temperature, Chlorophyll *a* (Chl *a*) concentration, and oyster growth from April to December in 2014, 2016, and 2017 in Nagatsuraura Bay, Miyagi Prefecture, Japan. We also calculated the remaining phytoplankton biomass by subtracting total filtration of oysters in aquaculture areas. We estimated that suitable oyster culture density is when that value is positive. Water temperature was high in summer, exceeding 20 °C from mid-June to mid-September. Chl *a* concentration gradually increased from April through July, and remained high from July through September, before decreasing after October. Maximum Chl *a* exceeded 9 μg/L in the water column. In Nagatsuraura, which is a closed bay, the periods of phytoplankton bloom from Spring forward were longer than in open or semi-open bays. Therefore, Nagatsuraura oysters grow more quickly than those in open or semi-open bays. Oyster growth varied with the season. Although periodic weight loss by egg-laying was predicted from July to October, oyster weights tended to increase easily during this season compared with other periods. The mass balance of oyster feed in the aquaculture was calculated based on phytoplankton amount > 0 in most periods. As values were phytoplankton biomass in an aquacultural area > amount required by oysters, we inferred that Nagatsuraura is not deficient in oyster food. With the post-tsunami retirement of many fishery employees, and reduction in the number of oyster culture companies, the total quantity of oysters in the aquaculture grounds has decreased. As a result, the aquaculture grounds are not currently overcrowded.

**Keywords** Closed bay · Suitable culture density · Phytoplankton biomass · Tsunami disaster

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## 1 Introduction

The Great Eastern Japanese Earthquake and resulting tsunami of 11 March 2011 seriously damaged non-feeding aquaculture, including shellfish and seaweeds, throughout the Tohoku coastal area. Although pre-tsunami oyster harvest levels in Miyagi Prefecture ranged from 40,000 to 60,000 tons with shell, the harvest yield just after the tsunami was drastically reduced to about 5000 tons (Fig. 1) Since then, post-tsunami oyster harvest levels have gradually recovered, and were about 20,000 tons from 2014 to 2016. However, oyster stocks within the Miyagi Prefecture have been half that of pre-tsunami levels, and recovery speed has recently slowed.

For effective recovery of shellfish production and to avoid overcrowded aquaculture, suitable culture quantities of shellfish have been calculated for the Miyagi coast (Nagasawa et al. 2016; Okumura et al. 2017a). We previously investigated oyster growth (Okumura et al. 2017b) and the dietary environment in this coastal area. In calculating suitable culture densities, we analyzed one year of data (Okumura et al. 2017a, 2018). However, the dietary environment of oyster is expected to change every year, depending on oceanographic conditions. Therefore, from the viewpoint of improving precision, we thought a multiple-year investigation was necessary.

Oyster cultivation in Miyagi prefecture is a large-scale business, second only to Hiroshima prefecture. The dietary environment has been investigated since before the tsunami (Kamiyama et al. 2005, 2006). After the tsunami, the horizontal distribution of dinoflagellates (Kamiyama et al. 2014), diatom diversity (Watanabe et al. 2017), and the phenology of phytoplankton bloom (Taniuchi et al. 2017) were studied in Sendai Bay, a semi-open bay in the southern part of Miyagi Prefecture. The dietary environment (Okumura et al. 2017a) and the effects of the tsunami on phytoplankton (Okumura et al. 2015) have been shown to vary with the place. The coastline from the north to the middle of Miyagi prefecture is a rias coast with complex terrain. Therefore, surveys of each coastal area are necessary.

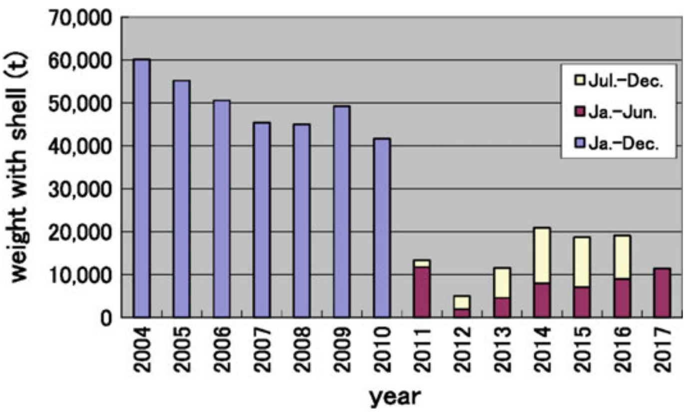



**Fig. 1** Temporal trend of oyster production in Miyagi Prefecture (MAFF 2018)

Nagatsuraura Bay is one of the closed bays in the middle of the coast of Miyagi prefecture. Its area is less than 2 $km^2$ (Takasaki and Tanaka 2004). Because of the moderate conditions and abundant nutrients separated from the outside (Kanesato et al. 2005), oyster has been cultured in Nagatsuraura for 60 years (Okajima et al. 2004). Before the tsunami, low dissolved oxygen (DO) caused by eutrophication (Okajima et al. 2004), mass mortality of oysters due to low DO (Igarashi 2006), and paralytic shellfish poison toxin (Ichimi et al. 2002) had all become problems in the bay. Various physical, chemical, and biological investigations were conducted (Ichimi et al. 2001; Kanesato et al. 2005; Santoso et al. 2007). The shape of the bay mouth was significantly changed by the tsunami (Kaneko personal communication). It was inferred that the oyster culture environment might also be different before and after the tsunami.

In this study, we calculated the relevant culture densities by assigning the obtained multi-year data to the simplified model that we have used for Nagatsuraura. We also analyzed the relationship between a slow recovery and the dietary environment of oyster, using statistical data from fishery companies and employees.

## 2 Materials and Methods

### 2.1 *Chlorophyll* a *and Water Temperature Observations*

The investigation to determine oyster feeding was conducted in Nagatsuraura Bay (38.5445° N, 141.4591° E) from April–December 2014 and 2017 (Fig. 2).

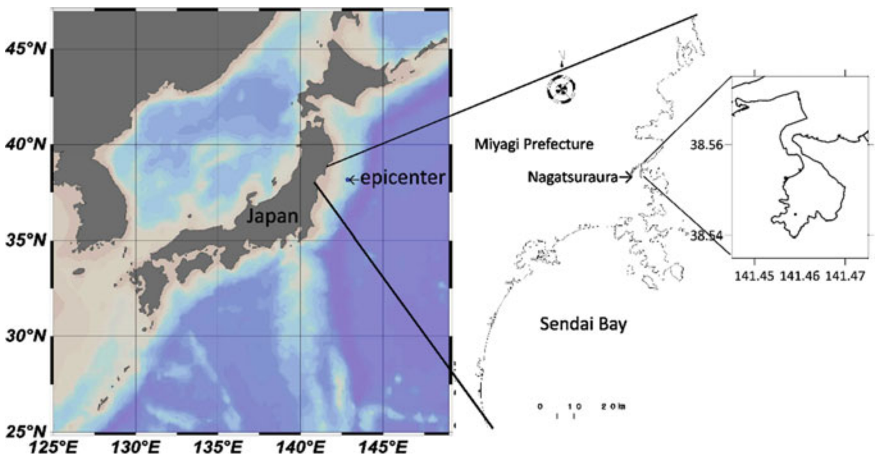



**Fig. 2** Sampling site of Oginohama and Nagatsuraura bays in Miyagi Prefecture, Japan

Chl *a* concentration was regularly measured by multiple water-quality meters (Rinko-Profiler, JEF Advantech CO., Ltd., Hyogo, Japan) positioned close to oyster rafts. In 2014, the water temperature was measured continuously with a water temperature sensor (ACTW-USB, JEF Advantech CO., Ltd., Tokyo, Japan) attached to an oyster raft. In 2017, multiple water-quality meters (Rinko-Profiler, JEF Advantech CO., Ltd., Tokyo, Japan) were used to measure temperature near oyster rafts.

## 2.2 Measurement of Oyster Growth and Calculation of Filtration Rate of Shellfish

To calculate the filtration rate and oyster growth rate, the weight of oysters in culture nets were measured over time ($n = 3$–$8$). The oyster filtration rates were calculated by substituting either equation modified (Okumura et al. 2017b) from original equations (Akashige et al. 2005).

When, water temperature $t$ (°C) < 11.8, $\mathrm{FR} = 0.26\mathrm{e}^{(0.1584 \times t)} \times W$
When, water temperature $11.8 \leqq t$ (°C) < 18.5, $\mathrm{FR} = (0.70 \times t - 6.6) \times W_{\mathrm{d}}$.
When, $t$ (°C) $\geqq$ 18.5 (season of egg laying), $\mathrm{FR}=4.9 \times W_{\mathrm{d}}$.

where FR is filtration rate, $W_{\mathrm{d}}$ is dry weight of oyster.

The ratio of the wet weight of soft tissue to the whole shelled body of oyster was 0.21 from the results of December 21, 2016 (Appendix). The ratio of dry weight to wet weight of soft body was 0.2 (Kawaguchi et al. 2011). The dry weight of soft tissue was converted from the whole-body weight with the shell using these ratios. Oyster growth rates were also calculated according to the method described in Akashige and Takayama (2003), with modifications (Okumura et al. 2017b).

## 2.3 Calculation of Suitable Oyster Culture Density

Suitable oyster culture level is defined as phytoplankton quantity in an aquaculture area exceeding the total filtration of phytoplankton by oyster. It indicates that the oyster culture has a sufficient food source. We calculated the phytoplankton quantity in the aquaculture areas minus the total filtration of phytoplankton by oysters each day, based on previous reports (Okumura et al. 2017a, 2018). Phytoplankton growth in the culture area was calculated by multiplying Chl *a* concentration by average growth rate (Okumura et al. 2018). The total filtration of oyster in the culture area was calculated by multiplying total biomass by filtration rate.

### 2.4 Collection of Parameters, and Statistical Data

The total number of rafts, ropes, collectors, and oysters per collector, and the growth rate of phytoplankton were obtained from data collected in previous studies (Okumura et al. 2017a). The parameters of oyster quantity used in this study were: 98 rafts × 300 ropes × 12.5 collectors × 14 ind./collector. The growth rate of phytoplankton was set at 0.54/day. Area, maximum depth, rate of aquaculture area to area of Nagatsuraura, and volume of aquaculture were set as 1.4 km$^2$, 9 m, 0.42, and 2,869,562 m$^2$, respectively.

The number of oyster culture companies and all fishery employees were obtained from the literature [Ministry of Agriculture, Forestry and Fisheries, Japan (M.A.F.F.), 2013, 2015]. Time trends of water temperature, Chl *a* concentration, and calculated oyster growth in 2016 were also obtained from a previous study (Okumura et al. 2017a).

## 3 Results and Discussion

### 3.1 Water Temperature

Patterns of water temperature variation in Nagatsuraura fluctuated with the observation year (Fig. 3). The maximum, minimum, and average values of water temperature in 2014 were 22.1, 7.5, and 15.0 °C, respectively; in 2016, those values were 24.4, 8.4, and 16.6 °C, trending higher than in 2014. Water temperature exceeded 20 °C from mid-June to mid-September. The period during which temperatures exceeded 20 °C was longer in 2016 than in other observation years. Maximum, minimum, and average value of water temperature in 2017 were 20.1, 7.7, and 15.3 °C, respectively. This water temperature variation pattern resembled that of 2014.

If the water temperature is either too low or too high, it is thought to influence oyster growth. In low-temperature water, oyster filtration decreases (Akashige et al.

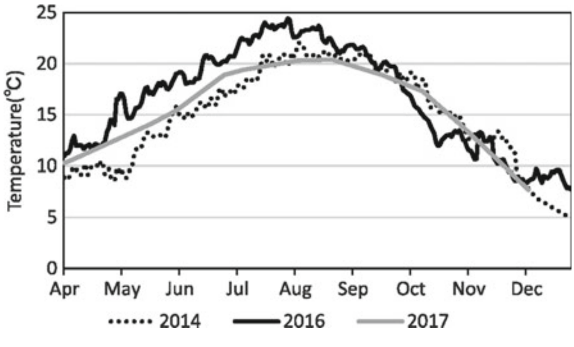



**Fig. 3** Water temperature in the oyster culture areas of Nagatsuraura. The data for 2016 is from a previous report (Okumura et al. 2017a)

2005). When filtration is low, growth is slowed. Conversely, if the water temperature is too high, the oyster growth is also thought to slow. This is because nutritional energy must be used preferentially for metabolism instead of growth. The upper limit of water temperature, at which there is no influence on metabolism, is thought to be lower than 18.5–20 °C (Akashige and Takayama 2003; Okumura et al., 2017b). Water temperature is also thought to influence egg-laying. Cumulative temperature of 600 °C is considered as a guide for egg-laying (Sugawara and Koganezawa 1995; Nakamura et al. 2003). If the water temperature is high, body weight can easily be reduced by egg-laying. The water temperature in 2016 tended to be higher than that in 2014 and 2017 and was considered the least suitable for oyster growth of the three observation years.

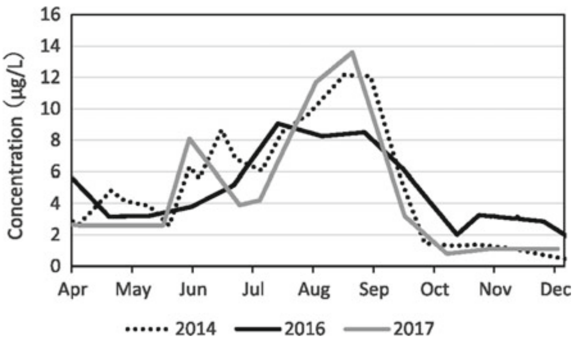
## *3.2 Chl* a *Concentration*

Patterns of Chl *a* concentration variation also fluctuated with observation year (Fig. 4) and resembled that of water temperature.

In 2014, the maximum, minimum, and average concentrations of Chl *a* were 12.2, 0.6, and 5.1 μg/L, respectively. Chl *a* concentrations were high from August to September, and decreased after October. In 2016, those values were 9.1, 2.0, and 4.9 μg/L, respectively. Although the average value was similar in 2014, Chl *a* concentration from August to September was lower than in 2014. Chl *a* concentrations in 2017 were 13.6, 0.8, and 4.6 μg/L, respectively. This maximum value was the highest of the three observation years, while the average was the lowest. Chl *a* concentration was high from August to September and decreased after October; the time trend pattern in 2017 was similar in 2014.

Although phytoplankton bloom in offshore or semi-open ocean is thought to be highest in the spring (Taniuchi et al. 2017; Watanabe et al. 2017; Okumura et al. 2018; Kaneko personal communication), Chl *a* concentration in Nagatsuraura, a closed bay, was continuously high until summer.

**Fig. 4** Time trend of average Chl *a* concentration measured in the water column at Nagatsuraura. The data for 2016 is from a previous report (Okumura et al. 2017a)



The quantity of oyster dietary demand varied with the season. The filtration of oysters was thought to increase with increasing water temperature. Phytoplankton quantity in summer is important for oyster growth. As Chl *a* concentration in Nagatsuraura in the summer is higher than that offshore the Miyagi coast, the period until shipment in Nagatsuraura is one year (discussion with fisherman), less than the two years necessary in open and semi-open sea (Tanabe 2013). Summer Chl *a* concentration was the lowest in 2016, and we inferred that the dietary environment for oyster that year was the most severe of the three observation years.

## 3.3 Oyster Growth

In Nagatsuraura, oysters grow quickly. In the three observation years, estimations of the soft body weight ranged from 1.7 to 4.0 gw.w. in May, from 2.7 to 6.0 gw.w. in July, and from 10.3 to 19.2 gw.w. in November. Over about 8 months, from late April to late December, oyster weight increased about 9 times (16.6 g/1.8 g) in 2014, 7 times (11.6 g/1.7 g) in 2016, and about 5 times (19.7 g/4.0 g) in 2017 (Fig. 5).

In general, the culture period of oyster to shipment in an open or semi-open bay is thought to be two years (Tanabe 2013). In Nagatsuraura, where culture periods are one year (discussion with fisherman), oysters grow more quickly than in an open or semi-open bay (Okumura et al. 2017a). Oyster growth varied with the season. Although periodic weight loss due to egg-laying was predicted from July to October, the oyster weights tended to easily increase from July to October compared to other periods. Oyster growth also varied with the year. Comparing 2014 and 2016, oyster growth after mid-July was faster in 2014, despite an almost equal weight in May. A comparison of 2014 and 2017 showed that oyster growth was better in 2017 than in 2014.

One reason why oyster growth in 2016 was the slowest of the three years was that year saw the lowest phytoplankton biomass in summer (August and September;

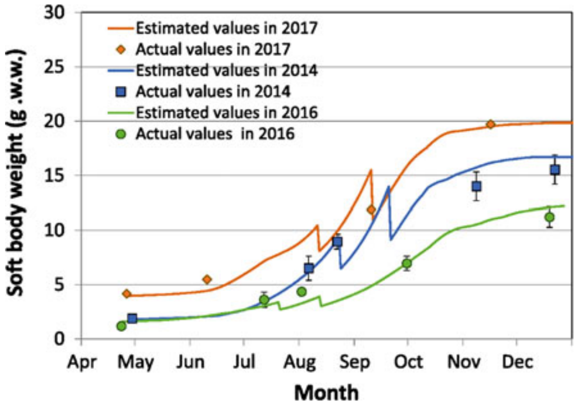



**Fig. 5** Comparison of growth model of oyster in Nagatsuraura for three years. The estimated values fit well with the measured values. The data for 2016 are from a previous report (Okumura et al. 2017a)

Fig. 4), and the highest water temperature (Fig. 3). We inferred that nutrition by feeding was used for metabolism rather than growth. Despite the water temperature and Chl *a* being almost the same in 2017 and 2014, oyster weight in 2017 was heavier throughout the observation period. We thought this was because the initial weight of oyster in 2017 was heavier than in 2014 and 2016. If the individual size is larger, shipping time may be accelerated. Meanwhile, the growth rate of 2014 (about 9 times), when initial weight was smaller than in 2016, was higher than in 2016 (about 5 times).

### *3.4 Mass Balance of Diet in Aquaculture Ground*

The mass balance of oyster feed in the aquaculture ground, calculated from the average aquaculture volume was the phytoplankton amount > 0 over a period (Fig. 6).

As it was feed amount by phytoplankton > necessary amount by the oyster, we inferred that Nagatsuraura is not deficient in oyster food. Although the values of estimated phytoplankton biomass varied with the year, the change patterns were similar in the three years. Phytoplankton biomass from April–August was estimated to be 5 $kg^{-1}$ $day^{-1}$ aquaculture ground, and the phytoplankton biomass was sufficient at this time. Thereafter, phytoplankton biomass decreased, and was slightly negative from August to October in 2014 and 2017, before gradually recovering. Estimated phytoplankton biomass in 2016 was the highest of the three years, except from May to June.

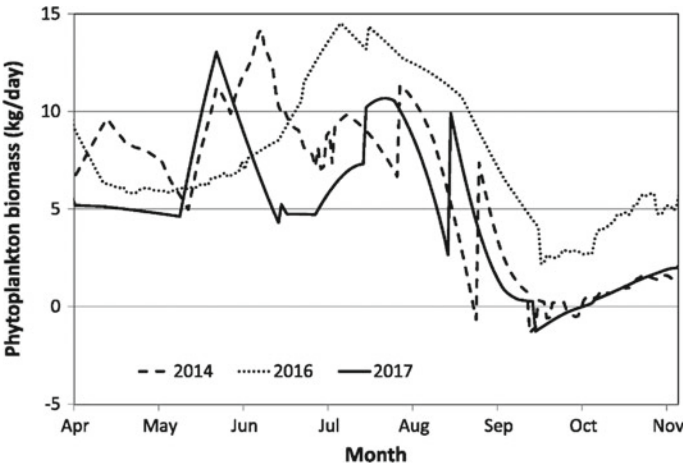



**Fig. 6** Estimated phytoplankton biomass in Nagatsuraura. The data for 2016 is from a previous report (Okumura et al. 2017a)

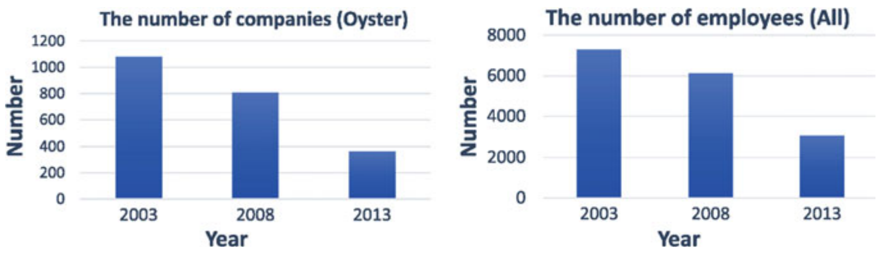



**Fig. 7** The number of oyster companies and all fishery employees

After the tsunami, the number of rafts decreased to about half. There were about 200 rafts before the earthquake (Takasaki and Tanaka 2004), although there is no certified information on raft number and size from 2005 to 2011. The average in 2014 and 2016 was about 110 (Okumura et al. 2017a). We suspect that one reason why food insufficiency has not occurred is that the number of rafts was reduced after the tsunami.

We presumed that the reason why estimated phytoplankton biomass from April to August at Nagatsuraura was sufficient was the continued high Chl *a* concentration after the spring bloom in Nagatsuraura. Subsequently, estimated phytoplankton biomass gradually decreased due to the end of bloom and increase infiltration by oyster growing in suitable water temperature conditions. There were 120 rafts in 2014, but only 98 in 2016. The estimated large phytoplankton biomass in 2016 was attributed to the smaller number of rafts and smaller oysters than in other years.

### *3.5 Number of Companies and Employees*

The number of fishery employees has gradually decreased, with values in 2003, 2008, and 2013 of 7305, 6127 and 3013, respectively (Fig. 7).

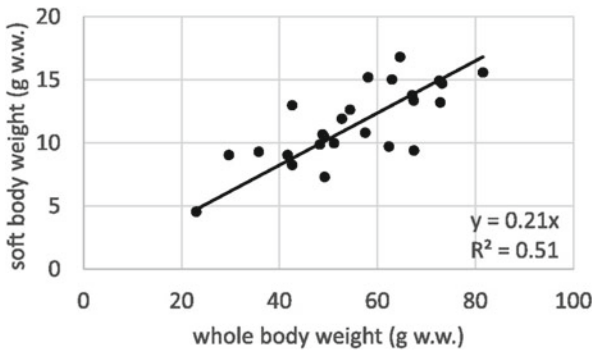
The number of all fishery employees decreased particularly after the 2011 tsunami; the reduction rate from 2003–2008, and 2008–2013 were 25.2 and 55.0%, respectively. The number of companies producing oysters has also gradually decreased. In 2003, 2008 and 2013, there were 1082, 809 and 364 businesses, respectively. The number of companies producing oysters also decreased steeply after the tsunami; the reduction rate from 2003–2008, and 2008–2013 was 16.1 and 49.9%, respectively. With the post-tsunami retirement of many employees, and a reduction in number of companies, the total quantity of oysters in the aquaculture grounds has decreased. As a result, the aquaculture grounds are currently not overcrowded

## 4 Conclusion

We calculated the mass balance of oyster diet in three observation years and determined that oyster culture in Nagatsuraura Bay is not overcrowded, as in other open and semi-open bays. We think that one reason why oyster culture was not overcrowded was the decrease in fishery employees after the tsunami. In order to understand the oyster food environment in more detail, we are currently analyzing seawater and gut contents of oysters using the next-generation sequencer.

## 5 Appendix

The ratio of the wet weight of soft tissue to the whole shelled body of oyster.

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# Seagrass–Oyster Farmers Interaction Detected by Eelgrass DNA Analysis in Hinase Area of the Seto Inland Sea, Japan

**Masakazu Hori, Masaaki Sato, and Masami Hamaguchi**

**Abstract** Seagrass beds are one of the most important coastal habitats with high productivity and biodiversity, which can provide various ecosystem services for human beings. Therefore, seagrass beds are often considered as a target for ecosystem restoration. This study demonstrated the contribution of oyster farmers' long-term activities to eelgrass bed restoration in the Hinase area, based on a DNA analysis of the eelgrass population genetic structure using seven microsatellite markers. The Hinase area was famous for the fishing by coastal pound netting to catch the fish and shrimp migrating to eelgrass beds; however, the fishing was gradually replaced with oyster farming because of the massive loss of eelgrass distribution. The fishermen decided to conduct eelgrass bed restoration, which used a seeding method for several decades even after the oyster farming became their major activity, because they already knew eelgrass vegetation can maintain a better coastal environment for oyster farming as well as coastal productivity for fishing. The farmers collected eelgrass seeds from natural sites with better environmental conditions and then sowed those seeds in the sites where eelgrass beds had disappeared. We collected eelgrass shoots as DNA samples from each of the nine sites where they sowed the seeds and from where the farmers collected seeds. The analysis revealed the farmers' seeding activity did not disturb the genetic structure of natural dispersal but facilitated the recovery of the eelgrass distribution, suggesting that the eelgrass–oyster farmer relationship in Hinase is a good practice as an ideal ecosystem restoration.

**Keywords** *Zostera marina* · Seagrass restoration · Microsatellite markers · Oyster farming · Indigenous local knowledge

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# 1 Introduction

## *1.1 History of Eelgrass Restoration by the Hinase Fishers*

Seagrass beds are one of the most important coastal habitats with high productivity and biodiversity that are contributed to human beings through various ecosystem services including sea food provision and environmental regulation such as nutrient absorption (Larkum et al. 2006), greenhouse gas ($CO_2$) sequestration (Hori et al. 2018b), pathogenic microbiome (disease) reduction (Lamb et al. 2017), and mitigation of anoxic sediments (Bjork et al. 2008). These ecosystem services are essential for regional stakeholders and also globally for human lives. Especially in Japan, local people have traditionally utilized seagrass beds not only as a fishery ground but also as commons for harvesting seagrass shoots to use as a fertilizer for vegetable farming on land (Innami 2010). Therefore, Japanese fishers and farmers living along coastal areas have developed their local indigenous knowledge toward sustainable use of seagrass beds over several centuries.

The Hinase area is a traditional fisher's town with a more than 400-year history of fisheries in the Seto Inland Sea, Japan, and is the origin of Japanese coastal pound netting in shallower coastal areas. The Hinase fishers have caught fish and shrimp inhabiting or migrating into eelgrass beds using the pound net, under their own resource management through seasonal closures and quantitative restriction of members and vessels (Tsurita et al. 2018). In the 1960s, eelgrass distribution in the Hinase area gradually decreased from 590 ha in the 1950s during the Japanese period of high economic growth and reduced to 12 ha in the 1980s (Tanaka 2014). With the decrease of eelgrass distribution, the size and amount of fishery catch by pound netting also declined. In 1985, the pound netting fishers officially started the eelgrass restoration activity using a seeding method to recover the amount of catch by the pond netting.

However, the eelgrass distribution did not increase for several decades even though the fishers continuously sowed eelgrass seeds every year. This is presumably because environmental conditions, represented by high turbidity of surface seawater under eutrophication (Ministry of Environment 2019), rendered unsuitable environment for eelgrass growth. During this period, many fishers have changed their occupation from the net fishing to oyster farming with the promotion of aquaculture by the national government (Tsurita et al. 2018) and with the massive loss of eelgrass distributions. Still, the fishers continued eelgrass seeding even after the oyster farming became the majority practice, because they already knew eelgrass can maintain a better coastal environment for oyster farming as well as coastal productivity for net fishing. This is local indigenous knowledge of the fishers in the Hinase area.

### 1.2 Objective This Study

Recently, legal restrictions by the law for environmental conservation and special measures in the Seto Inland Sea, which aimed to improve seawater environmental conditions of the Seto Inland Sea, had successfully caused the shift from eutrophication to oligotrophication, resulting in higher transparency in the water column (Hori and Tarutani 2015; Yanagi 2015). Eelgrass distribution in the Seto Inland Sea has gradually recovered (Hori et al. 2018a), and eelgrass beds in the Hinase area have also recovered to about 200 ha in 2011 (Tanaka 2014). Therefore, the objective of this study is to demonstrate how long-term activity of eelgrass bed restoration by the fishers/oyster farmers contributed to the recovery of eelgrass beds in the Hinase area. DNA analyses that we developed were conducted specially for examining two working hypotheses: (i) whether the eelgrass seeding activity by the fishers (oyster farmers) changed the population genetic structure of eelgrass beds in the Hinase area, and (ii) the recovery of eelgrass beds in the Hinase area due to the fishers' restoration efforts.

## 2 Methods, Preliminarily Results, and Discussion

### 2.1 Fundamental Genetic Structure of Eelgrass Vegetation in the Hinase Area

Eelgrass strain samples were collected from nine sites located in the Hinase area to conduct DNA analysis for estimating the contribution of fishers' seeding to the recovered eelgrass distribution (Fig. 1). Within nine sites, the Otabujima site and Katakami

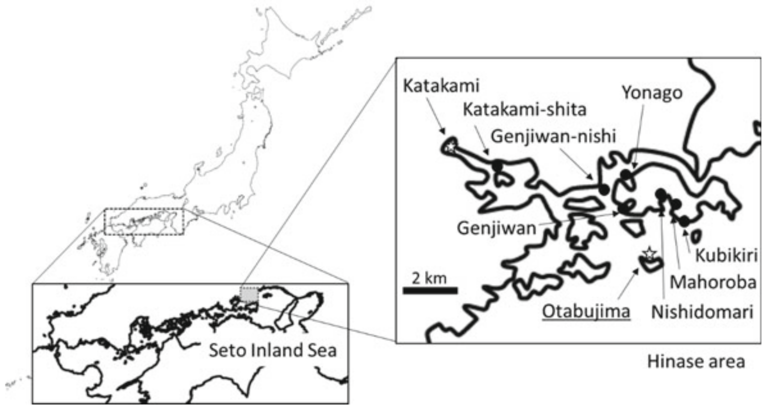


**Fig. 1** Sampling sites of the Hinase area in the Seto Inland Sea, Japan. There is seagrass vegetation in all sites now

site were sites where the fishers harvested eelgrass flowering shoots to collect eelgrass seeds. In each site, 20–50 eelgrass shoots were randomly collected, dried, and grinded as samples for eelgrass population genetic analysis. In the laboratory, genomic DNA was extracted and fragments amplified, and all samples were genotyped for seven microsatellite *loci*, which were developed to be suitable for eelgrass genetic structure in the Japanese archipelago (Tanaka et al. 2011; Shimabukuro et al. 2012). General genetic variables such as clonal richness, allelic richness, observed heterozygosity (Ho), and expected heterozygosity (He) in each site were calculated and also the genetic differentiation (Fst) of population groups between the two sites in the nine study sites was estimated.

The preliminarily results from the fundamental genetic structure revealed that clonal richness was very high in all sites (Table 1), suggesting that the local eelgrass beds in each site were established by generative reproduction rather than by vegetative reproduction. In addition, the Ho value in each site was not extremely lower than the other populations of all Japan (Ho: 0.044–0.774; Tanaka et al. 2011). These preliminarily results suggest that eelgrass beds in the Hinase area recovered not from the clonal rhizome expansion by a few vegetative shoots, but from many seedlings by natural or artificial (the fishers') seed dispersal.

A preliminarily result of the Fst values between sites detected that there are genetically two groups in the Hinase area (Fig. 2). This result suggests that contribution from the Katakami site as the origin of eelgrass seedings was quite lower than the Otabujima site.

**Table 1** Fundamental genetic variables in each site of the Hinase area

| Population | No. sample | No. genotype | Clonal richness[a] | Allelic richness | Observed heterozygosity (Ho) | Expected heterozygosity (He) |
|---|---|---|---|---|---|---|
| Otabujima | 46 | 45 | 0.978 | 6.701 | 0.546 | 0.562 |
| Nishidomari | 38 | 31 | 0.816 | 8.057 | 0.594 | 0.599 |
| Kubikiri | 47 | 43 | 0.915 | 6.978 | 0.595 | 0.582 |
| Mahoroba | 21 | 20 | 0.952 | 6.714 | 0.564 | 0.567 |
| Katakami | 37 | 36 | 0.973 | 8.326 | 0.603 | 0.608 |
| Katakami-shita | 26 | 22 | 0.846 | 7.992 | 0.571 | 0.604 |
| Genjiwan | 51 | 47 | 0.922 | 7.165 | 0.596 | 0.584 |
| Genjiwan-nishi | 40 | 31 | 0.775 | 7.619 | 0.577 | 0.573 |
| Yonago | 49 | 45 | 0.918 | 7.580 | 0.606 | 0.596 |
| Total | 355 | 320 | 0.901 | | | |

[a]Clonal richness = No. genotype/No. sample

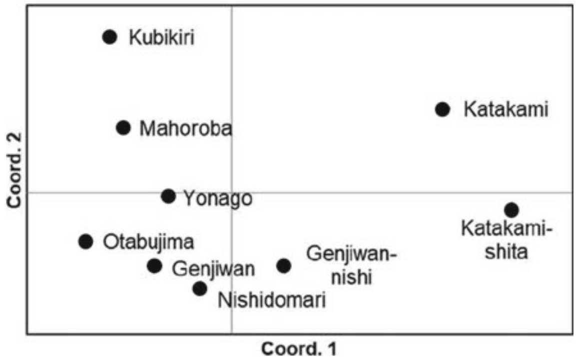


**Fig. 2** Principal Coordinate Analysis (PCoA) plots of genetic differentiation coefficient (Fst). This figure shows the closer the plotted positions, the closer the genetic similarity. This figure was revised from Tsurita et al. (2018)

## 2.2 *The Relationship Between the Fishers' Seeding Intensity and the Genetic Structure of Eelgrass Beds in the Hinase Area*

The fisher's seeding activity kept the record of seeding in the Hinase area from 1985 to 2014, especially where and how many eelgrass seeds have been collected, and where and how many of these collected eelgrass seeds were sowed by the fishers.

Using this data provided by the Okayama prefectural office, seeding intensity as the number of seeds totally sown by the fishers from the two source sites (Otabujima site and Katakami sites) was calculated. In addition, all geographic distances between one site and the other site in nine sites were calculated as an index of natural dispersal intensity of eelgrass seeds. Using these data, the relationships between the Fst value as an index of genetic distance, seeding intensity, and geographic distance were analyzed by a multiple regression matrix with randomization.

In the simple relationship between seeding intensity and genetic difference that is the genetic distance from the Otabujima site as the dominant seed-origin site, significant correlation was detected (Fig. 3, Spearman's rank correlation; $rs = -0.778$, $r^2 = 0.734$, $p = 0.023$). This result seems to suggest that the fishers' seeding

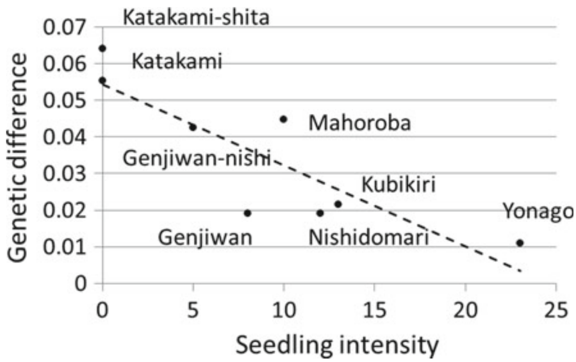


**Fig. 3** Simple correlation between seeding intensity and genetic difference. The genetic difference in this figure was calculated as the genetic distance (Fst) between the Otabujima site and other sites, because the Otabujima site is the origin where the fishers took eelgrass seeds for seeding. This figure was arranged by Tsurita et al. (2018)

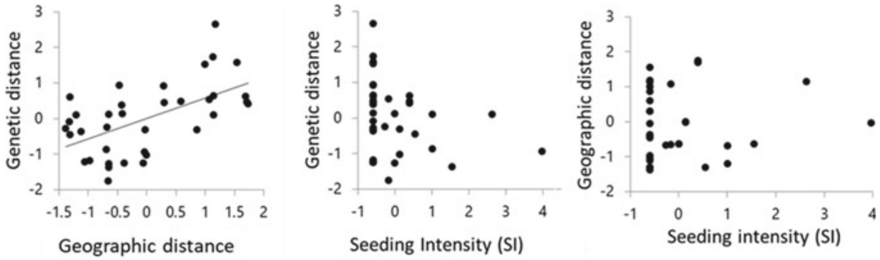


**Fig. 4** Correlation between the geographic distance, the seeding intensity, and the genetic distance. All variables were standardized for the analysis

activity strongly influenced the genetic structure of seagrass beds in the Hinase area. However, this correlation involves not only the artificial dispersal component by the fishers' seeding but also the natural dispersal component. In fact, there was no significant correlation between the genetic distance and the seeding intensity (Fig. 4, $r^2 = 0.074$, $p = 0.187$) or between the geographic distance and the seeding intensity ($r^2 = 0.055$, $p = 0.807$), while there was a significant correlation between the genetic distance and the geographic distance ($r^2 = 0.325$, $p = 0.019$). These results seem to suggest that the fishers' seeding activity did not significantly affect the genetic structure of seagrass beds in the Hinase area.

In the preliminarily analysis, however, the best model to statistically explain the genetic distance of eelgrass beds was not the simple correlation with the geographic distance but the multiple regression that consists of the geographic distance and the seeding intensity as independent factors with positive and negative variables, respectively ($r^2 = 0.417$, $p = 0.012$, Hori and Sato, submitted). This result suggests that the natural dispersal is the main factor of eelgrass recovery, and that the fishers' seeding activity has enhanced further recovery of the eelgrass beds.

## 3 Conclusion and Perspectives

Our preliminary DNA analyses suggested that genetic structure of the recovered eelgrass beds in the Hinase area would mainly derive from natural dispersal because the local eelgrass beds in each site were established mainly by seedlings, and that the fishers' seeding activity also affected the genetic structure, especially shortened the genetic distances caused by natural dispersal. Although further detailed statistical analyses would be needed to demonstrate the two working hypotheses, it can be considered that the fishers' seeding activity did not disturb the genetic structure derived from the natural dispersal, and therefore, the seeding activity did not make artificial eelgrass beds but facilitated natural recovery of eelgrass beds in the Hinase area. Therefore, we can conclude at this moment that the eelgrass–oyster farmer relationship in the Hinase area is a good practice as an ideal ecosystem restoration.

Such ecosystem management based on indigenous local knowledge is regarded as an important adaptive countermeasure under global climate change in the framework of IPBES (IPBES 2019) and also important to promote sustainable use of biodiversity and ecosystems in the achievement of the sustainable development goals (SDGs) by the United Nations (Hori et al. 2018a; Kuwae and Hori 2018). Further studies on making connectivity between local ecosystem managements and international social communities, such as social-ecological systems (SES) mapping, would be a key to achieve more effective conservation for biodiversity, more effective management for the sustainable use of ecosystem services, and more effective mitigation measures for global warming in the global scale.

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# Fisheries Biology of Blue Sharks in Sagami Bay, Japan

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**Abstract** Blue shark (*Prionace glauca*) and shortfin mako shark (*Isurus oxyrinchus*) are recognized as pelagic sharks and highly migratory species, but these sharks appear in coastal areas. It is suggested that sharks migrate in the growth stage, but we do not know the details and how sharks use coastal areas. A fishing survey of these species in coastal areas like Sagami Bay is rare, and thus we carried out two types of longline operations to survey catch trends about the shark in Sagami Bay from August 2011 to July 2017: vertical and horizontal longline operations. Both species were caught throughout the year, with peaks in July and December for both blue sharks and shortfin mako sharks. Many of the male juvenile blue sharks caught had not reached sexual maturity, and pregnant blue sharks were also present among the females. The birthing period of blue sharks is reported to be from April to July, and the young are believed to be born and grow up in the open ocean of the North Pacific. However, the fact that we caught pregnant blue sharks close to giving birth suggests that they may give birth in coastal areas such as Sagami Bay. We were unable to catch young shark larvae because of the size selectivity of the longline fishing gear. Future studies, using net sampling, will be necessary to search for new-born blue sharks in this coastal area.

**Keywords** Vertical longline · Horizontal longline · Blue shark · Shortfin mako shark · Juvenile shark · Pregnant shark · Seiyo Maru

## 1 Introduction

Sagami Bay is located on the southern coast of Japan. It is one of the deepest bays in Japan, with a maximum depth of more than 1500 m. The south side of Sagami Bay is connected to the Pacific Ocean. The Kuroshio is the north-flowing western boundary current of the Pacific Ocean, and its branch intrudes into the surface layer of Sagami Bay through the east/west channel of Oshima, while the first branch of

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**Table 1** Catches of shark by Japanese fishing vessels from the different fishing grounds, 2010–2017

| Year | Pelagic | Northwest Pacific | Japan coast | Total (ton) | Rate of Japan coast to total (%) |
|---|---|---|---|---|---|
| 2010 | 17,373 | 13,300 | 1292 | 31,965 | 4.0 |
| 2011 | 17,047 | 6176 | 70 | 20,293 | 0.3 |
| 2012 | 17,576 | 10,501 | 965 | 29,042 | 3.3 |
| 2013 | 12,914 | 9215 | 1538 | 23,667 | 6.5 |
| 2014 | 15,388 | 10,602 | 741 | 26,731 | 2.8 |
| 2015 | 15,308 | 11,026 | 985 | 27,319 | 3.6 |
| 2016 | 14,818 | 9862 | 845 | 25,525 | 3.3 |
| 2017 | 17,600 | 10,900 | 1100 | 29,600 | 3.7 |

The unit of the catch is tons, and the catch in 2011 from the Northwest Pacific and the Japanese coast was negatively affected by the Great East Japan Earthquake of March 11, 2011

the south-flowing Oyashio current sometimes flows into the middle layer of the bay. These currents affect the ecosystems and fisheries in Sagami Bay.

Pelagic sharks are caught in Sagami Bay, especially the blue shark (*Prionace glauca*) and the shortfin mako shark (*Isurus oxyrinchus*), but they are known mainly as highly migratory species and are caught mainly on the longline operations set for tuna in the open ocean (Table 1).

Few systematic surveys have been carried out at the coast and the fisheries biology in this region is not sufficiently well understood. This study analyzed seasonal trends concerning the age and sex of the blue sharks and shortfin mako sharks in Sagami Bay from longline fishing survey regularly operated. In addition, we discuss the frequency of pregnant blue sharks and juveniles to understand the fisheries biology of the blue sharks.

## 2 Materials and Methods

### *2.1 Shark Longlining*

We carried out two types of longline operations. The vertical longline operation is excellent at estimating the vertical catch depth, while the horizontal longline operation spreads the fishing gear more widely in the horizontal direction (Fig. 1). The fishing gear specification of the vertical longline was 104 hooks for eight mainlines, whereas that of the horizontal longline was 240 hooks for 40 mainlines (Joshima et al. 2017). The sizes of hooks were 9.09, 10.9, and 12.1 cm (3.0, 3.6, and 4.0 sun).

The longlines were operated from the research and training vessel (RT/V) Seiyo Maru (170 t) during the daytime (Fig. 2).

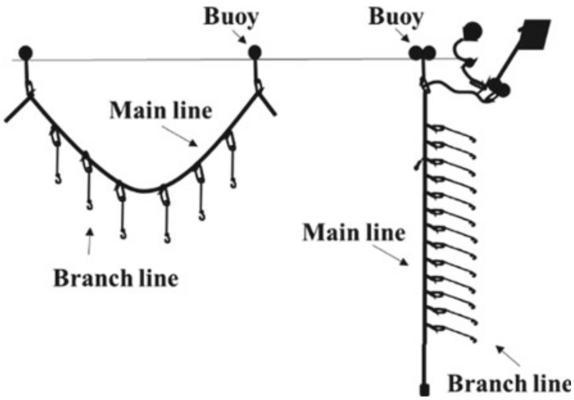


**Fig. 1** Fishing gear of a single set. A horizontal longline uses 240 hooks on 40 sets, and mainline; 245 m, branch line; 20 m, the distance between 2 branch lines; 35 m. A vertical longline uses 104 hooks on 8 sets, and mainline; 245 m, branch line; 5 m, the distance between 2 branch lines; 17.5 m

**Fig. 2** RT/V Seiyo Maru (170 t). The owner is the National University Corporation, Tokyo University of Ocean Science

We set up the longline for 1 h from 08:30, and returned to the first station, heaving up the longline over 2 h from 12:30; the immersion time of the fishing gear was about 4 h. The fishing ground was at the center of Sagami Bay, at a depth of between 500 and 1600 m (Fig. 3). We used depth data that is J-EGG500: JODC-Expert grid data for geography and used mapping tool that is GMT version 5.4.3.

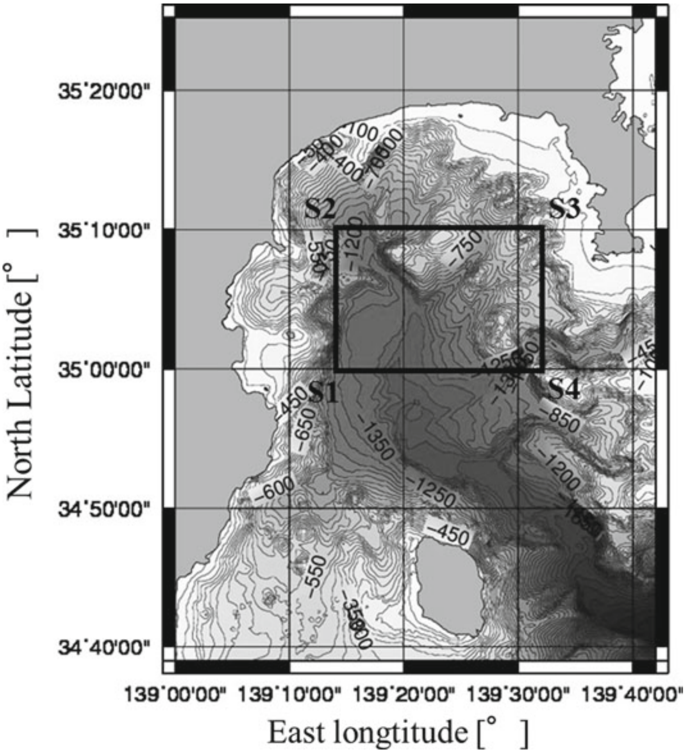


**Fig. 3** Fishing ground in Sagami Bay. S1: 35°00′ N/139°14′ E, S2: 35°10′ N/139°14′ E, S3: 35°10′ N/139°33′ E, S4: 35°00′ N/139°33′ E

## *2.2 Shark Parameters*

The sharks caught were measured and examined with regard to sex, mouth width, age, and pregnancy. The full-length caudal fin (precaudal length, PCL) (cm) was measured for the body length. Sex was determined from the presence of claspers in males. The mouth width (cm) of sharks is defined as a straight line measured from the end of one corner of the mouth to the other, because the shark mouth draws an arc shape to the tip of the snout. The size selectivity of the longline was checked by comparing the relationship between the hook size and both PCL and mouth width. The mouth width was examined from July 2015.

The age of a shark ($t$) was assessed from the PCL ($L_t$)-to-age ($t$) relationship as described below and we aligned significant digits about cited expression.

Blue shark (Nakano 1994):

$$\text{Males} \quad L_t = 290\left(1 - e^{-0.129(t-(-0.756))}\right) \tag{1}$$

$$\text{Females} \quad L_t = 243\left(1 - e^{-0.144(t-(-0.849))}\right) \tag{2}$$

Shortfin mako shark (Semba et al. 2009):

$$\text{Males} \quad L_t = 60.0 + 171\left(1 - e^{-0.156t}\right) \tag{3}$$

$$\text{Females} \quad L_t = 60.0 + 249\left(1 - e^{-0.0900t}\right) \tag{4}$$

The birthing period for blue shark has been reported to be from spring to early summer (April to July) (Fujinami et al. 2017), whereas that for shortfin mako shark is from the end of winter to summer (Compagno 2001). The blue shark is viviparous, with females having an average litter size of 35.5 pups, ranging from 15 to 112 pups per fish, and the body length (PCL) at birth is 34–36 cm (Fujinami et al. 2017). The gestation period is about 11 months. Ovulation occurs immediately after giving birth, and thus female blue sharks can breed continuously, with the reproductive cycle considered to be one year long (Fujinami et al. 2017).

The degree of maturity was judged from the stage of the reproductive parts. Generally, *L50* (the body length at which *50%* of the fish are *mature)* is used as a criterion to determine the maturity stage from the body length (PCL). The PCL at which blue sharks reach maturity ranges from 140 to 160 cm in both sexes in the North Pacific (Nakano 1994), which converts to age 6 for females and 5 for males. In a recent report, the L50 of the blue shark was 160.9 cm in males and 156.6 cm in females (Fujinami et al. 2017), whereas the PCL at reaching maturity for shortfin mako sharks ranged from 150 to 183 cm in males and 230 to 260 cm in females, which were converted to age 6 for females and 5 for males (Semba et al. 2011).

### *2.3 Statistical Analysis*

Pearson correlation coefficient test is used to check the linear regression of PCL and mouth width. The *P*-value is the probability that you would have found the current result if the correlation coefficient were null hypothesis. In this paper, we reject the null hypothesis by the level of significance less than 0.05. This probability is lower than the conventional 5% ($P < 0.05$), and thus the correlation coefficient is called statistically significant. We tested sharks PCL and mouth width by Pearson correlation coefficient. We used (cor.test; *R* version 3.5.2) for statistical analysis.

## 3 Results

We carried out horizontal longline operations 60 times and vertical longline operations 36 times, from August 2011 to July 2017 (Table 2).

**Table 2** Number of horizontal and vertical longline operations carried out in Sagami Bay from August 2011 to July 2017 by RT/V Seiyo Maru

| Fiscal year | Number of horizontal longline | Number of vertical longline |
|---|---|---|
| 2011 | 4 | – |
| 2012 | 7 | – |
| 2013 | 11 | – |
| 2014 | 11 | 8 |
| 2015 | 12 | 13 |
| 2016 | 12 | 11 |
| 2017 | 3 | 4 |
| Total | 60 | 36 |

During this period, we caught 143 blue sharks (132 males, 11 females) and 78 shortfin mako sharks (61 males and 17 females). There were four pregnant female blue sharks, but no pregnant shortfin mako sharks.

To analyze the seasonal trends of catch numbers and PCL, we focused on the monthly trends rather than the year-on-year fluctuations. Thus, fishing data for the 6 years of the survey were summarized from January 1 to December 31 (Figs. 4 and 5). Blue sharks were caught throughout the fishing season, with peaks in July and December. Similar trends were observed for shortfin mako sharks, with peaks in July and December.

The relationship between PCL ($L_t$) and age ($t$) was different for males and females of each shark species (Eqs. 1–4), and therefore we determined relationships separately for blue sharks and shortfin mako sharks, each separated into males and

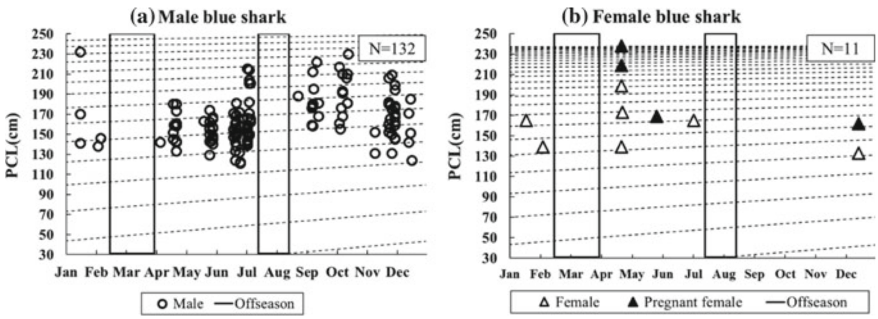


**Fig. 4** Seasonal patterns of catches of blue sharks. This graph plots all the blue sharks caught by horizontal and vertical longlines. **a** Male and **b** female blue sharks. The *x*-axis indicates the month and day. The *y*-axis shows the body length: PCL (cm). Circles are male sharks and triangles are female sharks. Pregnant sharks are indicated by closed triangles. Bold grid lines indicate the off-season of fishing. Black sloped dotted lines represent the age of the sharks based on the growth equations of male and female blue sharks. In the growth equations, the age is extended to continuous time based on the date. The date of birth is assumed to be July 1, and thus the growth equation (dotted lines) starts that day. Dotted lines are sloped to the right side (December 31) and restart from the left side (January 1), and age is counted from July 1

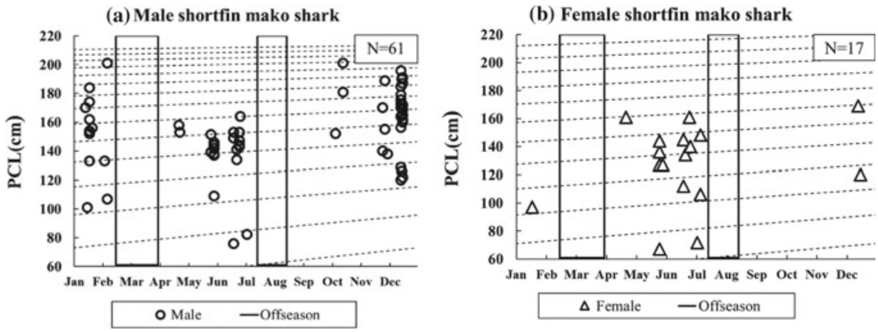


**Fig. 5** Seasonal patterns of catches of shortfin mako sharks. The labels and symbols are the same as those for Fig. 4, but are based on all the shortfin mako sharks instead of the blue sharks

females. We drew a line calculated from the growth equation (Figs. 4 and 5) to easily check the age and PCL. Lines were started at the date of birth, which was assumed to be July 1, and the growth equation was applied to start that day.

Correlation coefficients of PCL to mouth width were blue shark; $r = 0.86$, $N = 75$, and shortfin mako shark; $r = 0.91$, $N = 45$ (Fig. 6). Thus, we checked both species by Pearson's correlation coefficient test at the level of significance; $P < 0.00001$. The linear relationships between the mouth width and PCL for blue sharks and shortfin mako sharks were statistically significant. The shortfin mako sharks were generally shorter, with narrower mouths than the blue sharks in Sagami Bay (Fig. 6).

The PCL for blue sharks caught in this study ranged from 121 to 232 cm in males, and 133 to 238 cm in females (Fig. 4). The seasonal trend of the numbers of blue sharks caught differed between the seasons before and after the off-season in August (when the research vessel was not available), and we focused on the differences in

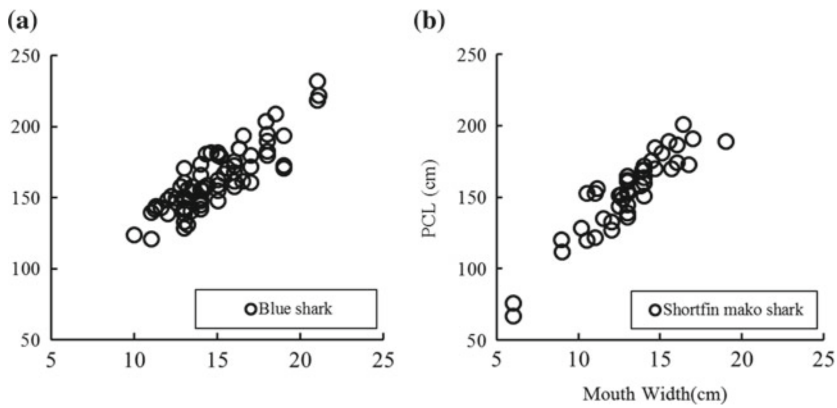


**Fig. 6** Size selectivity about PCL and mouth size for both shark species. **a** Circles are blue sharks ($r = 0.86$, $N = 75$) and **b** circles are shortfin mako sharks ($r = 0.91$, $N = 45$). The *x*-axis indicates the mouth width (cm) and the *y*-axis shows the PCL value (cm)

the PCL of sharks caught during the spring season (April to July), that is, pre-August, from that during the autumn season (September to December), that is, post-August. The spring corresponded to the birthing season April to July, and many young juvenile blue sharks were caught during the spring, compared with more mature blue sharks in the autumn.

To facilitate interpretation, we represented Fig. 4 in the form of frequency histograms of the PCL for blue sharks (Fig. 7). The shape of the frequency distribution histogram was asymmetric in the spring, with a peak frequency of sharks measuring 140–160 cm, corresponding to 6–7-year-old sharks. This was the age at which sharks reach sexual maturity; juvenile males were also higher levels of recruitment in Sagami Bay.

Furthermore, we focused on seasonal PCL trend annually. We calculated mean and standard deviation (SD) of male blue sharks PCL in Sagami Bay from August 2011 to July 2017 separated by two seasons April to July and September to December (Table 3).

Mean of male blue shark PCL was repeated up and down each season, April to July was low and September to December was high, and the fluctuation was about 20 cm. We caught about 10 male blue sharks every season, and hence the seasonal trend of male blue sharks PCL tended to be similar. However, we caught 24 male blue sharks only from April to July 2015. Blue sharks' growth rate of 6–7 year-old was about 16 cm annually, but blue sharks PCL were different from 20 cm during half year (Fig. 4; Table 3). Accordingly, it was hard to apply PCL fluctuation to the conventional growth equation.

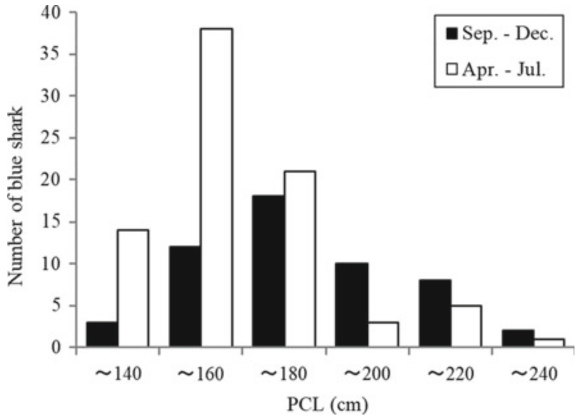


**Fig. 7** Frequency distribution histogram of the length (PCL) of blue sharks caught by longlines. The black bar denotes the numbers of male and female blue sharks caught from September to December ($N = 53$). The white bar denotes the numbers of male and female blue sharks caught from April to July ($N = 82$). The $x$-axis indicates the PCL values (cm) every 20 cm and each class includes less than displayed value; e.g., ~140 means less than 140 cm, and the $y$-axis shows the number of blue sharks caught

**Table 3** Mean and standard deviation (SD) of blue sharks PCL (cm) in Sagami Bay from August 2011 to July 2017 separated by April to July and September to December

| Year | 2012 | 2013 | 2013 | 2014 | 2014 | 2015 | 2015 | 2016 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|---|---|
| Month | Sep.–Dec. | Apr.–Jul. | Sep.–Dec. | Apr.–Jul. | Sep.–Dec. | Apr.–Jul. | Sep.–Dec. | Apr.–Jul. | Sep.–Dec. | Apr.–Jul. |
| Mean | 181.0 | 155.6 | 175.5 | 149.3 | 172.5 | 157.3 | 175.1 | 152.0 | 176.0 | 154.2 |
| SD | 19.8 | 26.6 | 27.8 | 14.8 | 15.3 | 15.0 | 26.5 | 7.2 | 25.0 | 22.0 |
| N(male) | 7 | 8 | 10 | 8 | 14 | 24 | 7 | 12 | 11 | 12 |

*N* (male) is number of caught male blue sharks in the season. September to December in 2011 and April to July in 2012 was caught only one blue shark (PCL 180.0 cm) by each season

These results indicated that sharks had different migratory patterns before and after August, with young male individuals forming a school and traveling to the coast in the spring, whereas larger males tended to migrate to coastal areas in the autumn.

## 4 Discussion

Comparing males and females, females were caught more in the spring, especially in April, with fewer and smaller ones caught in the autumn, and therefore female blue sharks could be migrating to coastal areas in the spring. Among the blue shark females, both the largest individuals caught, exceeding 200 cm in PCL, were pregnant. This finding suggests that large females migrate to the coastal area in the spring to give birth.

However, no female blue sharks were caught from September to November. A similar trend was observed for the shortfin mako shark, although no females were caught. After giving birth, the female sharks of both species are thought to travel to the mating sea area beyond the coast. Mating probably occurs in the open ocean in August, with the larger (sexually mature) males. The results indicated that large male sharks tend not to be at the coast in the spring, with the coastal areas being preferred by pregnant females. At precisely analysis, female blue sharks caught 11 in total, 5 of them were caught with immature males by same operation at a same day (PCL 11 males less than 162.0 cm ≒ L50: 160.9 cm), and thus 6 of them were caught only female at the day that no males caught by same longline operation. As mating involves the larger males biting the females, the coastal areas are possibly regarded as safer refuges for pregnant females that are afraid of the large males during the breeding season.

Thus, our findings indicate that pregnant females migrate to the coastal areas on the grounds of safety between April and July, that is, the birthing period, suggesting that Sagami Bay is available for the birthing area of the blue shark. However, no young individuals, with a PCL of 110 cm or less, were caught during the survey. There was also no evidence of females that had recently given birth or of juvenile blue sharks. The absence of juveniles was probably due to the fact that the longline fishing gear is selective: The younger (and therefore smaller) blue sharks, with narrower mouth widths, would not have been able to take even the smallest hook and be caught. Net sampling could be considered as a method to catch the smaller specimens by eliminating the selectivity of longline fishing gear (Yoshimitsu et al. 2018).

We caught shortfin mako sharks with PCLs as short as 67 cm (Fig. 6), with a mouth width smaller than that of any blue shark ever caught in our research. Unlike the situation with blue sharks, this result with the shortfin mako sharks was less a reflection of the fishing gear selectivity against the shortfin mako shark larvae than that pregnant shortfin mako sharks were not found in Sagami Bay, indicating that Sagami Bay is not a birthing area for the shortfin mako shark. However, it is conceivable that shortfin mako shark juveniles, born in areas near Sagami Bay or the Kuroshio downstream area, may have reached Sagami Bay.

The role of the coastal zone in the ecology of the early stages of shark development will become clearer when juvenile blue sharks are caught by net sampling. This will be the next step to confirm whether Sagami Bay is a birthing area for highly migratory fish like the blue shark, or not, and to understand more about the role of the coastal area in the life cycle and migration of the blue shark. Due to the schedule of the research vessel, the fishery survey conducted during the off-seasons, in March and August, was insufficient. However, this is a very important time of the season between the spring and autumn when we can focus on the juvenile blue shark, the sexually mature blue shark, and the pregnant female shark.

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# Vulnerability of Coastal Ecosystems and Risk Assessment

# Temperature and Salinity Changes in Coastal Waters of Western Europe: Variability, Trends and Extreme Events

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**Abstract** Coastal marine ecosystems worldwide are not only highly affected by the effects of human activities, but also by the influence of natural climate variability and global climate change. However, it is still a challenge to assess the spatial and temporal scales at which forcings operate and their persistence over time, to determine the vulnerability of coastal ecosystems to climate changes and climate extreme events, and therefore to anticipate the ecological and biological responses of these areas. By investigating these knowledge gaps, our recent studies have shown that the combination of large- and local-scale hydro-climatic influences have induced obvious changes in the physical and chemical characteristics of coastal waters in Western Europe. Because of the complex and non-linear climate-coastal ecosystem relationships, a thorough understanding of the underlying processes is still needed, while extending the spatial and temporal scales of inference. Here, using both high- and low-frequency observations collected from 1998 onwards at the outlet of the Bay

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of Brest and off Roscoff, we described and documented monthly changes in (1) sea surface temperature, (2) sea surface salinity, (3) river discharges and (4) precipitation patterns. By focusing on the winter period (from December to February), our study revealed that coastal waters of Western Europe are not only significantly connected to large-scale atmospheric conditions and patterns, but also to local-scale drivers such as river discharges. Current strong impacts of regional climate extreme events worldwide led us to devote more attention on understanding the possible impacts of such episodes on the long-term variability and trends of these ecosystems in coastal waters of Western Europe. The signature of extreme events in the Bay of Brest is described and the numerical simulations allowed us to highlight the link between local rivers and changes in salinity.

**Keywords** Coastal ecosystems · Climate variability · Extreme events · Large and local forcings · High- and low-frequency in situ sampling

## 1 Introduction

Coastal waters of Western Brittany are strongly influenced by the combined effects of local- and large-scale climate processes. At large-scale, air masses that circulate over the North Atlantic Ocean induce important exchanges with the surface ocean, with consequences on both warming and cooling of coastal waters (e.g. Goberville et al. 2014; Chaalali et al. 2013). Strong and significant relationships between atmospheric circulation over the North Atlantic Ocean and precipitation patterns have also been detected with changes in large-scale atmospheric variability that led to a modulation of mean precipitation rates and hydrological processes in Western Europe (e.g. Bojarriu and Reverdin 2002; Msadek and Frankignoul 2009; Goberville et al. 2010). On a local scale, winter precipitations can influence river discharges, especially when aquifer capacity is limited like in Western Brittany watersheds (Aulne, Elorn and Penzé rivers).

By allowing to unambiguously separate the main drivers of changes that can affect an ecosystem (Hawkins et al. 2003), long-term in situ ocean observations are essential to better depict, characterise and understand the current impact of climate change on coastal environments. Since 1998, the physical and chemical properties of Western Brittany waters have been monitored at two stations in the Bay of Brest and off Roscoff (Astan). Using and analysing those observations, and supported by numerical simulations, our study aims to better understand and quantify the role of local- and large-scale atmospheric forcings that act on these coastal environments and their possible consequences, looking at the different temporal scale of influence: from the annual/seasonal/monthly scales to abrupt and intense extreme events that can have strong—but still seldom documented—influences on coastal ecosystems.

Using long-term observations from 1998 to 2013, Tréguer et al. (2014) have highlighted that North Atlantic atmospheric circulation and local precipitations have predominantly influenced both the physical and chemical variability of coastal waters of Western Europe. However, and because of the well-known non-linearity of coastal ecosystems (e.g. the strength and direction of correlations may vary locally and temporally; Peters et al. 2007; Harley et al. 2006) and the sensitivity of the response of natural systems to climate influence, we first updated their analyses by considering observations from 1998 to 2018 and assessed whether already detected relationships are still observable. We then extended the description by considering the high-frequency observations and documenting for the first time, how extreme events have impacted coastal waters of Western Europe over the last decades.

# 2 Materials and Methods

## *2.1 In Situ Observations*

### 2.1.1 Low-Frequency Environmental Data

Changes in physical properties of coastal waters at both the Bay of Brest (hereafter named SOMLIT-Brest) and off Roscoff (hereafter named SOMLIT-Astan) sites were assessed from 1998 to 2018 using data from the 'Service d'Observation en Milieu LITtoral' (SOMLIT; somlit.epoc.u-bordeaux1.fr; Goberville et al. 2010). Sampling is carried out at sub-surface and in constant tidal conditions at high tide: (1) weekly at −2 m at the Brest station (48° 21′ 29″ N, 4° 33′ 05″ W) and (2) bi-monthly at −1 m at the Astan station (48° 46′ 40″ N, 3° 56′ 15″ W). Here, we focused on sea surface temperature (SST; measurement precision ±0.02 °C) and salinity (SSS; measurement precision ±0.005 pss). In order to compare Brest and Astan stations with neighbouring coastal ecosystems, we used long-term observations carried out at two sites located in the Western English: (1) the L4 (50° 15′ N, 4° 13′ W, https://www.westernchannelobservatory.org.uk/data.php) and the Weymouth (50° 37′ N, 2° 27′ W; https://www.cefas.co.uk/cefas-data-hub/sea-temperature-and-salinity-trends/presentation-of-results/station-24-weymouth/) stations. More information on these datasets was provided by Smyth et al. (2010) and Tréguer et al. (2014).

### 2.1.2 High-Frequency Environmental Data

High-frequency environmental data are collected by the COAST-HF network, a French marine monitoring program based on automated buoys equipped with physical and chemical sensors (see http://www.coriolis-cotier.org/). Those automated and continuous measurements allow to record a wide range of events from short-time events (less than 1-h time period) to interannual variability.

The MAREL-Iroise buoy (http://www-iuem.univ-brest.fr/observatoire/observation-cotiere/parametres-physico-chimiques/testpeg) records environmental parameters every 20 min at 2 m depth in an autonomous mode (48° 21′ 29″ N, 4° 33′

05″ W). The multiparameter probe is a C/T/D/TBD/DO/Fluo[1] probe NKE equipped with an electrochlorination system that cleans sensors and guarantees measurement precision over a 3-month-period. Quality control was conducted (1) by performing pre- and post-deployment metrology assay of sensors to examine data exactitude and (2) by comparing MAREL-Iroise and SOMLIT-Brest measurements. Sea surface temperature and salinity from 2000 to 2018 were determined with a precision of ±0.1 °C and ±0.3 pss, respectively.

#### 2.1.3 Meteorological Data

Data on monthly and hourly precipitation rates recorded at the Guipavas site (48° 44′ N, 4° 41′ W) originated from Meteo-France (http://france.meteofrance.com) and were used to examine the potential effect of local environmental conditions—that results from larger spatial scale climate influence—on the physical variability of both coastal sites.

#### 2.1.4 River Discharge Data

To evaluate the influence of river discharge (Q in $m^3\ s^{-1}$) on the two coastal ecosystems, we used data on mean river discharge originated from the ECOFLUX river monitoring network (https://www-iuem.univ-brest.fr/ecoflux; Tréguer et al. 2014). Freshwater flux of the Aulne (watershed surface = 1224 $km^2$), Elorn (watershed surface = 260 $km^2$) and Penzé (watershed surface = 141 $km^2$) rivers were gauged daily by the Agence de l'Eau Loire-Bretagne (www.hydro.eaufrance.fr). To estimate the volume of freshwater at the Bay of Brest site, we summed the Aulne and Elorn river discharges (hereafter named the 'Aulne + Elorn').

### *2.2 Numerical Model Simulations*

Model results were based on simulations performed using the MARS3D model[2] in a configuration (hereafter named BACH—BiscAy CHannel) described in detail in Charria et al. (2017). This model, solving primitive equations, was set up for a region extending from the Bay of Biscay to the English Channel (41 to 52.5° N and 14.3° W to 4.5° E). The spatial resolution was 1 km with 100 vertical sigma levels and the simulation was carried out for the period 2001–2012. Further details about the model configuration are available in Theetten et al. (2017). Atmospheric forcings were provided by ERA-Interim, produced by the European Centre for Medium-Range Weather Forecasts (ECMWF; Berrisford et al. 2011). The open boundary and initial

[1] Conductivity/Temperature/Depth/Turbidity/Dissolved Oxygen/Fluorimetry.

[2] http://wwz.ifremer.fr/mars3d.

conditions were based on a DRAKKAR global configuration named ORCA12_L46-MJM88 (Molines et al. 2014).

## 2.3 *Large-Scale Atmospheric Indices*

### 2.3.1 Large-Scale Hydro-climatic Indices (or Teleconnection Patterns)

Two large-scale hydro-climatic indices were selected because of their possible influence over the period 1998–2018 in the study area (e.g. Marshall et al. 2001; Goberville et al. 2010). The winter (December–March; Hurrell et al. 2001) North Atlantic Oscillation (NAO; Fig. 1a; Hurrel 1995), with a periodicity of about 8 years, represents the basin-scale gradient of atmospheric pressures over the North Atlantic between the high pressures centred on the subtropical Atlantic and the low pressures over Iceland (Dickson and Turrell 2000). In the literature, this index has been linked to several ecosystem changes such as species productivity (e.g. Alheit and Hagen 1997) or precipitation patterns (Hurrell 1995). Data were downloaded from the National Oceanic & Atmospheric Administration (NOAA; www.cpc.ncep.noaa.gov).

The East Atlantic Pattern (EAP; Fig. 1b; www.cpc.ncep.noaa.gov), the second of three prominent modes of low-frequency variability over the North Atlantic (Msadek and Frankignoul 2009), is defined by a centre of action over 55° N and 20°–35° W (Barnston and Livezey 1987). Previous studies have related its patent influence on changes in temperature in Western Europe (Goberville et al. 2014), precipitation rates and hydrological processes (e.g. Msadek and Frankignoul 2009).

### 2.3.2 Weather Regime (WR) Indices

In line with our previous works (e.g. Tréguer et al. 2014), four weather regime indices were computed. Weather regimes are recurrent, quasi-stationary large-scale atmospheric patterns (Cassou et al. 2004, 2011; Michelangi et al. 1995; Vautard 1990 among others), that account for the existence of preferred large-scale spatial states of the extratropical atmosphere set by the stationary waves (Molteni et al. 1990). This framework allows to get rid of orthogonality and symmetry constraints peculiar to the classical modes of variability (Cassou et al. 2004). In the present study, weather regime indices were computed as follows. Monthly climatology of sea-level pressure has been computed by using the ERA-Interim reanalysis (Dee et al. 2011) over the period 1979–2007. This climatology was used to compute monthly sea-level pressure anomalies over the North Atlantic (20 N–80 N, 80 W–30 E) from 1979 to 2018. For each winter month (December–February), spatial correlations between these monthly anomalies and the climatological states (centroids) of the four winter weather regimes described in Barrier et al. (2013) were calculated. These four regimes are (1–2) the positive (NAO+; Fig. 1c) and negative (NAO−; Fig. 1e) components of the North Atlantic Oscillation, (3) the Scandinavian Blocking (BLK; Fig. 1f)

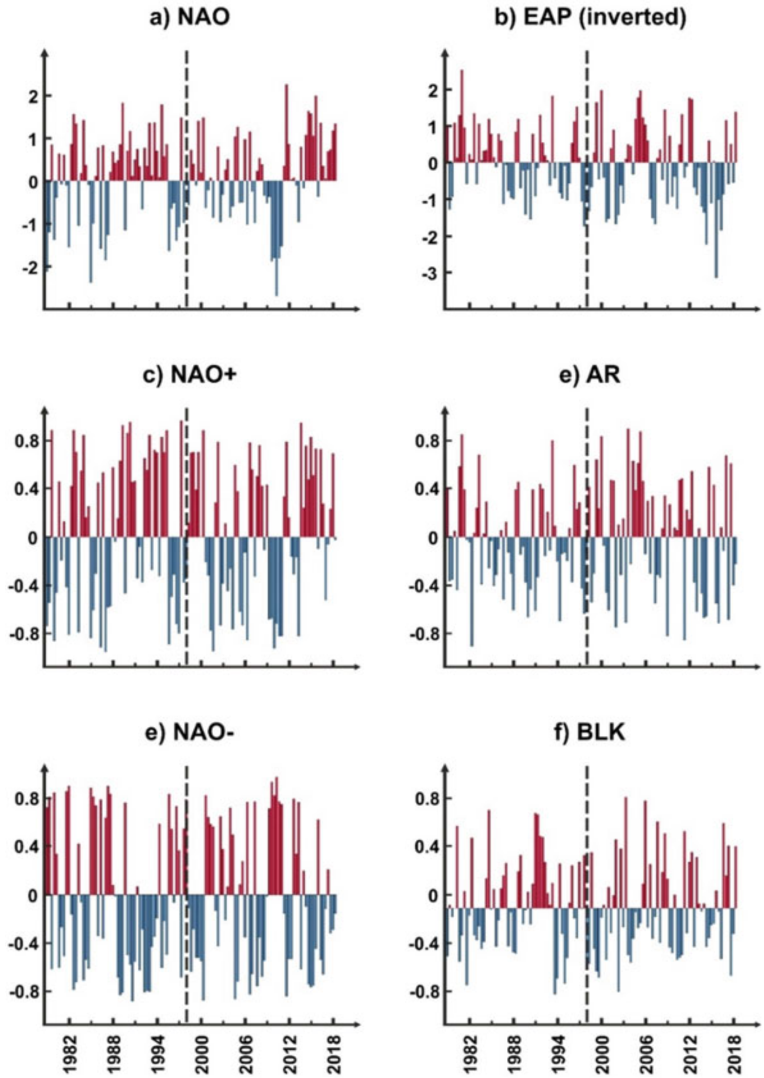


**Fig. 1** **a**, **b** Large-scale climate indices and **c**–**f** weather regime indices calculated for the winter months (December, January, February) and from 1979 to 2018. Positive anomalies are in red and negative in blue. The black dotted line shows the beginning of the study period (i.e. 1998). **a** NAO: the North Atlantic Oscillation; **b** EAP: the East Atlantic Pattern; **c** NAO+: positive phase of the NAO; **d** AR: the Atlantic Ridge; **e** NAO−: negative phase of the NAO; **f** BLK: the Scandinavian blocking regime. The East Atlantic Pattern was inverted (multiplied by −1) for visual comparison with the Atlantic ridge

regime—characterised by negative sea-level pressure anomalies over Greenland and by positive sea-level pressure anomalies over Northern Europe—and (4) the Atlantic Ridge (AR; Fig. 1d), characterised by anticyclonic anomalies centred in the eastern North Atlantic and that can be considered as the negative component of the EAP. The weather regime indices used here can be interpreted as the degree of likeness between the monthly mean sea-level pressure anomalies and the centroids: a value of 1 indicates that anomalies perfectly project onto the WR centroid, while a null correlation indicates no similarity.

### *2.4 Correlation Analysis*

The Pearson linear correlation coefficient was used to quantify the relationships between changes in coastal waters and both large and local hydro-climatic forcings. The coefficient of determination ($R^2$) was calculated from the coefficient of linear correlation ($r$) to measure how much of the variability of a variable was explained by the other one (Legendre and Legendre 2012). Probabilities were estimated and the Box and Jenkins (1976) autocorrelation function modified by Chatfield (1996) was applied to assess the temporal dependence of years. When data were autocorrelated, the autocorrelation function was applied to adjust the degree of freedom and re-estimate the probability of significance ($p_{\mathrm{ACF}}$) using Chelton's formula (1984) as performed by Pyper and Peterman (1998).

## 3 Results

### *3.1 Temporal Variability and Trends in Sea Surface Temperature, Salinity and Water Discharge*

Typical seasonal variations in sea surface temperature (SST; Fig. 2a), salinity (SSS; Fig. 2b) and river discharge (Q; Fig. 2c) were observed at the Brest and Roscoff sites over the period 1998–2018. While variations in sea surface temperature and river discharge (the Aulne + Elorn and the Penzé for Brest and Astan, respectively) appeared synchronous and in phase at both sites, the range between minimum and maximum salinity was well more constricted at the Astan site. In Brest, changes in salinity appeared strongly influenced by freshening events that followed marked flood periods (e.g. in 2001 and 2014).

While temporal variations in monthly SST estimated from the low-frequency SOMLIT and from the high-frequency COAST-HF (MAREL-Iroise in the present study) programs were quasi-undistinguishable over the common period of sampling (2000–2018)—suggesting that the SOMLIT dataset can be used to investigate the

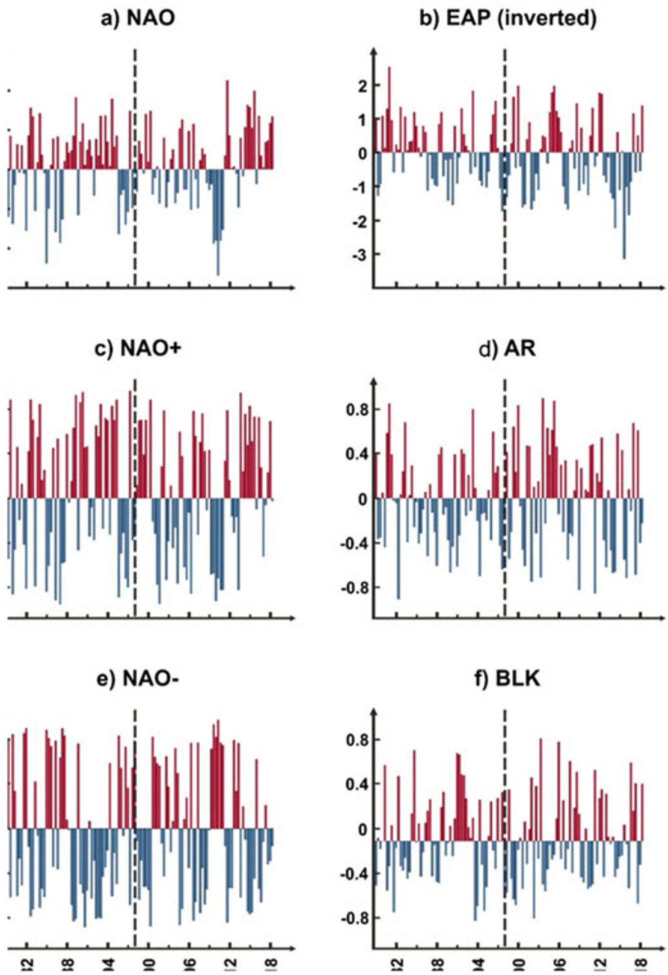


**Fig. 2** **a** Monthly mean sea surface temperature (SST; in °C) and **b** sea surface salinity (SSS; in pss) at the MAREL-Iroise (black), SOMLIT-Brest (red) and SOMLIT-Astan (blue) sites. **c** Monthly mean river discharge (Q; in $m^3$ $s^{-1}$) of the Aulne + Elorn (red) and the Penzé (blue) rivers. For a visual comparison, the Penzé River discharge was multiplied by 10

potential influence of large- and local-scale hydro-climatic processes—some differences in monthly SSS emerged (Fig. 2b): during flood events, SOMLIT overestimated salinity values and missed short-term variations in SSS induced by sudden discharges from the Aulne and Elorn rivers. This could be explained by the SOMLIT sampling strategy, i.e. a low-frequency data acquisition (i.e. monthly averages were computed from weekly measures) at high tide. Measurements on a weekly basis are, therefore, not well-adapted to capture extreme (minimum or maximum) events such as an abrupt freshening of coastal waters.

By using descriptive statistics (averages, minimum and maximum values; Table 1) to compare—on an annual and seasonal scale—SOMLIT-Brest, MAREL-Iroise, SOMLIT-Astan and the two stations located further north in the Western English Channel (L4 and Weymouth), we showed that SST and SSS values are quite comparable, except for the low SST (5.80 °C) recorded at the Weymouth site in January 2010. During our study period, the mean monthly SST was minimal (8.14 °C) in February 2010 and maximal (18.04 °C) in August 2003 in Brest and minimal (8.65 °C) in March 2010 and maximal (16.52 °C) in September 2009 in Astan. SOMLIT-Brest and MAREL-Iroise were more constrained by freshening events than the Astan and L4 stations (Table 1). In Brest, the mean monthly SSS reached a minimum of 31.98 pss in February 2014 but of 34.25 pss in January 2001 in Astan. In winter, salinity remained generally close to values commonly reported for North Atlantic Ocean adjacent waters (e.g. Tréguer et al. 1979); both SOMLIT stations can, therefore, be considered as coastal ecosystems. This result (1) substantiated that either SOMLIT or MAREL can be used to describe long-term variations of coastal waters of the Bay of Brest and (2) suggested that the four coastal sites were tied to common (large and/or local) hydro-climatic forcings.

After having removed the seasonal cycles from each time series, we estimated the trends of SST, SSS and river discharge anomalies for the two SOMLIT sites and the period 1998 onwards, i.e. more than 20 years of observation (Fig. 3). Following Niu (2012), anomalies were obtained by removing the 21-year monthly mean and expressed long-term monthly variability.

**Table 1** 48° N (SOMLIT-Brest, SOMLIT-Astan and MAREL-Iroise) and 50° N (Plymouth L4 and Weymouth) stations: mean values (and standard deviations) of sea surface temperature (SST; in °C) and sea surface salinity (SSS; in pss)

| | | All months | | | Winter months | | |
|---|---|---|---|---|---|---|---|
| | | Mean | Min | Max | Mean | Min | Max |
| SST (°C) | Brest | 13.35 ± 2.79 | 8.15 | 18.05 | 10.28 ± 0.97 | 8.15 | 12.67 |
| | Marel | 13.21 ± 2.83 | 8.14 | 18.04 | 10.19 ± 1.04 | 8.14 | 12.68 |
| | Astan | 12.88 ± 2.16 | 8.65 | 16.52 | 11.04 ± 1.12 | 8.85 | 13.70 |
| | L4 | 12.64 ± 2.72 | 7.62 | 17.92 | 10.26 ± 1.24 | 8.15 | 12.56 |
| | Weymouth | 12.42 ± 3.73 | 5.80 | 19.22 | 8.62 ± 1.38 | 5.80 | 12.08 |
| SSS (psu) | Brest | 34.60 ± 0.58 | 32.41 | 35.53 | 34.11 ± 0.58 | 32.41 | 35.09 |
| | Marel | 34.42 ± 0.72 | 31.98 | 35.49 | 33.89 ± 0.72 | 31.98 | 35.09 |
| | Astan | 35.22 ± 0.20 | 34.25 | 35.54 | 35.22 ± 0.22 | 34.25 | 35.49 |
| | L4 | 35.04 ± 0.22 | 34.01 | 35.39 | 34.97 ± 0.25 | 34.19 | 35.37 |

Annual and winter (December, January, February) values were calculated for the periods: (1) 1998–2018 for SOMLIT sites, (2) 2000–2018 for MAREL-Iroise, (3) 1998–2016 for Weymouth and (4) 1998–2017 for Plymouth L4

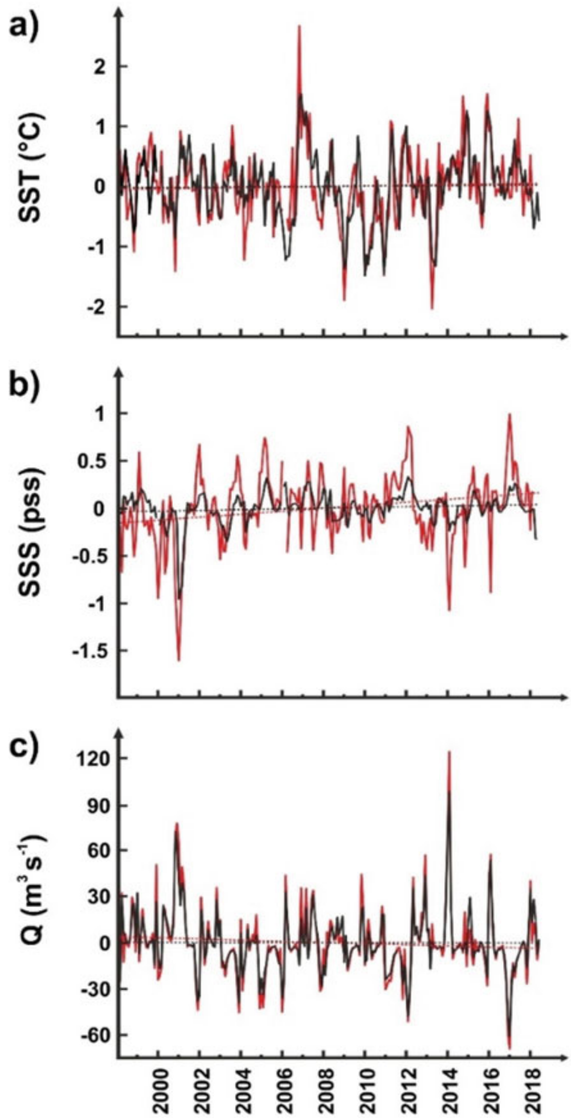


**Fig. 3** **a** Monthly mean sea surface temperature (SST; in °C) anomalies and **b** sea surface salinity (SSS; in pss) anomalies at the SOMLIT-Brest (red) and SOMLIT-Astan (black) sites. **c** Monthly mean river discharge (Q; in $m^3$ $s^{-1}$) anomalies of the Aulne + Elorn (red) and the Penzé (black) rivers. For a visual comparison, the anomalies of the discharge of the Penzé were multiplied by 10. The dotted lines correspond to the trends of each time series

Slight increases in SST (+0.008 and +0.003 °C $year^{-1}$ for Brest and Astan, respectively; Fig. 3a) and SSS (+0.026 and +0.006 pss $year^{-1}$ for Brest and Astan, respectively; Fig. 3b) were observed over the last two decades and were paralleled by a reduction in river discharges (−0.63 $m^3$ $s^{-1}$ per year for both the Aulne and Elorn rivers and −0.47 $m^3$ $s^{-1}$ per year for the Penzé River; Fig. 3c). During this period, obvious extreme anomalies were detected: a clear increase in SST in 2007

(Fig. 3a), a strong decrease in SSS in 2001 (Fig. 3b) and high river discharges at the end of 2014 and in 2001 but to a limited extent (Fig. 3c).

### *3.2 Relationships Between Trends in Coastal Waters, Local Climate and Large-Scale Hydro-climatic and Weather Regime Indices*

To assess the effect of local and large-scale hydro-climatic processes on coastal waters in Brest and Astan during winter, we compared December-January-February (hereafter DJF) anomalies of SST, SSS and river discharges (retrieved from Fig. 3), DJF precipitation anomalies and DJF teleconnection and weather regime indices. In so doing, we revealed an obvious influence of large and local-scale hydro-climatic processes on the coastal waters of Western Brittany from 1998 onwards (Table 2).

With a contribution ranging from 11 to 33%, significant correlations between winter SST anomalies and the North Atlantic Oscillation (NAO) teleconnection index and its components (NAO+ and NAO−) were found at the two study sites. SST was not related to other large-scale indices (Table 2): at both sites, the NAO only influenced SST over the period 1998–2018. No significant influence of large-scale processes was found with salinity, suggesting the prevalence of local forcings, as we discussed below.

While precipitation patterns and river discharges were highly related to the EAP ($r$ ranging from 0.468 to 0.608; Table 2), significant—but weaker—impacts of the AR and the BLK regimes were also detected (with a contribution ranging from 12 to 30%). In winter, the EAP, the AR and the BLK acted therefore on precipitation patterns and river discharges from 1998 onwards (Table 2), suggesting that atmospheric processes at the scale of the North Atlantic were closely tied to the hydrological variability of Western Europe coastal ecosystems (Goberville et al. 2010, 2011; Harley et al. 2006).

At a more local scale, long-term variability in precipitation (the Guipavas station being the reference for the two study sites) is strongly positively correlated with changes in river discharges ($r = 0.828$, $p_{ACF} < 0.001$ and $r = 0.735$, $p_{ACF} < 0.001$, respectively; Table 3). This result revealed that the decreasing trends in freshwater outflows were mainly explained by a reduction in the amount of precipitations over the last two decades. Winter sea surface salinity at both sites was mainly related to changes in river discharges: the long-term decrease in the Aulne + Elorn and Penzé discharges led to an increase in SSS in both coastal sites ($r = -0.754$, $p_{ACF} < 0.001$ and $r = -0.492$, $p_{ACF} < 0.001$, respectively; Table 3).

**Table 2** Pearson correlations between sea surface temperature (SST) anomalies (SOMLIT-Brest and SOMLIT-Astan), rain rates anomalies (Guipavas station), and river discharge anomalies (Aulne + Elorn and Penzé) and (1) the teleconnection and (2) weather regimes indices

| | (1) Teleconnection indices | | | | | | (2) Weather regimes | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NAO | | | EAP | | | AR | | | BLK | | | NAO+ | | | NAO- | | |
| | *r* | % | *p* | *r* | % | *p* | *r* | % | *p* | *r* | % | *p* | *r* | % | *p* | *r* | % | *p* |
| SST (*SOMLIT-Brest*) | **0.528** | **27.88** | <0.001 | 0.215 | 4.63 | 0.146 | −0.001 | 0.00 | 0.997 | −0.178 | 3.18 | 0.177 | **0.413** | **17.06** | 0.006 | **−0.339** | **11.48** | 0.028 |
| SST (*SOMLIT-Astan*) | **0.576** | **33.12** | <0.001 | 0.196 | 3.86 | 0.224 | 0.026 | 0.07 | 0.844 | −0.064 | 0.41 | 0.631 | **0.450** | **20.29** | 0.004 | **−0.447** | **20.00** | 0.003 |
| Rain rate anomalies (*Guipavas*) | 0.045 | 0.07 | 0.731 | **0.608** | **36.93** | <0.001 | **−0.546** | **29.80** | <0.001 | **−0.355** | **12.58** | 0.005 | 0.277 | 7.67 | 0.032 | 0.194 | 3.78 | 0.137 |
| River discharge*Brest* (*Aulne–Elorn*) | 0.035 | 0.12 | 0.807 | **0.547** | **29.94** | <0.001 | **−0.427** | **18.23** | <0.001 | **−0.400** | **15.98** | 0.002 | 0.202 | 4.09 | 0.150 | 0.219 | 4.77 | 0.123 |
| River discharge *Astan* (*Penzé*) | 0.042 | 0.18 | 0.778 | **0.468** | **21.86** | <0.001 | **−0.346** | **11.96** | 0.007 | **−0.407** | **16.59** | 0.001 | 0.195 | 3.81 | 0.174 | 0.181 | 3.29 | 0.208 |

The explained variability (%) was assessed using the coefficient of determination ($R^2$). NAO: the North Atlantic Oscillation; EAP: the East Atlantic Pattern; AR: the Atlantic Ridge; BLK: the Scandinavian Blocking regime; NAO+ and NAO−, positive and negative phases of the NAO, respectively. Probabilities were corrected to account for temporal autocorrelation. Coefficient of determination ($r^2$) > 10% are in bold

**Table 3** Pearson correlations between rain rate anomalies recorded at the Guipavas station, sea surface salinity (SSS) anomalies calculated at the SOMLIT-Brest and SOMLIT-Astan sites and the river discharge anomalies (1) in Brest (the Aulne + Elorn River discharges) and (2) in Astan (the Penzé River discharge)

| | Rain rate anomalies (Guipavas) | | | | SSS anomalies | | | |
|---|---|---|---|---|---|---|---|---|
| River discharge | *r* | *p* | % | *n* | *r* | *p* | % | *n* |
| Brest (Aulne + Elorn) | **0.828** | <0.001 | **68.61** | 60 | **−0.754** | <0.001 | **56.83** | 60 |
| Astan (Penzé) | **0.735** | <0.001 | **53.98** | 60 | **−0.492** | <0.001 | **24.19** | 60 |

The explained variability (%) was assessed using the coefficient of determination ($R^2$). Probabilities were corrected to account for temporal autocorrelation
*n* number of months considered. Coefficient of determination ($R^2$) > 10% are in bold

### *3.3 Ocean Hydrological Signature of Extreme Events*

In the Bay of Brest, in situ observations have contributed to increasing our knowledge about the dynamics of coastal environments of Western Brittany under a wide range of temporal scales, from hourly to interannual periods. After having characterised the long-term variability and trends, we then focused on short-term variability and extreme events.

Sea surface temperature (Fig. 4—top panel) was dominated by a seasonal cycle with values ranging from 8 to 10 °C in winter and from 16 to 18 °C in summer. This cycle was observed in both datasets collected by the MAREL-Iroise buoy and by low-frequency measurements recorded at SOMLIT-Brest. By running the MARS3D model (using the BACH configuration—Theetten et al. 2017; Charria et al. 2017), our numerical simulations were able to mirror this seasonality but also year-to-year changes. For example, both warm waters observed during summer 2003 (an exceptional heatwave—without equivalent over the last 500 years—occurred in Europe in 2003; Trigo et al. 2005) and the low temperatures recorded during the cold and dry winter 2005 (Somavilla et al. 2009) were reproduced in our simulations. High-frequency variations were also detected although their amplitude remains negligible in comparison to seasonal and interannual variability.

Sea surface salinity (Fig. 4—bottom panel) also followed a seasonal cycle with higher values in spring/summer and lower values in winter, probably under the influence of precipitations which in turn modulate river discharges. Changes in salinity also highlighted the signature of intense and intermittent events. Such events, visible as minimum in salinity (Fig. 4), can lead to values below 22. The impact of extreme events on sea surface temperature is quite limited, however. These minimum salinity values are a signature of extreme (or at least unusual) conditions in the Bay of Brest. High-frequency measurements allowed to accurately detect and depict these events, i.e. to better characterise their magnitude, frequency of occurrence and exact timing. At the opposite, low-frequency data from SOMLIT systematically underestimated their amplitude. This was linked to the SOMLIT sampling strategy (weekly and a high tide). While model simulations (considering daily averages for the time period

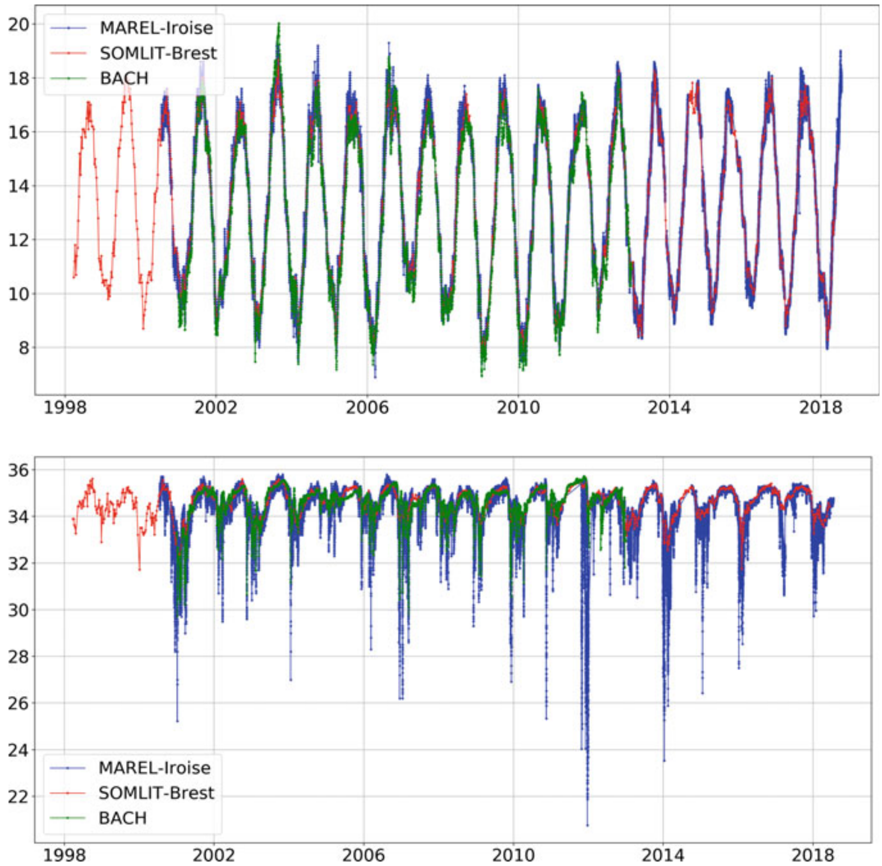


**Fig. 4** Time series of sea surface temperature (top) and salinity (bottom) observed in the Bay of Brest from low-frequency sampling (red), continuous automated measurements (blue) and numerical simulations (green)

2001–2012) reproduced changes in salinity well, including the apparition of extreme events, we acknowledged that the amplitude of extreme events was underestimated.

To evaluate the impact of low salinity events on coastal environments, we first aimed to characterise their occurrence: a low salinity event, below 33.93, was identified from high-frequency sampling and values below this threshold represented 20% of the total number of observations for the whole time period.

Considering those unusual salinity conditions, the number (not shown) and the duration of the low salinity events were analysed. By considering the cumulated length of low salinity events (Fig. 5) as a proxy of both the number and the intensity of events, a strong interannual variability was observed among years: from only 20 to 30 days to more than 100 days of low salinity values. It is interesting to note that the influence of large-scale features, such as the extremely cold winter 2005 which

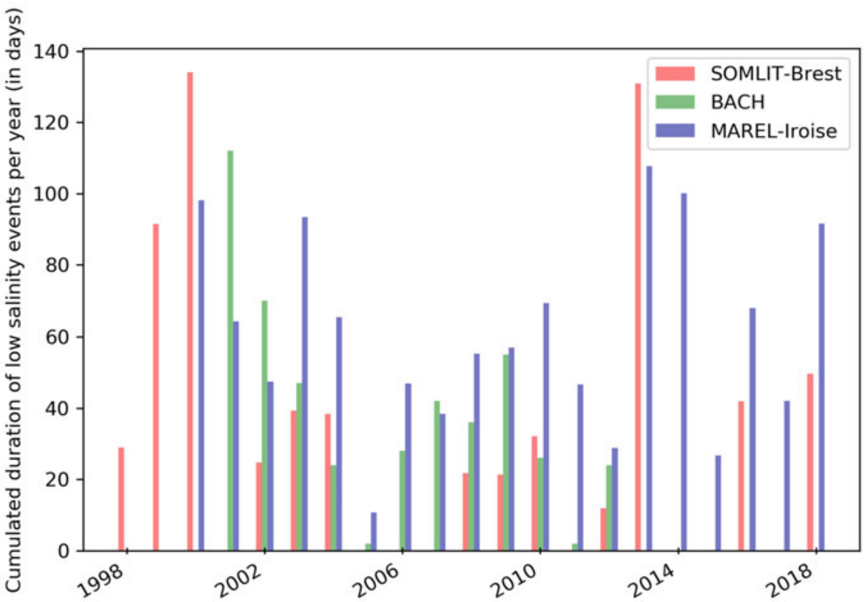


**Fig. 5** Cumulated length (in days) of low sea surface salinity events per year for the high-frequency sampled (blue—MAREL-Iroise), the low-frequency sampled (red—SOMLIT-Brest) and the simulated (green—BACH) time series. We can note that no observation is available for MAREL-Iroise in 1998 and 1999 and that the simulated time series covers the period 2001–2012

was induced by circulation changes at the scale of the North Atlantic (Somavilla et al. 2016), was clearly identified, at a local scale, by our procedure.

However, some discrepancies appeared when we compare in situ observations (low/high-frequency measurements) with numerical simulations. Low-frequency data (i.e. SOMLIT-Brest) generally displayed the minimum cumulated duration of extreme events, i.e. the lower number of extreme salinity events (Fig. 5). This was explained by the sampling strategy mainly oriented in assessing long-term changes but not devoted to the examination of sporadic and abrupt phenomenon. Modelled events successfully reproduced the events we detected observationally (e.g. 2009, 2013), while over(under)estimating their duration (e.g. 2001, 2002). This was mainly explained by model limitations and the difficulty in mirroring stochastic events. For example, while river runoffs implemented in the model were daily observations, atmospheric forcings had a coarse spatial resolution (~80 km). Model outputs consist in daily averages. Such features (mainly related to the computing time cost of pluri-annual simulations of coastal dynamics) will be improved in the near future.

Despite these limitations, extreme events were reproduced and can be interpreted, considering the full 3D dynamics solved in simulations. To illustrate the processes underlying low salinity episodes, we described here the events that took place in December 2009 and during which two major events were detected between the 1st and the 10th (Fig. 6). Using in situ observations, monthly changes in salinity can be investigated. The oscillations, related to lunar semi-diurnal tides (M2 component), showed a strong variability of salinity even during extreme episodes. During a tidal cycle, values ranged from a typical seasonal value slightly below 34 and extremely

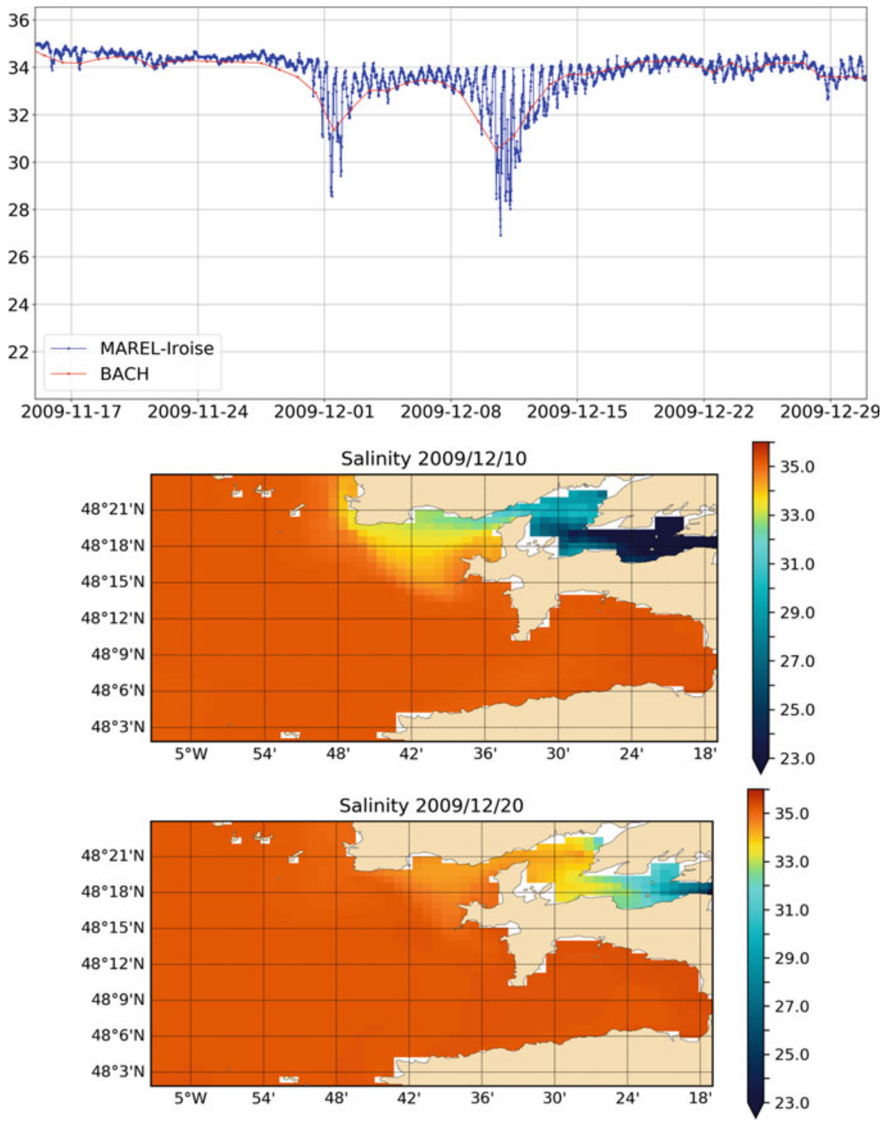


**Fig. 6** In situ observed (blue) and simulated (red) sea surface salinity (SSS) at the MAREL-Iroise buoy over the period mi-November–December 2009 and spatial representation of modelled SSS for December, 10 and December, 20

low salinity (below 30). With our model, results were similar to a low-pass filtered signature of low salinity events.

Based on the smoothed view provided by our model, we analysed spatial patterns of salinity in the Bay of Brest during episodic events. Spatial changes in sea surface salinity (examples in Fig. 6) displayed that these events were related to obvious changes in river runoffs: the 10th December 2009, sea surface salinity showed a large panache of low salinity that extended in the Iroise Sea to 4.8 W and low salinity waters remained flowing near the coast. Episodes of high runoffs can be mainly explained by local intense precipitations over the river watershed (Tréguer et al. 2014). During 'normal' periods, the plume of low salinity is confined in the eastern part of the Bay of Brest (Fig. 6).

## 4 Discussion and Conclusion

Based on more than 20 years of in situ observations in Western Europe, increasing trends in SST (+0.008 and +0.003°C year$^{-1}$ for Brest and Astan, respectively) and SSS (+0.026 and +0.006 pss year$^{-1}$ for Brest and Astan, respectively) have been observed. A longer period of data acquisition allowed us to revise the study performed by Tréguer et al. (2014) that estimated negative trends in SST (−0.02 and −0.01 °C year$^{-1}$ for Brest and Astan, respectively) when based on the period 1998–2013. As such, we highlighted the clear impact of an acceleration of warming that followed a short period of cooling (or a deceleration phase in warming) identified, at a global scale, as the global warming hiatus (Somavilla et al. 2016). When salinity was considered, trends did not change significantly over time, with a constant relationship with changes in river discharges.

Year-to-year changes in sea surface temperature and salinity during the period 1998–2018 were linked to large-scale processes such as revealed by the strong correlations that emerged with teleconnection and weather regime indices. By focusing on the winter period, we showed that (1) SST was related to the winter NAO, (2) SSS was indirectly modulated by precipitations which influenced river discharges and (3) precipitation patterns are under the influence of large-scale hydro-climatic processes as revealed by the strong links with the EAP (East Atlantic Pattern), AR (Atlantic Ridge) and BLK (Scandinavian Blocking regime) large-scale climatic indices and weather regimes. The correlations we observed between the EAP and precipitations in the studied region substantiate the study of Casanueva et al. (2014) performed for the period 1950–2010. Due to the non-linear changes of coastal ecosystems, those relationships can evolve with the increasing amount of available observations.

By considering high-frequency processes, low and extreme salinity events have been identified. Both the number and the duration of these events were associated to strong interannual variations. Using high-frequency strategies is required to detect and quantify such short-term features. Numerical simulations highlighted the important role of river discharges that induced a spread of freshwater in the Bay of Brest, with a residual signal despite tidal fluctuations.

Our study introduced the main hydrological features that occurred in the Bay of Brest over the last two decades. The prominent extreme events, particularly detectable when winter salinity values were considered, we detected in the waters of the Bay of Brest were directly under the influence of intense atmospheric circulation patterns that acted on a more global scale. Such large-scale processes have shaped the hydrological features in this region. In the context of intense climate change, a better understanding of the role of extreme events on long-term changes that took place in coastal ecosystems represent a current scientific challenge requiring further investigations.

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# Risk-Based Consenting of Offshore Renewable Energy Projects (RICORE)

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**Abstract** Consenting and environmental impact assessment (EIA) procedures are two of the major non-technical barriers to the further expansion of offshore renewable energy (ORE). Risk-based consenting of offshore renewable energy (RiCORE) is a Horizon 2020 funded project which aims to promote the successful development of ORE in the European Union by developing an environmental risk-based approach to the consenting of ORE projects, where the level of survey requirement is based on the environmental sensitivity of the site, the risk profile of the technology and the scale of the proposed project. The project aims to provide guidance on how to potentially improve consenting processes to ensure cost-efficient delivery of the necessary surveys, clear and transparent reasoning for work undertaken, improving knowledge sharing and reducing the non-technical barriers to the development of the ORE sector. The output from RiCORE includes deliverables over six work packages including four expert workshops conducted with relevant stakeholders (regulators, industry and EIA practitioners). The first workshop considered the practices, methodologies and implementation of pre-consent surveys, post-consent and post-deployment monitoring. The second workshop examined the legal framework in place in the partner Member States (MS) to ensure that the framework developed will be applicable for roll out across these MS and further afield. Two further workshops have involved target stakeholders to develop and refine recommendations and discuss their effective

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implementation. This communication highlights the main findings and draft recommendations from the RiCORE project to date. For further information and associated deliverable reports visit http://ricore-project.eu.

**Keywords** Offshore renewables · Consenting · Environmental impact · Risk-based approach · Monitoring

## 1 Introduction

The RiCORE project was an 18-month project, funded by the Horizon 2020 programme. The project was charged with promoting a risk-based approach to the consenting of offshore renewable energy (ORE). The cost and time taken to conduct environmental impact assessment remain one of the key barriers to the deployment of offshore energy arrays. Costly and time-consuming environmental surveys are a prerequisite, even for known technologies in areas of low environmental sensitivity. There is little standardisation across different EU Member States in terms of the regulatory environment, how the consenting process is administered, and the interpretation of EU environmental legislation.

The aim of the RiCORE project was to establish a risk-based approach to consenting where the level of survey requirement is based on the environmental sensitivity of the site, the risk profile of the technology and the scale of the proposed project. Based on ecological risk assessment (EcoRA), risk-based approach is a well-founded method, that, in addition to its many applications on land, has been used in marine renewable energy (Nunneri et al. 2008; Boehlert and Gill 2010; Stelzenmüller et al. 2010; Burger et al. 2011; Chou and Ongkowijoyo 2014; Hammar et al. 2014).

RiCORE set out to examine the legal framework in place in the partner Member States to ensure the framework developed would be applicable for roll out not only across these Member States, but also in other non-European countries with ORE developments in progress. The next stage of the RiCORE project was to consider the practices, methodologies and implementation of pre-consent surveys, post-consent and post-deployment monitoring. This would allow a feedback loop to inform the development of the risk-based framework for the environmental aspects of consent and provide best practice.

Consequently, RiCORE was expected to contribute to efforts by scientists, licensing bodies, stakeholders and lobby groups and the offshore renewables industry to reduce the time and cost involved in consenting small-scale arrays of known risk. Using risk profiles, scientists and regulators could potentially reduce the amount of survey data required prior to the deployment of relatively small arrays of known technology in areas of low environmental sensitivity.

There were three main objectives of this work:

- Understanding what happens in different Member States regarding the consenting process, the application of legislation and any legal barriers to the application of a risk-based approach;

- Examining the potential for developing and using risk profiles in different partner countries;
- Building the case for more standardisation in post-deployment environmental impact monitoring allows developers, scientists and regulators to better understand the environmental effects of different devices.

The project used a combination of desk-based research and expert workshops. Experts were engaged from different stakeholder groups including developers, scientists, regulators, legislators, development agencies, academia and representatives of other marine users and special interest groups.

For this purpose, the project was divided into six work packages:

- Work package 1: Project management;
- Work package 2: Profiling Member State consenting processes and reconciling EU legal requirements;
- Work package 3: Survey, deploy and monitor;
- Work package 4: Pre-consent survey optimisation;
- Work package 5: Post-consent and post-deployment monitoring standardisation;
- Work package 6: Communication and dissemination.

This communication focus on the results obtained in work packages 2 to 5 that highlight the main findings and draft recommendations from the RiCORE project to date.

# 2 Results

For more information about the results explained in the present section, all the deliverables of the RICORE project can be downloaded from the web page of the project in the following link: http://ricore-project.eu/downloads/.

## *2.1 Profiling Member State Consenting Processes and Reconciling EU Legal Requirements*

### 2.1.1 Objective

The primary objective was to understand the consenting requirements across participant Member States, with a particular focus on environmental requirements, and their effects as a non-technical barrier on offshore renewable energy development. The work conducted sought to determine how environmental effects are addressed in existing national consenting processes, the extent to which these processes currently take a risk-based approach and the possible legal impediments to widespread uptake of risk-based management.

### 2.1.2 Key Findings

Legal and Institutional Review of National Consenting Processes

The ‘one-stop-shop’ approach developed in the UK is working well and is now fully achieved through the recent amendment of the Town and Country Planning Act. A ‘one-stop-shop’ approach offers a single point of contact providing all services attached to consents and EIA processes (EIA screening, EIA scoping, consultation coordination, application examination and licence delivery). ORE developers in Scotland are no longer required to submit separate planning permission applications in addition to the Section 36 application forms for the onshore works associated with offshore generating stations. The new scheme allows Marine Scotland to grant—on behalf of the Scottish Ministers—deemed planning permission for the onshore ancillary works. This scheme has positive impacts on offshore development. Thirteen consents for offshore renewable projects using wind and wave energy have been granted in Scottish waters since the amendment of the consenting scheme in 2013. Moreover, eleven projects are currently in a pre-application phase and two offshore projects using wind and tidal energy are now underdetermination by MS-LOT (Forthwind Offshore Windfarm in Methil and DP Marine Energy, Islay).[1]

In other European countries, a move towards more integrated licensing systems for ORE projects is noticeable. Although the implementation of a ‘one-stop-shop’ approach is in progress in France and Ireland, it is currently only implemented for the marine and associated environmental elements of ORE developments (occupation of the maritime domain and associated EIA for offshore works). Responsibilities relating to the electrical aspects of a development, grid connection, planning permission and associated terrestrial EIAs still reside in different departments or authorities.

In Spain and Portugal, consenting approaches remain fragmented and sequential even though efforts have been made to implement parallel administrative processes. In the short time, better coordination between licensing authorities is necessary. In Portugal, this may be achieved in the first instance by the establishment of a single point of contact in charge of coordinating the whole application process. This will permit a more integrated decision-making process.

Fragmentation of consenting processes creates complexities for developers. It is highly recommended that developers are provided with clear guidance on consenting processes through institutional websites and documents. In Ireland, guidelines on consenting may be developed following enactment of the forthcoming, new Maritime Area and Foreshore (Amendment) Bill. In France, Portugal and Spain, online or paper guidance should be issued to help developers navigate consenting systems. In France, a special procedure dedicated to marine renewable energy may also be incorporated in the Energy Code. Procedures should include statutory timelines to limit the period for consenting responses. Such timelines should be appropriate to the scale of development that is being installed. These propositions have already been

[1]Updated figures about consented renewable energy projects and projects under review in Scotland are available online: http://www.gov.scot/Topics/marine/Licensing/marine/scoping.

advanced as strategic and operational national recommendations with regards to consenting for wave energy in the SOWFIA project (Enabling Wave Power: Streamlining processes for progress, 2013). These recommendations are relevant and may be applied to other renewable energy technologies.

### Legal Feasibility of Implementing a Risk-Based Approach to ORE

Due to scientific uncertainty on the environmental effects of ORE technologies, competent authorities have been inclined to apply an overly precautionary approach, requiring mitigation for impacts that may not be occurring and have established cultures of imposing monitoring requirements based on conventional approaches to statistical significance testing that can provide data-rich but information-poor results. This combination of issues can be addressed through taking an adaptive and risk-based approach to monitoring and consenting. Evidence from legislation and case law on risk-based approaches is limited and, in some jurisdictions, competent authorities have become risk averse. Interpretation of risk and clarification of risk-appetite can be meaningfully, but not exclusively, informed by scientific and statistical information. This is considered to be useful compared to attempts to construe legal wording of court rulings and directives without recourse to the best available science and case-specific contexts.

Adaptive management (AM) is particularly relevant where decision makers consider that the level of scientific uncertainty needs to be reduced. Such scenarios are likely to be case specific, not being prescribed by statute, and adoption of AM can only be considered appropriate where it is coherent with conservation objectives for statutory designated/protected areas. Judgements around the use of AM approaches can be informed by a fuller understanding of the scientific uncertainties that would be the focus of the approach. Promotion of environmental assessments that quantify scientific uncertainties and will make decision makers more informed about the levels of confidence they require. Competent authorities need to be clear on whether the objective of monitoring is to reduce the scientific uncertainty associated with a one-off issue at a project level or to achieve learning that can be applied to future decisions by improving the confidence associated with assessment frameworks that rely upon quantitative modelling. The latter is one type of assessment approach, but learning can still be achieved and applied to future decisions without quantitative modelling. The greatest value of AM to wider society is likely to be in an approach that exemplifies the goal of learning-by-doing. In this instance, AM is more closely aligned with policy goals associated with future projects or phases of an existing project rather than the goal of relaxation of stringent management at the project site where data are gathered. It can be seen that AM offers flexibility in how it is applied under consenting processes but the underpinning philosophy and associated transparent consideration of risk-appetite are fundamental and existing risk-averse cultures associated with institutional and administrative systems may impede uptake.

Despite the advantages of AM, this approach to management should be applied with caution. In fact, this approach should not relieve developers and regulators from precaution. Doremus (2007) argued that 'in situations where the action is perceived to be necessary, but its consequences are uncertain, both an urge towards precaution and a commitment to science suggest that we look for ways to act incrementally while learning'. AM and the precautionary principle are not contradictory and should be implemented simultaneously to improve scientific understanding. Balancing the precautionary principle and AM in a regulatory framework for ORE is feasible if appropriately protective objectives and restrictive mitigation measures are agreed upon from the outset (set-up phase) to manage the risk of negative impacts to a level considered acceptable by regulators and stakeholders. Decision makers should strive towards making scientifically robust assessments of impact whilst taking account of the risks associated with the distribution of probabilities. Subsequent assessments should become progressively more robust with higher levels of confidence in the predictions. These can be used by decision makers to inform their decisions regarding existing and future projects.

There is a clear need for research on better AM practices and how it can be meaningfully applied. EU policymakers will need to consider how AM approaches can be further advanced and articulated with existing environmental legislation.

## *2.2 Survey, Deploy and Monitor*

### 2.2.1 Objective

The primary objective was to further develop the survey, deploy and monitor (SDM) policy guidance, pioneered by Marine Scotland,[2] to include all relevant technologies in the offshore renewable energy (ORE) sector, including the adaptation of the policy as new technologies are developed. The work conducted sought to review the state of the art of the SDM policy, review the novel technologies currently in development and further develop the SDM acting as a guide for users wishing to apply a risk-profiling approach at a Member State level.

### 2.2.2 Key Findings

Following the description of the SDM policy and the analysis of the case studies different aspects of improvement were identified:

- Extend the risk-based approach to post-consenting processes;
- Update the criteria for the evaluation of the scale of the project;

[2](http://www.gov.scot/Topics/marine/Licensing/marine/Applications/SDM).

- Establish a set of common *criteria* for the evaluation of the environmental sensitivity of a specific location;
- Update and review of the expected environmental impacts of the different technologies;
- Include some guidance on the methodology for pre- and post-consenting monitoring and;
- Introduce the aspect of uncertainty in the risk-based approach.

In a second stage, an inventory of the technology types (within the tidal, wave and offshore wind categories) that the RiCORE project considers when providing recommendations and guidelines in favour of implementing a risk-based consenting approach was undertaken. Eleven technology types across all three technology categories were identified together with their technology maturity according to the technology readiness levels (TRL) scale (Table 1).

Finally, based on the previous findings, a review and further development of the three main pillars on which the SDM approach is based (environmental sensitivity of the site, the risk profile of the technology and the scale of the proposed project) was undertaken in order to develop a new proposal for the assessment of the risk of an ORE development.

Similar to Sparling et al. (2015), the assessment of the risk of an ORE development is based on the combined outcomes of the overall sensitivity of the receptors, taking into account the sensitivity of the location, and the risk posed by the project, taking into account the scale and the technology (Fig. 1).

- Environmental Sensitivity

**Table 1** ORE technology types identified in deliverable 3.2. Adapted from Mascarenhas et al. (2015)

| Technology category | Technology type | Technology readiness level (TRL) |
|---|---|---|
| Tidal | Tidal impoundment | 9 |
| | Tidal stream—horizontal axis turbine | 8 |
| | Tidal stream—enclosed tips (Venturi) | 8 |
| Wave | Attenuator | 8 |
| | Point absorber | 7 |
| | Oscillating wave surge converter | 8 |
| | Oscillating water column (OWC) | 7 |
| Floating wind | Spar-horizontal axis WT | 7–8 |
| | Semi-submersible platform—horizontal axis WT | 8–9 |
| | Semi-submersible platform—vertical axis WT | 7 |
| | Tension leg—submerged platform | 7 |

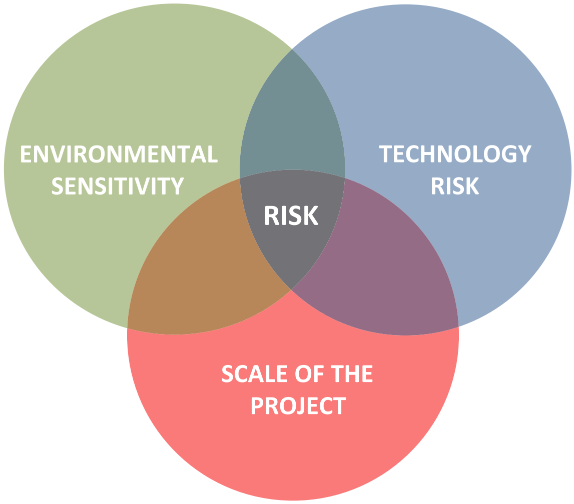


**Fig. 1** Risk assessment approach

As previously stated, in developing SDM, Marine Scotland chose to take a qualitative approach to classify the overall environmental sensitivity of the project location using expert judgment based upon the mapping exercise of all environmental sensitivities combined. An alternative and potentially more transparent approach to scoring the overall environmental sensitivity of a potential development location is given in Table 2.

For each environmental sensitivity of concern at the location a value of 1, 2 or 3 is assigned for low, medium and high-risk assessments, respectively, depending on the perceived importance of the location. For example, locations that are protected areas for habitats or species would score more highly than other areas, and areas of

**Table 2** Calculating overall environmental risk of the proposed location for MRE development: score (1, 2 or 3 for low, medium or high, respectively); GM = Geometric Mean

| Location of project | Environmental sensitivity layers (receptors) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Physical environment | | | | Biotic environment | | | |
| | (a) Marine dynamics | (b) Seafloor integrity | (c) Water quality | (d) Landscape | (e) Benthos | (f) Fish | (g) Marine mammals | (e) Birds |
| Low, medium or high sensitivity at the location | Score a: 1, 2 or 3 | Score b: 1, 2 or 3 | Score c: 1, 2 or 3 | Score d: 1, 2 or 3 | Score e: 1, 2 or 3 | Score f: 1, 2 or 3 | Score g: 1, 2 or 3 | Score e: 1, 2 or 3 |
| Overall risk | GM | | | | | | | |

the wider marine environment with relatively higher densities of a particular species would score relatively more highly than other areas. This exercise would be informed by the environmental sensitivity mapping at a national scale that was of sufficient robustness to allow quantification at local scales to be undertaken with confidence. As such it would appear to be more appropriate for Member States who have access to comprehensive and reliable data sets on environmental sensitivity. Having obtained a risk value for each receptor of interest at the project location the overall environmental sensitivity of the location can be calculated using the geometric mean.

In principle, scoring environmental sensitivity in this manner should make it more transparent which factors at a particular location are of particular importance for the subsequent assessment of environmental impacts from the project. This may be particularly useful where a scoping exercise is undertaken as part of an environmental impact assessment.

- Technology risk (TR) profiling

Defining an appropriate risk assessment approach involves consideration of potential impacts. Therefore, it follows that survey requirements should be determined by the potential significant impacts that could arise from a proposed development. These impacts will depend on the characteristics of a project including the type of energy generation technology, support vessels and infrastructure to be used.

All of them have common aspects that are subject to act as stressors (action of the project that can generate impacts) over different receptors (environmental factors that can be affected by the project actions) of the marine environment. According to Boehlert and Gill (2010), the main stressors of ORE developments are associated with:

1. The **physical presence** of the devices.
2. The **physical presence of moorings, mooring lines and supporting structures**.
3. The **dynamic components of the devices**: the moving parts of the devices can lead to “blade strike”.
4. The **chemicals** used in the devices (hydraulic fluids, anode erosion and anti-fouling paints) and the pollutants’ leaking from vessels during deployment, routine servicing and decommissioning.
5. The **acoustic effects** during deployment, routine servicing and operation of devices, and decommissioning.
6. The **electromagnetic field** generated during transmission of the produced electricity through the submarine cables during the operation of devices.

In this section, the different impact pathways (IP) of the ORE technology types were described. The objective was to provide the needed criteria to the experts in charge of the risk analysis of these technologies so they will be able to assign a value of low, medium or high risk according to the expected impacts. A detailed description of these IP can be found in the Deliverable 3.3 of the RICORE project.[3]

[3](http://ricore-project.eu/wp-content/uploads/2016/05/RiCORE-D3.3-Risk-Profiling-Final.pdf).

For each IP a value of 1, 2 or 3 is assigned for low, medium and high-risk assessments, respectively. In this way, a risk value can be obtained for each stressor and receptor by means of the calculation of the geometric mean (GM) of the assigned scores for each IP (Geometric Mean = ((IP1) (IP2) (IP3)…(IPn)1/n). This analysis needs to be done for each of the project stages, that is, construction, operation and decommissioning. For each of these project stages, we will obtain a low, medium or high-risk assessment. Thus, it is recommended that the overall risk assessment of the technology consists of the calculation of the geometric mean of the three scores (stressors, physical receptors and biotic receptors) as shown in Table 3.

- Scale of the Project

The scale of the project is assessed according to three factors: (i) generation capacity, (ii) area occupied by the project and (iii) duration of the project. For each of these factors, a value of 1, 2 or 3 is assigned for low, medium and high-risk assessments, respectively, depending on a specific scale for each factor (Tables 4, 5 and 6). Table 4 describes the risk assessment related to the scale of a project. Table 5 describes the risk assessment related.

**Table 3** Technology risk (TR) assessment

| Technology risk | GM score | Overall risk |
|---|---|---|
| $TR_{Construction} = ((IP_1)(IP_2)(IP_3)\ldots(IP_n))^{1/n}$ | 1–1.60 | Low |
| $TR_{Operation} = ((IP_1)(IP_2)(IP_3)\ldots(IP_n))^{1/n}$ | 1.61–2.20 | Medium |
| $TR_{Decommissioning} = ((IP_1)(IP_2)(IP_3)\ldots(IP_n))^{1/n}$<br>$TR = ((TR_{Construction}) * (TR_{Operation}) * (TR_{Decommissioning})\ldots(IP_n))^{1/n}$ | 2.21–3.0 | High |

*Key* GM = geometric mean

**Table 4** Risk assessment related to the scale of a project (according to SDM policy)

| Scale | Criteria (MW) | Assessment |
|---|---|---|
| Small scale | Up to 10 | Low |
| Medium scale | More than 10–50 | Medium |
| Large scale | More than 50 | High |

**Table 5** Risk assessment related to area of the project for wind, wave and tidal projects

| Scale | Wind ($km^2$) | Wave ($km^2$) | Tidal ($km^2$) | Assessment ($km^2$) |
|---|---|---|---|---|
| Small scale | <2 | <1.5 | <1 | Low |
| Medium scale | 2–10 | 1.5–7.5 | 1–5 | Medium |
| Large scale | >10 | >7.5 | >5 | High |

**Table 6** Risk assessment related to the duration of the operational phase of a project

| Scale | Criteria | Assessment |
|---|---|---|
| Small scale | 1–3 years | Low |
| Medium scale | 3–10 years | Medium |
| Large scale | >10 years | High |

**Table 7** Overall risk (OR) assessment related to an ORE project

| OR | GM score | Overall risk |
|---|---|---|
| Overall risk = ((ESR) * (TR) * (SPR))$^{1/3}$ | 1–1.60 | Low |
| | 1.61–2.20 | Medium |
| | 2.21–3.0 | High |

*Key* GM = geometric mean

- Overall assessment

The overall risk assessment is based on the geometric mean of the three scores previously calculated for environmental sensitivity, technology risk and project scale (Table 7).

## 2.3 *Pre-consent Survey Optimisation*

### 2.3.1 Objective

In order to implement, a risk-based approach existing requirement for pre-consent surveys in the participating countries were first assessed. Generally, such a pre-consent survey may be part of a preliminary site characterisation exercise or scoping as part of the EIA process. This work package utilised information collected in previous work packages and in a workshop to assess comprehensively how well existing methods could be optimised across EU Member States, taking into account the potential positive implications for project timescales and costs.

A key outcome of this work package was the development of guidance for pre-consent surveys considering the spectrum of survey requirements of existing project experience. The guidance encompasses the transferability of methods and technologies among ORE types.

### 2.3.2 Key Findings

Commonalities and Differences in Approaches to Pre-consent Surveys

In general, methodologies to assess most of the parameters identified for each receptor seemed to be applicable to all ORE types (wave, tidal, fixed offshore wind and floating offshore wind). However, there are some exceptions related to aspects of the specific marine environment where the developments are to be located. One such exception is the site depth, which in the case of floating offshore wind projects may be higher than for the rest of the considered technology types. This may influence the methods selected for the benthos and sediments assessment, which will possibly need to make much use of ROVs to collect images instead of samples. Another exception is related to the acoustic assessment of the physical environment. Although all listed approaches are valid for all MRE types considered, drifting systems are recommended in high tidal flow areas to minimise the effects of flow noise.

In some cases, the assessment of some parameters and even receptors may not be a concern for some of the MRE types. Examples of such parameters are the accurate measurement of wind resource conditions using LIDAR techniques for wave and tidal energy developments. Also, the assessment of bats is not considered a concern for wave and tidal developments.

### Potential Emerging Innovative Monitoring Approaches

A compilation of the innovative technologies that are currently being developed for marine environment monitoring was made. This is unlikely to be a comprehensive list, as other devices and approaches are likely being trialled at sites prior to them being outlined in technical reports, after which time it may be a period of months to years before this information is published in peer-reviewed academic journals. Ultimately, this is a clear indication of how rapidly this field is evolving in an attempt to improve all aspects of pre-consent monitoring (e.g. cost, data quantity, data quality, health and safety). Thus, among these innovative and emerging monitoring technologies, the following were identified: (i) High-definition photography and video for seabirds and marine mammals monitoring; (ii) unmanned aerial systems; (iii) remotely operated vehicles (ROV) for benthic communities monitoring; (iv) high-frequency SONAR for monitoring fish species; (v) The FLOw, Water column and Benthic ECology 4-D (FLOWBEC-4D) (Williamson et al. 2015); (vi) telemetry and other remote transmitters are well established in the study of marine mammals; (vii) passive acoustic monitoring (PAM) devices for marine mammals monitoring; (viii) vessel monitoring system (VMS) to monitor vessel traffic and fishing activity; (ix) radar for tracking birds.

The costs of many of the listed approaches were also considered. In many cases, these costs varied substantially within receptor groups, with some approaches more suitable for a particular data type or information (e.g. abundance estimates or informing collision risk modelling) or were more suitable given certain logistic constraints (e.g. offshore vs. nearshore, shallow waters vs. deeper waters). This highlighted the fact that, although the cost is an important consideration of survey design, the initial stage of the process should be to consider the logistic constraints of the site coupled with the requirements requested by regulators to ensure that these can be met by selecting a suitable survey method or combination of survey method.

Although the cost is an important consideration in survey design, the logistical constraints and the requirements requested by regulators should be coupled to ensure that these can be met by selecting a suitable survey method. The use of power analysis can provide useful information on the ability of data gathered to create a baseline for detecting change. It is likely to become a commonly used approach in pre-consent survey design, as it can identify how much data are required to address the requests made by regulators, and at the same time, it contributes to a better understanding of the costs involved, considering the data that already exists.

### Pre-consent Survey Guidance

Facing the dilemma of whether or not and to what extent (i.e. volume of data collected both spatially and temporally) pre-consent surveys are required, and the following remarks can be done.

First of all, a key point is to consider the question(s) that needs to be addressed through discussion between developers, regulators and stakeholders establishing adequate communication routes. Depending on the question(s) to be answered (within a pre-defined threshold of confidence), an analysis of the existing data needs to be done in order to ascertain if these data allow the question(s) to be answered:

(a) If so, pre-consent surveys are not required; or
(b) If not, then surveys must be designed with a thorough knowledge of the question and the requirements so as to maximise the value of the data (considering temporal and spatial variation, for example).

For the surveys, it is recommended that developers/regulators/stakeholders be aware of evolving and new technologies applicable to all MRE types (wave, tidal, fixed offshore wind and floating offshore wind) that can improve/maximise the quality of the information that can be derived from the surveys and remove risk (health and safety) of data collection. It is important to highlight that a monitoring programme/pre-consent needs to find a compromise between data requirements, the scales of the project and the cost.

Where applicable, the use of power analysis to assess the suitability of the data and the survey design for pre-consent surveys is recommended. However, it is expected that power analysis will show that the volume of data required to identify changes in the receptor over time will be too great to be financially viable and/or cannot be undertaken within a realistic timeframe.

As such, pre-consent surveys should be employed to assist in informing consenting decisions and thus be considered exclusively as pre-consent site characterisation surveys. The extent of data required for a site characterisation should be outlined by the regulator in a guidance note. Hopefully, this will allow more pre-existing survey work to be used rather than further data collection being required for site characterisation. This will hopefully allow a developer to undertake further, more useful, monitoring work post-consent. In other words, we advocate a move away from the commonplace approach of gathering pre-consent baseline data for comparison post-consent, as these data are likely to be not fit for purpose. The major concern being that the management decisions are then made based on potentially erroneous conclusions (due to a lack of statistical power) and, as a result, the true consequences of the decision-making process on the receptor will be poorly understood.

## *2.4 Post-consent and Post-deployment Monitoring Standardisation*

### 2.4.1 Objective

The focus of this work package was the development of best practices for post-consent and post-deployment monitoring strategies, including industry standards where appropriate, with particular reference to risk-based approaches to survey and consenting/licensing for novel technologies. Currently, Member States do not have cohesive strategies for undertaking monitoring at operational devices with the clear goal of reducing the scientific uncertainties associated with consenting in order to have greater confidence in future decision making associated with commercial scale arrays.

This 'learning-by-doing' process is formally known as adaptive management and the survey, deploy and monitor (SDM) policy is an example. The need for guidance to support licensing regimes and industry relates to the development of an over-arching adaptive management approach for marine renewables and to the scientific issues associated with undertaking monitoring that is able to reduce the uncertainties in a meaningful manner.

### 2.4.2 Key Findings

Monitoring potential impacts at MRE sites is likely to be extremely challenging given the relatively small spatial scale of current sites in combination with natural stochastic variation that will also inevitably influence how animals use and respond to the marine environment.

There is a growing body of evidence showing that standard approaches to post-consent monitoring often result in data-rich but information-poor (DRIP) studies (Wilding et al. 2017) that are unable to meaningfully inform future decision making. There is a need for regulators to take stock of alternative risk-based approaches and the most suitable ways of achieving the goals of adaptive management. The focus should be on the role of government institutions and advisors to decision makers who should reconsider policies to promote an open and transparent approach to monitoring that is able to meaningfully reduce key scientific uncertainties and improve decision making. This needs to be done in association with careful consideration of the associated conservation objectives for features of biodiversity importance. Adaptive management can provide an over-arching approach, within which the detail of implementation that is capable of providing good quality monitoring results should be planned on a case-by-case basis using some key guiding principles:

- Adopting a more open and transparent approach to accounting for scientific uncertainty within assessments to inform risk-appetite of decision makers.
- Adopting a question-led approach to post-consent monitoring that fully engages stakeholders.
- Ensuring the study design can meaningfully answer the question.
- Informing study design through careful selection of acceptable effect sizes, agreed rates for false positives and false negatives, and use of sequentially flexible approaches for minimising costs.
- Across Member States continued sharing of expertise and experience as good practice develops is recommended.
- It is good practice to always present the mean effect size and associated variances.
- Using demonstration projects in conjunction with meta-analysis techniques can help to more efficiently address shared priorities and would promote the adoption of standardised approaches.

## 3 Perspectives

In the near future, one of the main challenges of the key findings of the RiCORE project will be the implementation of the risk-based approach in the consenting processes for ORE in the Member States. At the same time, recent developments in the field of marine spatial planning (MSP), such as the development of decision support tools (DSTs) for MSP in the ORE sector, can help to overcome this non-technological barrier. The implementation of the risk-based approach developed in the framework of the RiCORE in these DSTs for MSP in the ORE sector could be another challenge for the success of the development of this sector.

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# Does Global Warming Favor the Occurrence of Recent Blue Mussel Mortality Events in France?

**Jean-François Pépin, Patrick Soletchnik, Olivier Le Moine, Pierre Polsenaere, Sylvie Génauzeau, Stéphane Robert, James Grizon, Jean Luc Seugnet, Anne Schmitt, Jean Michel Chabirand, Delphine Tourbiez, Marie-Agnès Travers, and Stéphane Guesdon**

**Abstract** We report in this work data of two independent studies carried out in the Pertuis Charentais for which a link might exist. A 30-year-local time series study of hydro-climatic variations in water temperature and salinity, which show significant warming of the water masses in the Marennes-Oleron bay (+1.5 °C) associated with a significant drop (≥15%) of freshwater intakes by nearby rivers. In this changing local climate context several major epizootics have appeared, severely affecting farmers and the production of Pacific oysters and mussels, from the first French shellfish-producing department (catching and growing, Agreste 2014). Following the massive mortality event of blue mussels in 2014, a specific study (MORBLEU) is conducted, trying to identify the factors favoring the development of the phenomenon which, furthermore, involves pathogenic bacteria. First analyzes of environmental conditions suggest that there may be a link between (i) the local climate context, (ii) a downward trend in phytoplankton diversity indices, (iii) imbalances in the dynamics of bacterial community composition. These last two points are concomitant with the recent emergence of spring mortalities of mussels. The hypothesis of this link asks the question of evolution in the interactions between the plankton communities of the water column, mussel microbiota and the emergence of pathogenic microbial flora in bivalve mollusks as underlying the recent shellfish mortality events. Such a question requires performing a functional ecology approach with long-term monitoring at different scales, involving particularly NGS technology (metabarcoding) for environmental DNA research. Such a study is underway.

**Keywords** Hydro-climate · Estuary · Phytoplankton · Mussels · Mortality · Environment · Microbial community

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## 1 Introduction

In the context of global change, increasing mariculture production has raised particular concerns regarding its environmental impact and sustainability. Mollusks and particularly blue mussel account for a significant part of this total production. Although blue mussels are considered as pretty resilient to environmental disturbances, we report in this work unprecedented mussel mortality events that occurred in 2014 (Béchemin et al. 2015), 2015 and 2016 (Pépin et al. 2017) in the Pertuis Charentais area (French Atlantic coast) (see Fig. 1). Following these massive mortality events of blue mussels in 2014, a specific study (MORBLEU[1] research project, DPMA-Ifremer agreement, Travers et al. 2016) was conducted, trying to identify the factors favoring the development of the phenomenon which, furthermore, seems to involve pathogenic bacteria and also genomic abnormalities in mussel hemocytes (Benabdelmouna and Ledu 2016). These recent episodes of mortality occurred in a disturbed climatic period, where the temperature rise was significant (Polsenaere et al. 2017). These temperature rises cause ecological changes, especially on the microbial

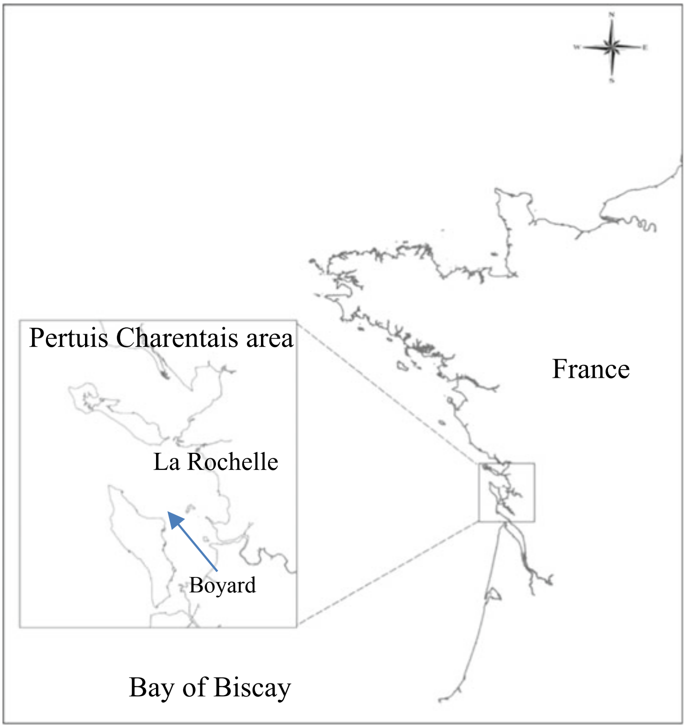



**Fig. 1** Location of the study on the French Atlantic coast

[1]MORBLEU: MORtalité de moules BLEUes. See https://wwz.ifremer.fr/lerpc/Activites-et-Missions/Etudes-et-Recherche/MORBLEU.

compartment of marine ecosystems. Thus, it is noted that environmental conditions are becoming more and more favorable to bacteria of the genus *Vibrio* sp. (Vezzulli et al. 2012), that interactions between bacteria and phytoplankton lead to changes in the structure of their communities, often due to heterotrophy (Degerman et al. 2013), with, in particular, the appearance of new bacterial taxa (Von Scheibner et al. 2014). Microbial dynamics are governed by the seasonal succession of communities (phytoplankton-bacteria-primary consumers), but the evolution of abundances and specific phytoplankton compositions may favor the development of specific bacterial types (Buchan et al. 2014).

In order to confirm the possible effect of the evolution of hydro-climate in the Pertuis Charentais zone on the emergence of massive mortalities of mollusks we sought to put into perspective these phenomena and their potential link with the variations of temperature and salinity of seawater obtained during an independent study. This second study carried out from our laboratory in the same area (Soletchnik et al. 1998, 2017) provides information on the local climate context in last decades and try to answer to the following question: Can we identify breaks and variations that could contribute to the evolution of the biotic environmental context?

Here, we report on two independent studies which address three issues: How much global warming impacts hydro-climate at local scale in Marennes-Oleron bay along last forty years?—Is there a link, between microbial balance and triggering of recent mussel mortality events in France?—Does the first issue could condition or favor the second one? Through a coupling approach, the present work aimed to better understand the potential environmental drivers associated to those mortalities.

## 2 Climate Change and Global Warming: Case of Marennes-Oleron Basin

### *2.1 Seawater Temperature*

The present study focused on the hydro-climatic evolution of the Marennes-Oleron Bay (French Western Atlantic coast, Fig. 1) between two 15 years-long periods (1977–1991 and 2000–2014) linked to a strong seawater temperature increase in the 1990s (Soletchnik et al. 2017) (Fig. 2). Between these two studied periods, the annual median seawater temperature value rise of about 3 °C endorsed the strong increase in higher temperature value frequency during the latest period (the annual mean temperature increase was 1.5 °C in the northern part of the Bay at Boyard Station). We have chosen not to consider the 1992–1999 period, because of the abrupt shift in sea surface temperature identified by Chaalali et al. (2013).

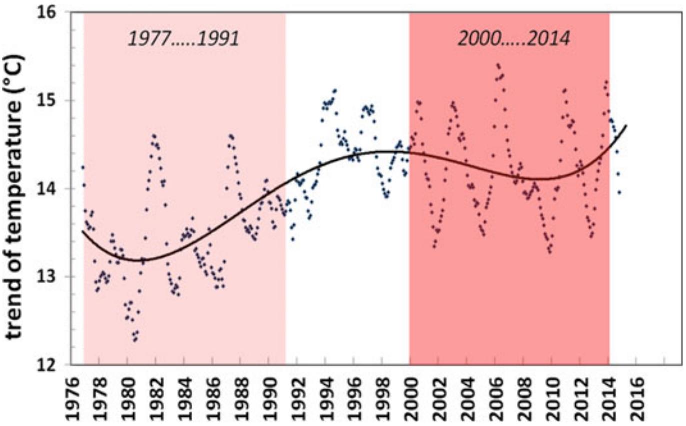



**Fig. 2** Evolution from 1977 to 2014 of the seawater temperature trend (monthly time scale) observed at Boyard Station (dotted line). The additive Census II model was used for time series decomposition (Statgraphic centurion XVI software, Shiskin 1957 from Bethoux et al. 1980). A polynomial model of order 4 ($R^2 = 0.46$) was then adjusted to median values (solid curve). (Data source, Ifremer LERPC)

## 2.2 *Salinity*

From nonparametric statistical analysis (Kruskal Wallis test, Statgraphic centurion XVI), a salinity time series comparison was realized between the two periods for each month of the year (Fig. 3).

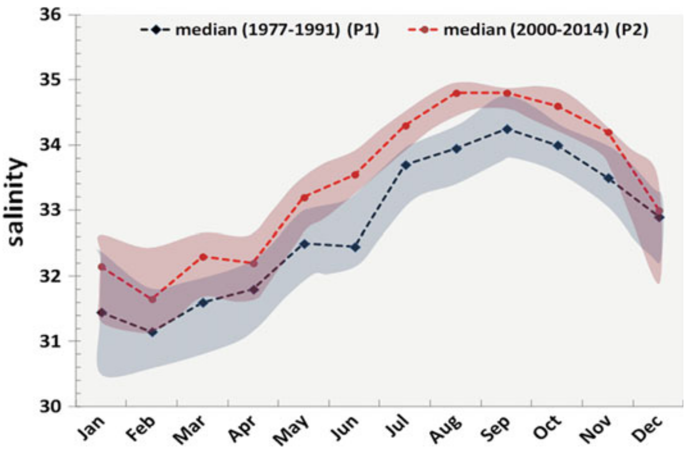



**Fig. 3** Seasonal median salinity values compared between 1977–1991 and 2000–2014 periods. Confidence ranges fixed at 95% for each median were based on order statistics of each sample (Statgraphic centurion XVI). Red and blue surface curves showed these confidence ranges for both studied periods (Boyard Station). (Data source, Ifremer LERPC)

Results showed that:

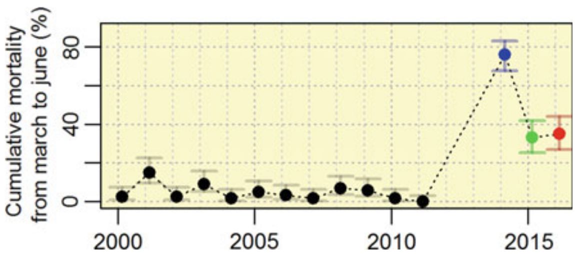
- Whatever the considered month, median salinity values were always higher during the latest period (2000–2014) (from +0.1 to +1.1 PSU in December and June, respectively);
- The significant differences (5% threshold) in salinity values observed in March, May months and the autumn season (September, October, and November months) delimited the summer season (June, July and August months) characterized by a stronger salinity value increase (1% threshold);
- At the annual scale, the salinity value difference between the two studied periods was +0.58 (from 32.9 to 33.48 PSU). It showed the «marinization» phenomenon of the Marennes-Oléron Bay coastal ecosystem.

Conclusion: At local scale of Marennes-Oleron bay, our 40-year in situ time series data show that hydro-climatic conditions have significantly changed (Soletchnik et al. 1998; Soletchnik et al 2017), as identified in Gironde estuary (Chaalali et al. 2013) or in the Bay of Biscay (Michel et al. 2009).

## 3 Biological Changes, Coincidence or Consequence?

After oyster spat crisis that farmers faced from 2008 to 2012 (Pépin et al. 2014), mussel farming of Charente-Maritime and Vendée has experienced an unprecedented crisis since the spring of 2014. Mass mortality events of blue mussel (*M. edulis*) have affected livestock areas, decimating up to 100% of production in some farming areas. In this context, the MORBLEU research project (DPMA-Ifremer agreement) was initiated to explore potentially aggravating factors associated or correlated with mortality of mussels (Fig. 4). Here, the work is to support the hypothesis that these mortality events could be linked to an evolution of microbial communities (water column and mussel microbiota).

**Fig. 4** Annual mussel cumulative mortality in Pertuis Breton site from specific batches monitored by Remoula and Mytilobs survey programs (Ifremer Networks/Quadrige)



## 3.1 Methods

### 3.1.1 Data Sources

Mussel mortality: Remoula and Mytilobs surveys recordings (Ifremer Networks/Quadrige database).

Meteorology (atmospheric temperature and precipitation): Chassiron station (Météo-France/Synop).

Phytoplankton abundances from the REPHY network (Ifremer/Quadrige database).

eDNA metabarcoding (NGS) of prokaryotic plankton (16S rRNA gene) analyzed as part of the MORBLEU 2015 project.

### 3.1.2 Data Processing

The diversity indices (Richness and Equitability) are calculated on the basis of the aggregated phytoplankton abundances at the genus level.

The years 2000–2016 are discriminated by a partial triadic analysis based on environmental variables (climate and diversity): matrix (years × variables) repeated from February to June, forming the cube of data analyzed.

## 3.2 Decrease in Phytoplankton Diversity

From 2000 to 2016 (warmer trend years, see Fig. 2), data analysis based on phytoplankton diversity indices and general climatic descriptors (atmospheric temperatures and cumulative rainfall) categorizes the years according to four typologies. Surprisingly, a group of 3 years is associated with high level of mortality. This group is characterized, in winter and spring, by weather rather hot and rainy, and diversity indices rather low (Fig. 5).

## 3.3 Change in Microbial Balance

Since 2015, monitoring of bacterial communities (through an NGS metabarcoding approach) is conducted on three stations from Pertuis Charentais. It confirmed that this period of initiation of mortality phenomenon is also marked by changes in bacterial equilibrium (Guesdon et al. 2017). A decrease in the most dominant taxa (abundance ratio >2.5%) is observed in favor of less present species (Fig. 6).

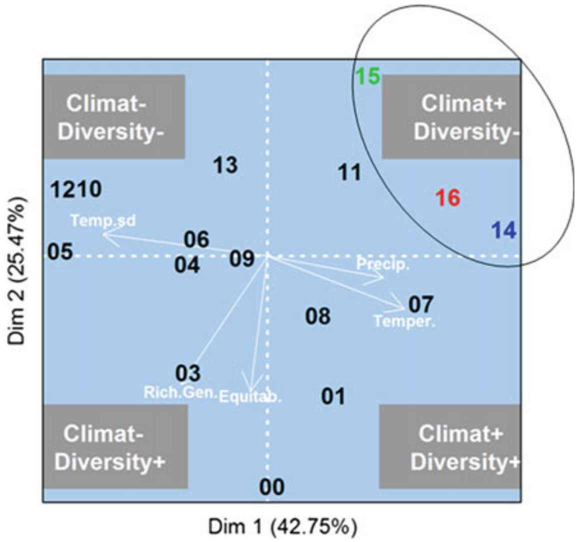



**Fig. 5** Results for the compromise of the partial triadic analysis (PTA); from 2000 to 2016, years in color in the circle correspond to years with high level of mortality

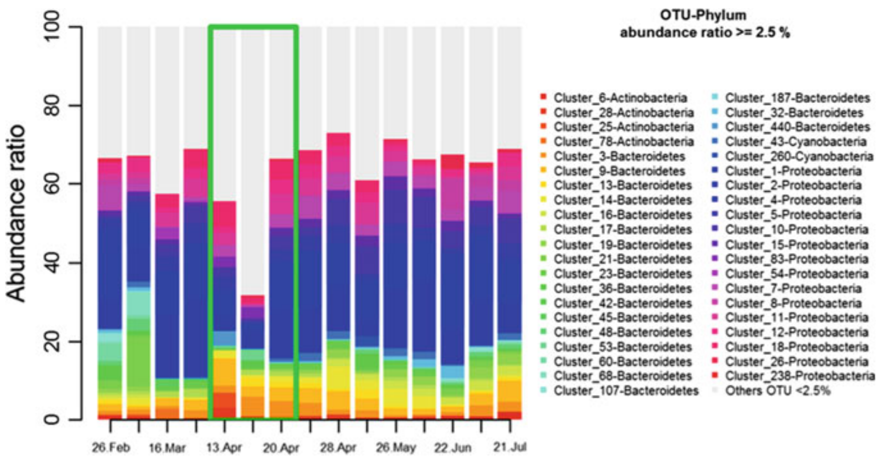



**Fig. 6** Winter and spring evolution of relative abundance of OTUs (operational taxonomic unit, 16S rRNA gene prokaryote metabarcoding) and classes of bacteria at the Filière station in 2015. Green frame indicates initiation of mussel mortalities

## 4 Conclusion

Although there is simultaneity between certain events of the microbial dynamics (imbalances) and the first spring mussel mortalities, no causal link is currently established between (i) the local climate context, (ii) a downward trend in phytoplankton diversity indices, (iii) imbalances in the dynamics of bacterial community composition. These last two points are concomitant with the recent emergence of spring mortalities of mussels. Our observations contribute to the hypothesis of a microbial origin (pathogenic bacteria and/or imbalance in mussel microbiota) responsible, or aggravating factor for the spring mortality of mussels, among those advanced since the emergence of the phenomenon (genomic abnormalities in mussel hemocytes, neoplasia). Whatever the temporal window of observation (seasonal, or medium-term historical), a link between the evolution of microbial balances and the spring mortality of mussels gets clear. If causal links existed, in addition to the fact that an organism or a group could be identified as responsible for mortality (seasonal dimension), the emergence of this phenomenon could have its origin in the evolution of microbial communities of shellfish ecosystems under the action of more global constraints such as warming change.

The holistic approach carried out in this work contributes to describe potential links between dynamic equilibrium of the planktonic microbial communities, and "health" of mussel livestock but in this context, more studies are still needed to characterize relationships and interactions between mussels and environmental factors. Such a question requires performing a functional ecology approach with long-term monitoring at different scales, involving particularly NGS technology for environmental DNA research.

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# Integrated Ecosystem Management for Exploited Coastal Ecosystem Dynamics Under Oligotrophication and Climate Changes

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**Abstract** Global change causes fluctuations as rainfall deficits that in some cases amplifies the reduction in nutrient intakes required for water quality regulation. In this context, oligotrophication reduces the pelagic production of coastal ecosystems and promotes the return of benthic macrophytes such as *Zostera* meadows. It is now necessary to know and understand the potential benefits related to the return of seagrass beds associated with the environmental recovery of shellfish-exploited-ecosystems (SEE). The French–Japanese SAKURA project aimed to (1) clarify and

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compare relationships between dynamics of nutrient levels, phytoplankton, and oyster production in the Thau Lagoon (France) and Hiroshima and Aki bays, using historical data analysis and carrying capacity models, (2) highlight the *Zostera* spp. contribution to oyster life cycles studying the variability of larval recruitment, survival, growth of juveniles, and trophic regime of oysters in the presence or in the absence of *Zostera* spp. meadows, (3) describe and compare the dynamics of socio-ecosystems of SEE under oligotrophication. First results of the SAKURA project permitted to start to improve knowledge on the influence of oligotrophication processes on the ecological status of shellfish-exploited-ecosystems and on the oyster life cycle. Analysis is still ongoing. Now, the French and Japanese partners want to deepen the interdisciplinary approach and the knowledge of this major sea and coastal challenge by expanding their partnership in the international community to address more holistically the conservation of biodiversity and the sustainable use of resources in the changing coastal seas.

**Keywords** Oyster aquaculture · Oligotrophication · Seagrass · Coastal productivity · Socio-ecosystem

## 1 Introduction

Global environmental change and recent continental and coastal management actions have gradually and successfully decreased nutrient contents of coastal waters in some regions (Collos et al. 2009; Yanagi 2015; Derolez et al. 2019). However, some stakeholders suggest that the improvement in water quality is now causing another issue in natural contribution to people called "oligotrophication." Oligotrophication could reduce pelagic primary productivity in coastal ecosystems, sometimes resulting in the decrease of fishery catch because coastal fisheries have adapted to the previous eutrophic environment from the 1970s to the 2000s. For example, in the Seto Inland Sea, Japan, most of the recent fishery target species are pelagic fishes and their preys derive from pelagic production. Typical raft culture of bivalves in offshore areas has been prospering with eutrophication. In France, oligotrophication has also been recently observed and raised some worries on oyster productivity for some shellfish farmers (Derolez et al. 2017; Bec et al. 2018). An especially issue is the improvement of oyster recruitment process which is an urgent treatment for sustainable farming (Lagarde et al. 2017, 2018). In contrast, oligotrophication with high water transparency has helped the recovery of benthic primary productivity including macrophytes including seagrass vegetation, which are important for climate change mitigation (i.e., limitation of hypoxia and acidification) and adaptation such as carbon storage and protection from sea-level rise and storm surges (Hori et al. 2018; Tsurita et al. 2017). The recovery of these ecosystem services has been warmly welcomed by other stakeholders concerned with environmental issues.

In this context, a French-Japanese SAKURA–Hubert Curien project funded by Japan Society for the Promotion of Science (JSPS) and Campus France (French

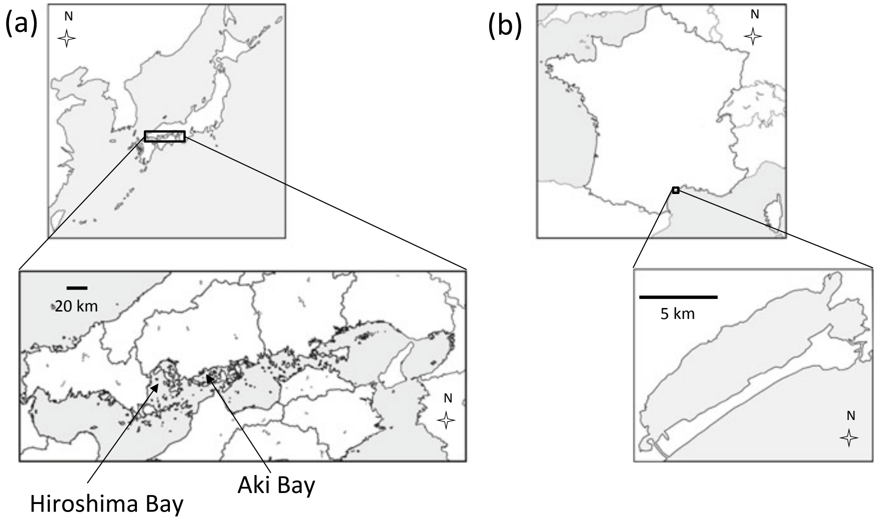


**Fig. 1** Two comparative study sites with **a** Seto Inland Sea, including Hiroshima and Aki bays and **b** Thau Lagoon near the Gulf of Lion, Mediterranean Sea. These maps were revised from Hori et al. (2018)

Embassy in Japan) triggered a collaboration between the MARBEC research unity Marine Biodiversity, Exploitation and Conservation (Ifremer, CNRS, IRD, Montpellier University) and the Japan Fisheries Research and Education Agency (FRA) from 2017 to 2018. The project had been developed to better understand the links between conservation and exploitation of shellfish-exploited-ecosystems (SEE) and the impacts on human well-being by developing an interdisciplinary approach among ecological and social dimensions. The two study sites were Hiroshima and Aki bays (Seto Inland Sea) and Thau Lagoon (Mediterranean Sea) (Fig. 1). These sites were both intensively exploited by shellfish farming and characterized by ecological trajectories of oligotrophication under global change.

Three tasks had been developed taken into account ecological, economic, and social issues. The first task aimed to clarify the state and process of ecosystem productivity under oligotrophication and global environmental change. The relationships between nutrient level and functioning of shellfish-exploited-ecosystems were described in terms of ecological status and oyster performances, using historical data analysis and ecosystem modeling.

The aim of the second task was to find good practices and the ecological tools for adaptation and mitigation to the oligotrophic environment under global change in shellfish farming ecosystems. In particular, we were interested in two ecological processes: oyster recruitment and seagrass-oyster interaction. Seagrass beds provided various ecosystem functions for oyster growth and survival in the original habitat of pacific oyster. As part of this task, in situ experiments were conducted in Japan and France in 2017 and 2018 in order: (i) to explore the larval recruitment variability in shellfish farming areas in the presence or absence of seagrass (*Zostera* spp.) meadows; (ii) to test the impact of seagrass vegetation on shellfish performances; and (iii) to identify seagrass trophic contribution to oysters.

The third task was to clarify the value chains of local communities surrounding the oyster industry, to identify human well-being. This task was carried out according to an interdisciplinary approach integrating interactions between ecological functions and social/economical activities, at the scale of social-ecological systems (SES).

## 2 Methods and Preliminary Results

### *2.1 Clarification of Nutrient Input Dynamics and Relationship Between Nutrient Levels, Phytoplankton, and Oyster Production*

#### 2.1.1 Analysis and Comparison of the Temporal Evolution of the Ecological Status of Water Column and Oyster Performances in the Thau Lagoon and in the Hiroshima and Aki Bays Using Long-Term Time-Series (1998–2016)

As part of the SAKURA (French-Japanese program for science and technology cooperation) and CAPATHAU (Trophic CAPAcity of THAU Lagoon) projects,[1] analyses of the temporal evolution of the ecological status of the water column and oyster performances were conducted using long-term time-series (1998–2016) in the Thau Lagoon (see Bec et al. 2018 for details on database) and in the Seto Inland Sea (Ministry of transportation[2]). Historical data concerned physicochemical parameters, nutrient inputs from the watershed, nutrient contents in water column, phytoplankton biomass and growth, and production of oysters. A decrease of water nutrients and phytoplankton concentrations and a lower contribution of diatoms to the phytoplankton abundance were highlighted in the Thau Lagoon from 1998 to 2016. This trend was associated with a decrease of nutrient inputs from the watershed and rainfall levels, and with an increase of temperature (Derolez et al. 2017; Bec et al. 2018). The production of shellfish halved from 2008 to 2010, due to high mortality rates of oyster juveniles, associated with the OsHV-1 pathogen. Growth rates and condition indexes of oysters were higher in the period of 2014–2017 than in the period of 1993–2007. The levels recorded from 2014 to 2017 still corresponded to high values, making the Thau Lagoon the best site in France for oyster growth (Bec et al. 2018).

[1] http://www.dlalbassindethau.fr/2017/09/12/capathau-un-programme-scientifique-pour-etudier-la-productivite-des-bassins-de-production-et-elaborer-des-scenarios-de-gestion-a-long-terme/, https://youtu.be/gmNwr5pqQS0.

[2] http://www.pa.cgr.mlit.go.jp/chiki/suishitu/.

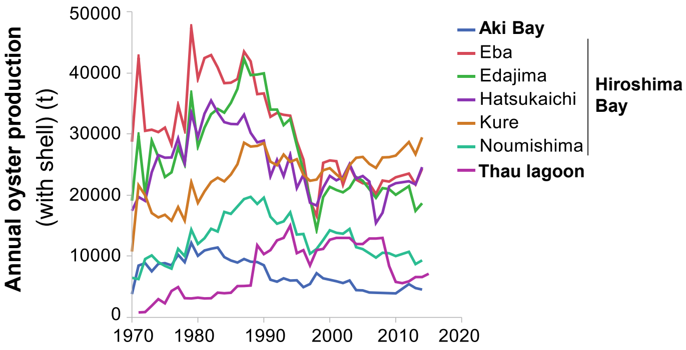


**Fig. 2** Evolution of oyster production (in tons with shell) recorded in Aki and Hiroshima bays (Eba, Edajima, Hatsukaichi, and Kure) in Japan and in Thau Lagoon in France, from 1970 to 2016

The historical databases from Thau Lagoon, Hiroshima and Aki bays were merged. The annual oyster production levels recorded in most of the sites of Hiroshima Bay (i.e., Kure, Eba, Hatsukaichi, and Edajima) are currently 3–4 times higher (18,662–29,452 t) than in Thau Lagoon (6651 t), whereas the production was comparable to Aki Bay's production (4549 t) (Fig 2). A significant decrease of oyster production occurred during the 1990s in most of the Japanese sites. Data on growth and condition index were not available for the Japanese sites.

First analyses on environmental data showed that the Thau Lagoon, Aki and Hiroshima bays were mainly discriminated by: (1) dissolved inorganic nitrogen (DIN) concentrations, with higher levels observed in the Japanese sites, and by (2) salinity, chlorophyll *a* and phosphate (DIP) concentrations, with higher levels observed in France. Comparative analysis of temporal evolution of ecological status is in progress. Results will help to better understand the environmental shifts that occurred and their potential consequences on oyster production (Fig. 3).

#### 2.1.2 Analyze the Influence of Several Management Scenarios on Ecological Status and Oyster Production Using Carrying Capacity Modeling

Carrying capacity modeling tools have been developed in Japan and France to test the effect of several scenarios of nutrient input and oyster exploitation on ecological components and oyster production. One of the main objectives of such tools was to help managers to maintain sustainable shellfish culture in coastal ecosystem under oligotrophication and global change. Exchanges of expertise between both countries facilitated the development of the tools and analysis of scenarios. Results from modeling carried out in France were further described (Pete et al., 2018a, b). Results highlighted that the variability of oyster production was mainly controlled by hydrometeorology, with oyster production being 1.8–2.3 times higher during rainy years than dry years. In comparison with the current situation (Reference scenario),

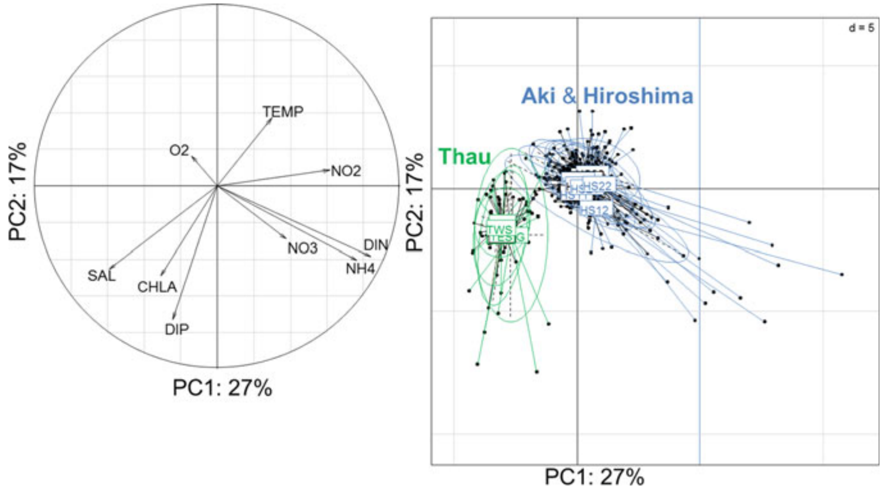


**Fig. 3** PCA analysis on French-Japanese historical database including physicochemical parameters (TEMP: temperature, SAL: salinity, $O_2$: oxygen, CHLA: phytoplankton chlorophyll a biomass, $NO_3$: nitrate, $NO_2$: nitrite, DIN: dissolved inorganic nitrogen, DIP: dissolved inorganic phosphate) recorded during summer from 1998 to 2016 in Thau Lagoon (France) (in green), Aki and Hiroshima bays (Japan) (in blue)

higher oyster productions (biomass at harvest = 13,981 tons) were achieved when normal wastewater treatment plant (WWTP) efficiency was used (decrease of 75% N and 60% P). Maximum WWTP efficiency (decrease of 90% N and P), however, induced a decrease of oyster production (biomass at harvest = 10,762 tons) by 12.9%, without significantly improving the ecological status of the Thau Lagoon. The scenario of stocking oyster density (biomass at harvest: 13,216 tons) to its authorized maximum (set by the French regulation body, initial condition seeding: $1047 \times 10^6$ of 1.4 cm–0.03 g Dry Flesh Mass for pre-growing oysters and $288.6 \times 10^6$ of 6.6 cm–0.18 g Dry Flesh Mass for growing oysters) triggered an increase of oyster productions by 7% at the expense of thinner oysters with a lower condition index. This result, therefore, highlighted the trophic competition between oysters within growing structures. Currently, considering the real N and P inputs and oyster stock (biomass at harvest = 12,360 tons; initial seeding condition: seeding $532 \times 10^6$ pre-growing oysters + $235.7 \times 10^6$ growing oysters), the Thau Lagoon remains an exceptional site for oyster farming associated with a “good” ecological status condition (Bec et al. 2018, Pete et al. 2018a, b). Nevertheless, this work also demonstrated that oyster production might be threatened if drastic measures are undertaken on WWTP, particularly on phosphorus that seems to control primary production in the Thau ecosystem (Pete et al. 2018b). The scientific collaboration with Japanese researchers will help to significantly improve the model of the Thau Lagoon by integrating a biological compartment for clams, which can be harvested and whose stock has considerably decreased since the 2000s.

## 2.2 *Ecological Tools of Adaptation and Mitigation to Oligotrophication: Highlighting the* Zostera *Spp. Contribution to Oyster Life Cycles (Years 2017–2018)*

Our hypothesis was that seagrass beds could support oyster production and improve its quality and sustainability. The seagrass contribution to oyster production was divided into two processes in relation to the oyster life cycle stage: recruitment processes from the larval stage to spat settlement and post-recruitment processes with spat growth. A series of in situ experiments were conducted in Japan and France in 2017 and 2018 in order: (1) to explore the larval recruitment variability in shellfish farming areas in the presence or absence of *Zostera marina and Z. noltii* meadows, (2) to test the influence of seagrass vegetation on shellfish performances (sanitary quality, survival, growth), and (3) to identify seagrass trophic contribution to oysters. The methods and preliminary results were described below. To our knowledge, there was no case study directly demonstrating the effect of oyster–seagrass interactions on ecosystem functioning of target ecosystems, although there were some modeling researches on the material cycling in a coastal ecosystem including oyster and seagrass beds (e.g., Kishi and Oshima 2008).

### 2.2.1 Larval Recruitment Variability in Shellfish Farming Areas

Settlement and recruitment of oysters were monitored at six contrasting stations during August 2017 from east to west, in the absence or presence of *Zostera* spp. meadow and shellfish farming in the Thau Lagoon (Fig. 4). The oyster collectors were deployed as described by Lagarde et al (2018, 2019) (Fig. 5). The collectors were deployed in the water column (Fig. 5a, b) inside/outside shellfish farm sites and above and below the canopy in *Zostera* spp. meadows inside sites with *Zostera* (Fig. 5c). All collectors were sampled after 2 weeks of immersion to assess pediveligers and postlarvae abundance and after 4 weeks of immersion to assess oyster spat abundance.

Figure 6 shows that in the two *Zostera* spp. sites (ZOST) of Montpénèdre and Bouzigues, young settlers' abundances were lower in the canopy of *Zostera* spp. meadows than in the water column. The best sites for settlement were the OSFZ sites (Listel, Meze); these results confirm those of Lagarde et al. (2017, 2018). *Zostera* meadows show no higher favorability for oyster settlement than other nearby sites in terms of abundances.

Results showed no positive effect of seagrass meadows on the oyster recruitment in the French study site (Fig. 7). The relationship between young settlers (pediveligers and postlarvae) and recruited oysters was different according to the sampling stations (Fig. 7). Sites with *Zostera* spp. meadows appeared to be less profitable than other sites in terms of recruited spat abundance. These differences reflected different ecological processes in the contrasting stations.

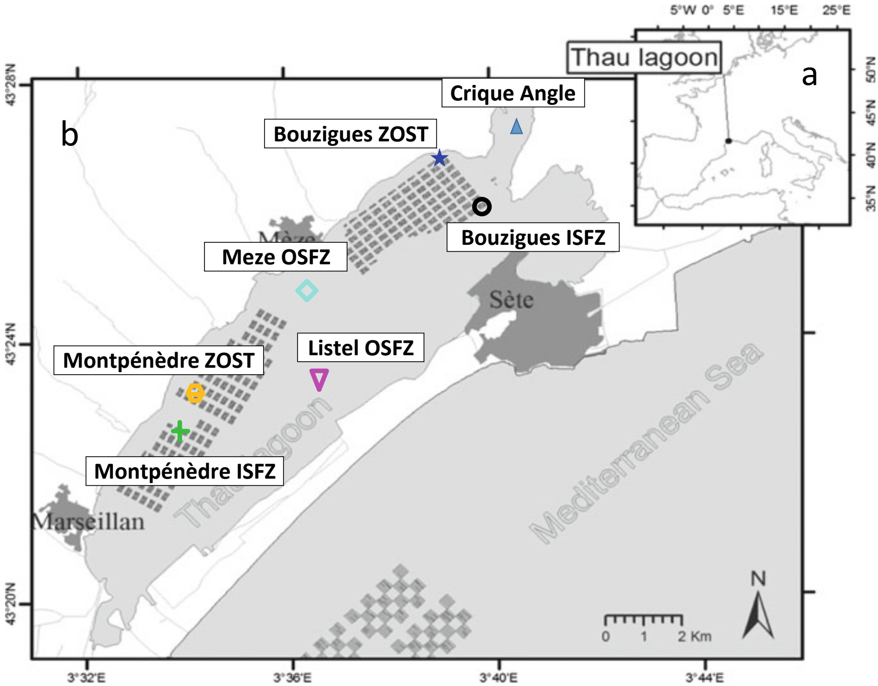


**Fig. 4** **a** Thau Lagoon in south of France with **b** the six sampling sites scattered from east to west with three conditions (ISFZ: inside shellfish farming zone, OSFZ: outside shellfish farming zone, ZOST: *Zostera* spp. meadows)

Perspectives will be to determine the ecological processes inducing spatial variability of the observed relationships between settlement and recruitment. Biochemical analyses (lipids, fatty acids) are ongoing on planktonic components and oyster larvae to understand the link between the nature of trophic resources (quantity and quantity of food intake by autotrophic or heterotrophic primary production) on each sampling station and, larval physiology and success and size of metamorphosis (lipids, fatty acids, prodissoconch 2 size, and abundances).

### 2.2.2 Influence of Seagrass Vegetation on Shellfish Performances (Sanitary Quality, Survival, Growth)

Some authors related a 50% reduction in the relative abundance of potential bacterial pathogens capable of causing disease in humans and marine organisms to seagrass beds presence (Lamb et al. 2017). Our hypothesis was thus that seagrass beds could maintain or improve the safety and sanitary condition of oysters that would possibly give an added value to oyster products. To clarify the effects of seagrass vegetation on microbiome in both oyster and ambient sea waters, two series of experiments

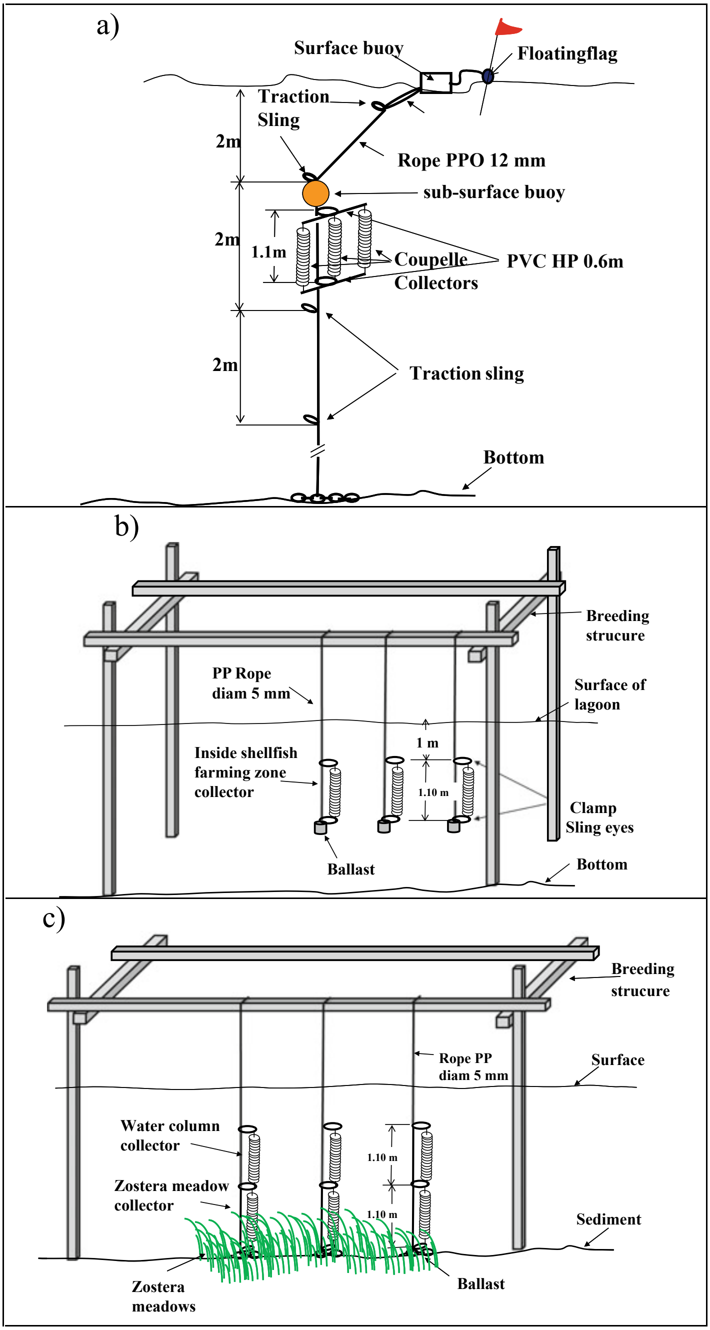


**Fig. 5** Mooring system used **a** outside shellfish farming zone (OSFZ) in the Thau Lagoon. The gear supported three replicates of "coupelles" collectors, **b** inside shellfish farming zone (ISFZ), and **c** inside shellfish farming zone with *Zostera* spp. meadows (ZOST). PP: polypropylene. These figures were revised from Lagarde et al (2017, 2018)

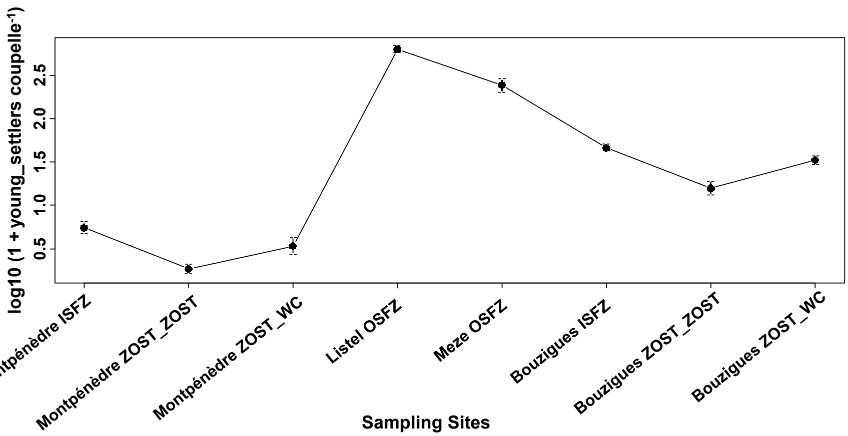


**Fig. 6** Young settlers (pediveligers and postlarvae) assessment (mean ± SE) on the different conditions, ISFZ inside shellfish farming zone, OSFZ outside shellfish farming zone, ZOST_ZOST collectors inside *Zostera* meadow, ZOST_WC collectors in water column above *Zostera* meadows

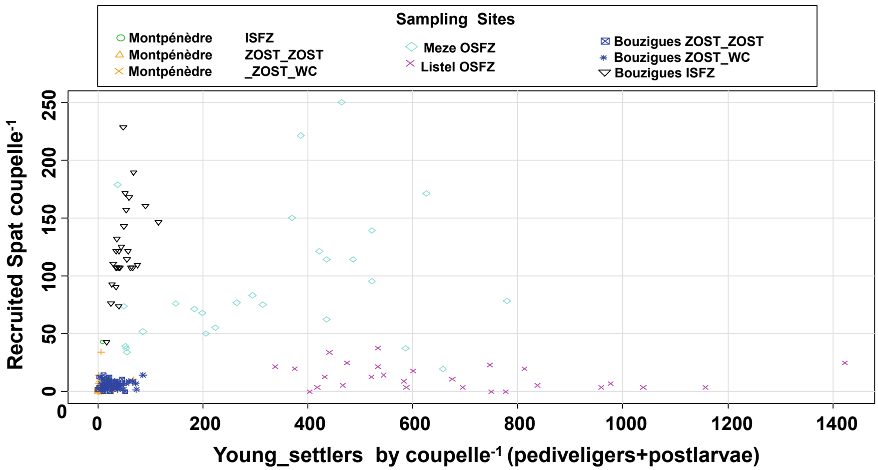


**Fig. 7** Relation between abundances of settlement (pediveligers and postlarvae) and recruited *Crassostrea gigas* on the six contrasted sampling sites in Thau Lagoon. Sampling collectors were ISFZ for sites inside shellfish farming zone, OSFZ for sites outside shellfish farming zone, ZOST_ZOST for sites with *Zostera* spp. and collectors were in *Zostera* spp. meadows, ZOST_WC for sites with *Zostera* spp. and collectors were in the water column (see Figs. 4 and 5)

were carried out in the Thau Lagoon in 2017 and 2018 in the presence and absence of *Zostera* spp. meadows (Fig. 5: Bouzigues ISFZ, Bouzigues ZOST, Montpénèdre ZOST, Montpénèdre ISFZ) for analyzing environmental DNA and oyster microbiomes. Analysis is ongoing. In parallel, the effect of *Zostera* spp. meadows was tested in 2018 on growth and survival of juvenile oysters after 3 months of growing

(September–December) inside and outside *Zostera* spp. meadows at Bouzigues and Montpénèdre in the Thau Lagoon (Fig. 5).

### 2.2.3 Seagrass Trophic Contribution to Oysters

To highlight the trophic contribution of seagrass to oysters, sampling of sea water, oysters at commercial size, benthic organism, fish, and sediment was done in the presence and in the absence of *Zostera* spp. meadows in Bouzigues, Montpénèdre, and Crique de l'Angle (Fig. 4) in 2017 and 2018 to analyze the difference in carbon and nitrogen circulation between oyster aquaculture areas within seagrass vegetation and those without seagrass vegetation. The analyses are ongoing but the tentative result from core samples exhibited clear differences in organic carbon (OC) storage in the sediment (Fig. 8).

The OC content at the topmost layer was about twice as high inside (b, c) than outside (a) shellfish farms, presumably due to OC inputs in the form of pseudofaeces from farmed oysters. However, the OC content in subsurface layers in sediments was higher in *Zostera* spp. meadows (a, c) than a site without seagrass coverage (b). The latter fact suggested that OC derived from *Zostera* spp. and associated algae was refractory and persisted for a long term inside sediments contributing effectively to carbon sequestration, compared to the OC derived from pseudofaecal deposition. The concentration of calcium carbonate (inorganic carbon) in sediment was also different between the inside (60–80% of dry weight) and outside of shellfish farms (30–50%), reflecting accumulation of oyster shell debris inside the farms (ANOVA: $F = 106.6$, $p < 0.0001$). Both *Zostera* spp. vegetation and the accumulation of carbonates would

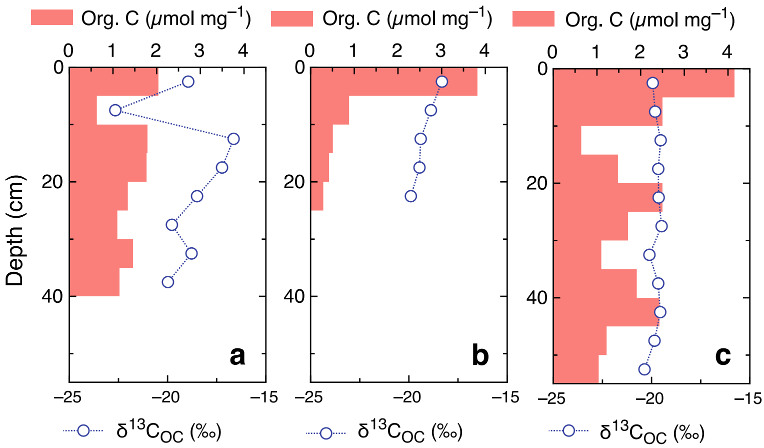


**Fig. 8** Vertical profiles of concentration and stable isotope ratio of organic carbon stored in the sediment of **a** a site with dense *Zostera* spp. vegetation and outside shellfish farms (Crique de l'Angle), **b** a site inside shellfish farm of Bouzigues but with no seagrass coverage, and **c** a site inside a shellfish farm and under dense *Zostera* spp. meadows (Bouzigues ZOST)

contribute to the reduction of mineral sediment re-suspension and siltation, thereby improving growth conditions for oysters.

In the Japanese site, the experiment of oyster spat cultivation on both the tidal flat with *Zostera* spp. seagrass vegetation and the offshore floating raft without seagrass vegetation exhibited some results (Hori et al. 2018). Oyster spats cultivated on the tidal flat had higher meat part ratio and stable carbon isotope ratios than spats cultivated in the area without seagrass vegetation (Fig. 9). These results suggested that trophic contribution of seagrass vegetation occurred. The seagrass trophic contribution was well known and reported as interactions between seagrasses and filter-feeding bivalves in various seagrass meadows from temperate to tropical regions of the world (Morimoto et al. 2017).

Seagrass meadows might also contribute to the trophic status of ecosystem components other than farmed oysters, such as indigenous fish populations. Figure 10 shows that the presence of intense oyster farming in Thau Lagoon caused a trophic shift of the indigenous fish Atherina boyeri from strong dependence on planktonic resources (pelagic channel) to more extensive exploitation of resources derived from seagrasses and their microepiphytes (benthic channel). This fact suggested that seagrasses and

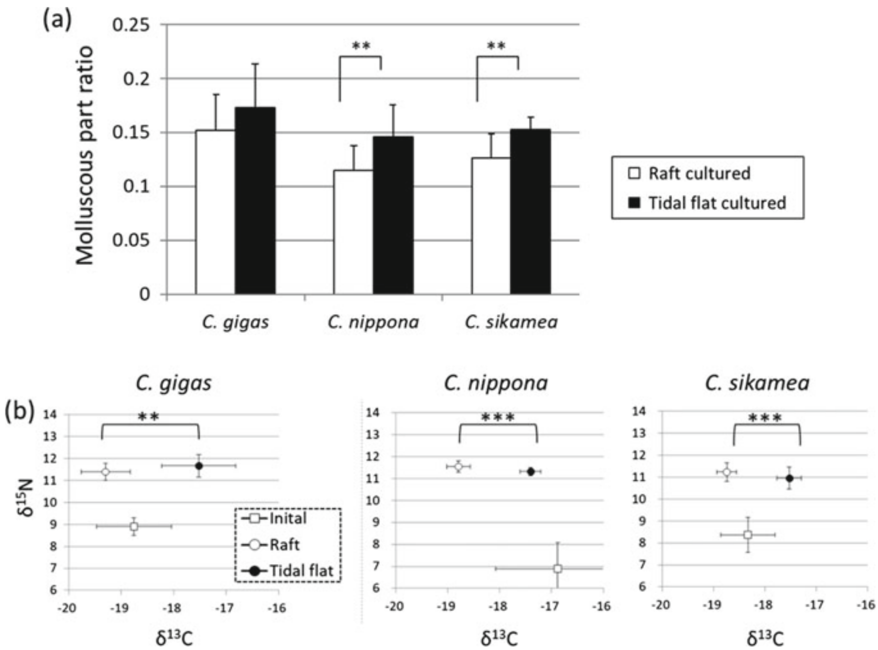


**Fig. 9** Comparison between tidal flat and raft cultured spat growth of three species (*Crassostrea gigas*, *C. nippona,* and *C. sikamea*) in the Japan site using **a** the ratio of mollusks part weight (gDW) to total (mollusks part and shell) weight (gDW) and **b** carbon and nitrogen stable isotope composition of each oyster species. Open squares indicate initial conditions. Significant *p*-values are represented by asterisks: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. These figures were arranged from Hori et al. (2018)

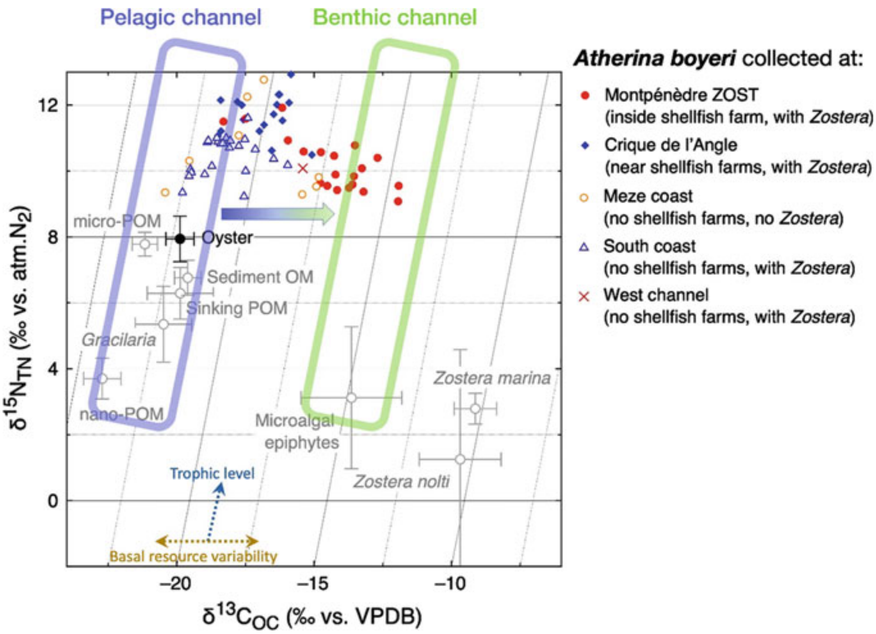


**Fig. 10** Stable carbon–nitrogen isotope ratio diagram for representative ecosystem components of Thau Lagoon, including the indigenous fish *Atherina boyeri*. Different color symbols represent *A. boyeri* individuals collected from five different sites. Individuals collected from inside or near shellfish farms (Montpénèdre ZOST and Crique de l'Angle) tended to show higher $\delta^{13}$C (i.e., higher dependence on the benthic trophic channel) than those collected at sites far from shellfish farms

microepiphytes subsidized *A. boyeri* with food source when the planktonic resource was exhausted by active filter feeding of farmed oysters. Such a feature could be regarded as an ecosystem function of *Zostera marina* meadows beneficial to the overall fisheries production of Thau Lagoon.

## 3 Description and Comparison of the Dynamics of Socio-Ecosystems of Shellfish-Exploited Coastal Areas Under Oligotrophication

We described and compared the dynamics (1970–2016) of both socio-ecosystems under oligotrophication, following an interdisciplinary framework approach, as outlined by Hori et al. (2018). The aims were to highlight the links between ecosystem regime shifts and modification of management compromises and to identify human well-being of societies living around Thau Lagoon and Hiroshima Bay.

A common analysis of governance and institutions was started by the French-Japanese team during the SAKURA project and highlighted some similarities of management actions and social perception of ecosystems degradations during the study period (Hori et al. 2018). Our initial results highlighted the importance of regional and local management measures carried out in response to eutrophication issues in both ecosystems. The local management actions performed since the 1990s were mainly focused on programs of regeneration of seagrass in the Hiroshima and Aki bays, while in the Thau Lagoon they mainly concerned efforts toward the improvement of the watershed's depuration system (Derolez et al. 2019). This analysis will be finalized and extended to include a study of the evolution of ecosystem services provided by both ecosystems and the evolution of the forms of social demands, which can target consumption and/or conservation.

A study had been carried out on marine protected areas (MPAs) located at the east of the Seto Inland Sea (Hinase Bay) in Japan, to evaluate the benefits people enjoyed from their coastal ecosystem, based on satisfaction levels of human well-being defined by the Millennium Ecosystem Assessment (Tsurita et al. 2017). This study showed that restoration activities favoring the regrowth of seagrass lead to an expansion of social networks. It also highlighted that mixed management systems could lead to flexible and long-term efforts for improving food security, livelihoods, and the marine environment. Such methods could be applied in Thau Lagoon/France and Hiroshima and Aki bays/Japan to identify and compare the human well-being of societies living around both sites.

## 4 Conclusion and Perspectives

As part of the SAKURA project, the French-Japanese collaboration allowed: (1) comparisons of long-term time-series, (2) expertise exchanges about modeling tools for the management of shellfish-exploited ecosystems under oligotrophication and global change, (3) to carry out field experiments on oyster/*Zostera* spp. interactions in Thau Lagoon and Hiroshima Bay, (4) transfers of expertise from Japan to France about social-ecological systems (SES) mapping that will be purchased from 2019. The SAKURA project improved international knowledge and expertise on the influence of oligotrophication processes on the ecological status of shellfish-exploited-ecosystems and on oyster life cycles (reproduction, recruitment, growth, production). Moreover, this project allowed the start of a research collaboration focused on the impact of submarine groundwater's discharges (SGD) on the functioning of shellfish-exploited-ecosystems. Now, the French and Japanese partners want to deepen the interdisciplinary approach and the knowledge of this major sea and coastal challenge by expanding their partnership in the framework of sustainable development goals. This openness to the international community will make it possible to address more holistically the conservation of biodiversity and the sustainable use of resources in the changing coastal seas.

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# Forty Years of Decline and 10 Years of Management Plan: Are European Eels (*Anguilla Anguilla*) Recovering?

**Eric Feunteun and Patrick Prouzet**

**Abstract** The genus *Anguilla* is worldwide distributed. Part of humanity's heritage, it represents a resource of proteins for many people. Most stages of the species within the genus Anguilla have experienced a drastic decrease of their abundance since at least the middle of the twentieth century. It is the case for European eel (*Anguilla Anguilla*) largely impacted by the climate change. To restore the population, an European Eel Management Plan has been implemented in 2010: fishery regulation, restocking, improvement of eel habitats, the first effects of which are expected to have improved eel abundance from 2013. Are we able to detect that such an increase has occured in the centre of the eel distribution area (north of the Iberian Peninsula, Gulf of Biscay)? Are the different potential management actions defined in the Eel Management Plan implemented? What are the necessary improvements to restore the eel population in Europe?

**Keywords** Eel · *Anguilla anguilla* · Eel management plan · UE · France

## 1 Introduction

Freshwater eels of the genus *Anguilla* are worldwide distributed. They are present in all the oceans (except the Arctic) and in all continents (except Antarctic). They have an outstanding biological cycle, with a birthplace in intertropical offshore pelagic habitats, and growth habitats located in inland waters or coastal waters from tropical to temperate regions. Eels are able to colonise most inland habitats from marine coastal zones (lagoons, estuaries, bays) to freshwaters including still waters, rivers and creeks of altitudes up to 1000 m (Tesch 1977; Adam et al. 2008).

Part of humanity's heritage, they represent a resource of proteins for many people, including native people as there are present in a large number of ecosystems. There

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behaviour (nocturnal, able to creep out of water, hiding and burrowing) and the mystery of their reproduction have always been a source of many legends, stories and even cults throughout the world (Kuroki and Tsukamoto 2012). A diversity of ancestral techniques have been developed throughout time and space to harvest all the continental stages from glass eels, to yellow eels during their sedentary growth stage and to silver eels on the onset of their spawning migration back to the ocean (Prouzet et al. 2010, 2018; Feunteun and Robinet 2013; Feunteun 2012).

Due to the high market prices of adult eels in Far East Asia, especially in Japan and China, and a lack of Japanese glass eels that have declined since the 1980s, an international trade for European glass eels has emerged in the late 80s and developed between the 1990s and early 2000s (Nielsen and Prouzet 2008). This situation has provoked an unprecedently high market price that culminated at up to around 1200€ $kg^{-1}$ from 2003 to 2007 when the European eel was listed on the red list of critically endangered species and more than 13,000 euros per kg for the Japanese eel (Omori 2017 oral communication).

Despite considerable research effort, the biology and ecology of European eels still remain very badly understood. The exact state, distribution patterns and abundance of the stock are still very poorly described and evaluated. Although the panmixia is a well-accepted fact, the exact genetic architecture (Côté et al. 2015; Pavey et al. 2015) and the geographical distribution of the morphological and life-history traits are still insufficiently described to be able to conclude on the existence of geographically singular stocks that would induce distinct management issues. Spawning places still remains a mystery. What leptocephali eat still not clearly understood. Migration routes and duration are still debated as the age of the glass eels when they arrived on the European coast. Migration routes and duration of silver eels are still not clearly described despite huge progress thanks to satellite telemetry (Aarestrup et al. 2009; Righton et al. 2016; Amilhat et al. 2016) (Fig. 1).

## 2 A General Decrease of the Abundance of the Main Commercial Eel Species

A drastic decline is recorded since the sixties for the Japanese eel, *Anguilla japonica*, since the eighties for the European eel, *Anguilla anguilla,* and more recently since the nineties for the American eel, *Anguilla rostrata* (Fig. 2).

In France, the main producer of glass eel in Europe and located in the centre of the eel distribution area (see Fig. 1), the trend of glass eel catches is similar to that of the Loire river (the main production area) where a drastic diminution of the catches occurred after the end of the seventies (Figs. 2, 3).

But the fishing constraints defined after the implementation of the French Eel Management Plan (see below): definition of a catch quota per eel management unit and splitting in a quota for human consumption and another one for restocking, impairs the quality of the signal since the season 2010 (Fig. 4).

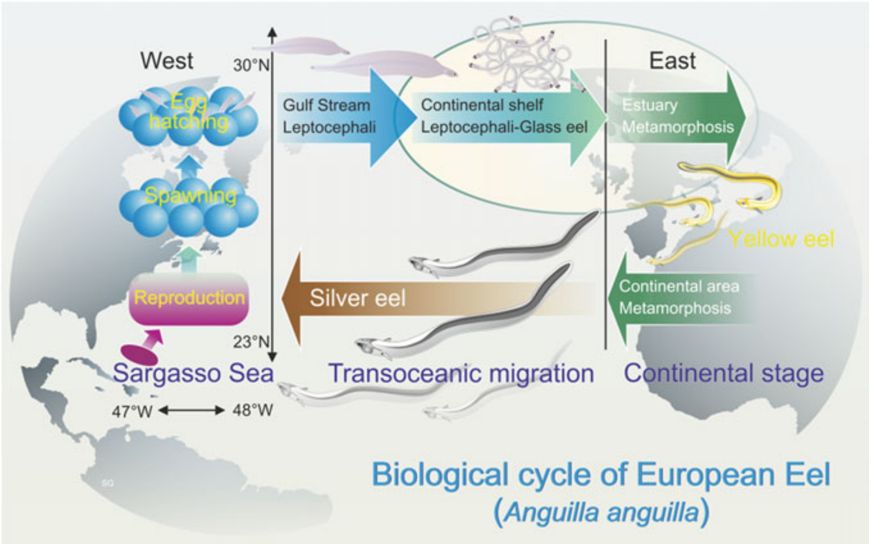


**Fig. 1** Main gaps on the knowledge of the biology of European eel (from Indicang project, Adam et al. 2008)

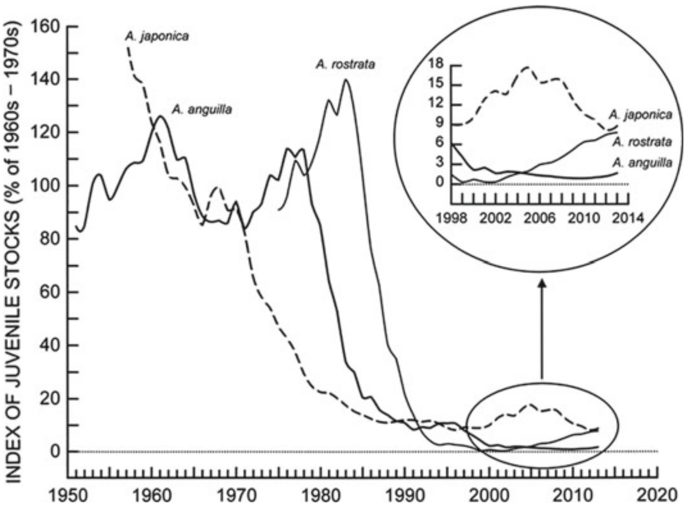


**Fig. 2** Decline of the main commercial eel species. Adapted from Dekker and Casselman 2014

Since 2009, a national quota is defined annually by a scientific group and then discussed with the French administration and the fisher representatives (CNPMEM[1]

[1]National Committee for Fisheries and Marine Aquaculture.

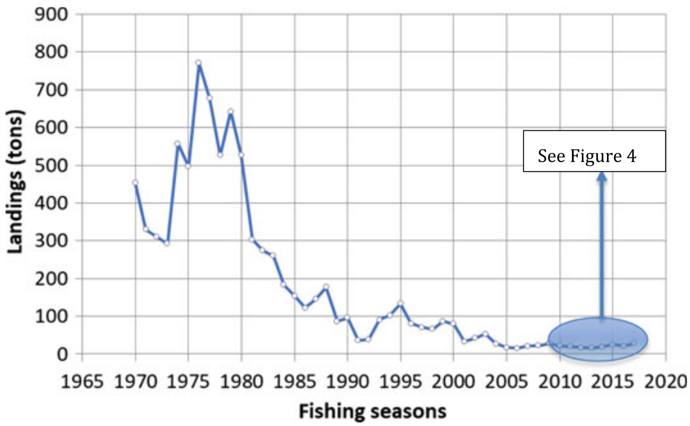


**Fig. 3** Evolution of the glass eel landings on the Loire River during the period 1965–2017

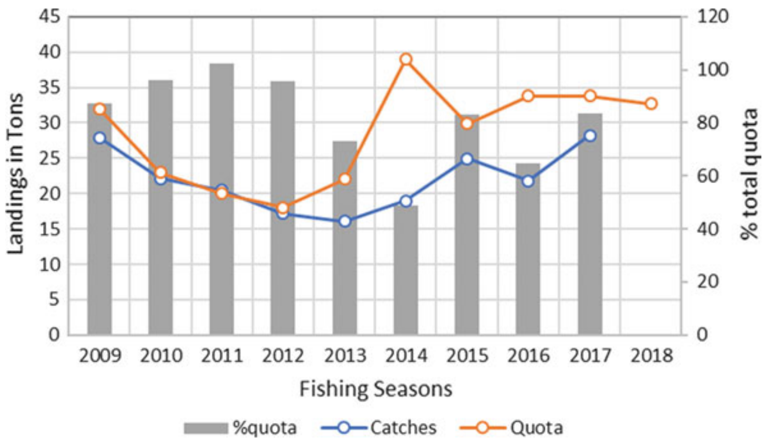


**Fig. 4** Evolution of the Loire glass eel catches and the Loire quota on the period 2009–2017 and percentage of the Loire quota used

and CONAPPED[2]) in order to find a trade-off between economic and environmental criteria. A part of this national quota is allocated, to each Eel Management Unit and split according to a ratio defined by the UE Eel Management Plan in a sub-quota for consumption and another one for restocking (Table 1).

Figure 5 shows that the constraint imposed by the quota does not allow on the period 2009–2017 to land annually on the Loire catchment more than 28 t in average if the quota is fully used. A level lower than the average landings of the period 2000–2008: 34 t. In addition, the quota is not fully used since 2013 linked to a slack glass eel restocking market with not very attractive prices for the fishers (Fig. 5).

[2]National Committee of Inland Professional Fishers.

**Table 1** UE key of dispatching of the glass eel production for consumption and restocking

| Year | % for restocking | % for consumption |
|---|---|---|
| 2009 | 40 | 60 |
| 2010 | 45 | 55 |
| 2011 | 50 | 50 |
| From 2012 | 60 | 40 |

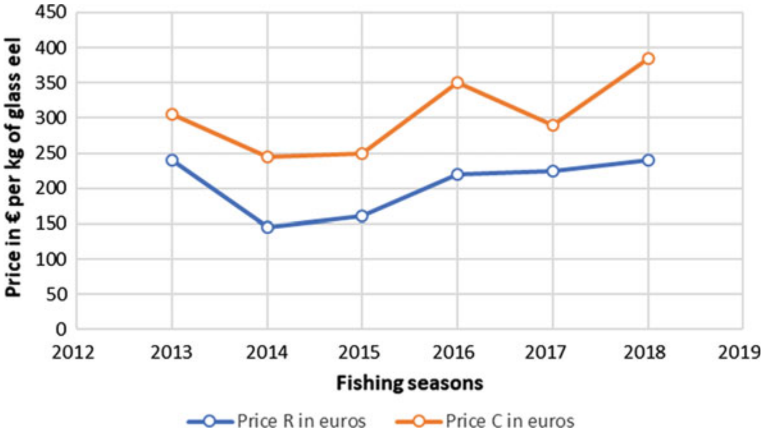


**Fig. 5** Evolution of the UE prices for restocking R and consumption C on the period 2013–2018 (from French administration data)

So, in France, global catches are certainly not a sufficient indicator to measure the true evolution of the trend of recruitment in these recent years after the implementation of the UE Eel Management Plan. Consequently, it is necessary to have some more precise indices such as the CPUE or the length of the fishing season to reach the consumption quota (see § 7). However, if the CPUE are clearly the best proxy of glass eel abundance, they need to be interpreted cautiously. Indeed, their values depend on fishing effort, glass eel abundance, catchability and attractivity of market prices of glass eels. The variation of CPUE can reflect a variation of abundance of the glass eels and/or a variation of the fishing strategy. This situation has been revealed in 2018 on the Loire management unit, by a survey of the professional fishermen that have deeply modified their fishing habits (unpublished data). This observation is probably true for a pushed sieve fishery, but does not apply for a hand-sieve fishery (see Fig. 13), due to lower exploitation costs. When the market price is high and no quotas are applied, fishermen work as much as possible to favour captures. In this case, CPUE reflect variations of abundance. When the market price is controlled and catches are limited by quotas, it is more cost-effective to fish when there is a high abundance, especially for the push-sieve fishery. In this case, the CPUE tend to overestimate abundance. Therefore, it is likely that (i) the significance of CPUE, especially from the push-sieve fishery, has changed since the quotas and market prices

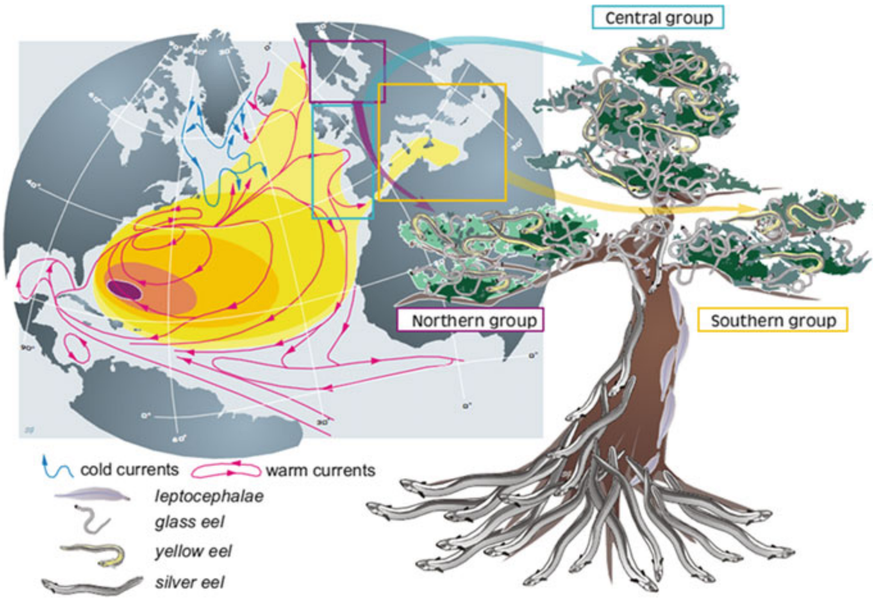


**Fig. 6** Eel tree (from Indicang project https://www.indicang.fr and from Adam et al 2008, p. 15). *Comment*: This "eel tree" can only work if its roots, anchored in the Sargasso Sea, are rich in spawners, i.e. silver eels. It can only flourish if sap rises or falls along its trunk, this represents the oceanic circulation. This circulation cannot stop or even slow down, otherwise the "leptocephalus" larvae (ascending sap) will not be oriented and transported eastwards at an appropriate speed, and the silver eels (descending sap) might loose orientation cues back to the spawning grounds. Hence the unanswered question: what will be the effect of climate change on oceanic circulation and hence on the functioning of this population? Finally, the tree can only prosper if glass eels, originating from larvae, colonise the different parts of its foliage (representing the river basins) and of course, if continuously thinned, the tree will eventually die

were fixed in 2009, and (ii) the significance of the CPUE differs between quotas for consumption (~300 €/kg) and for restocking (~200 €/kg) (see Fig. 5).

Consequently, there is an urgent need to better reconsider the significance of the recruitment indexes produced yearly by ICES which are mainly based on fishery-dependent surveys in the "elsewhere Europe" series. This is of uppermost importance to be able to assess the effects of the management plan on recruitment.

## 3 A Too Short-Sighted View of the Environmental Pressures Responsible for the Eel Population Decline

Despite the weakness of the recruitment indices and, more broadly, on the exact status of the European eel's population abundance, evolution, distribution and demography,

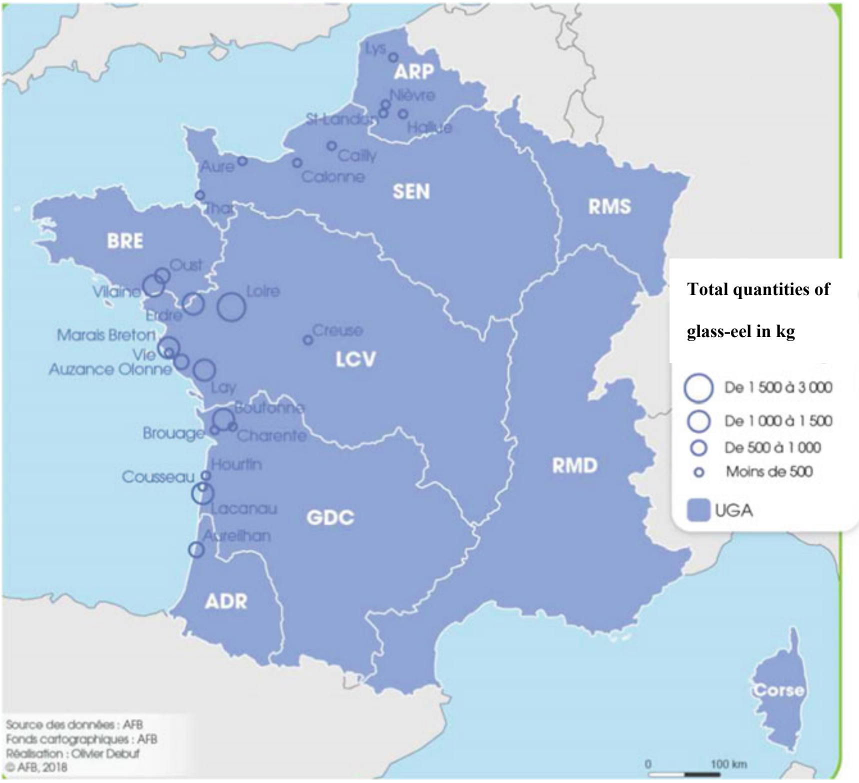


**Fig. 7** Restocking sites of glass eel between 2011 and 2016 (in Anon. 2018)

there is a general consensus to acknowledge the reality of the decline based on the analysis of the recruits throughout Europe.

If there is still a debate about the reasons and the hierarchy of the causes of the decline (Feunteun 2002; Adam et al. 2008; Miller et al. 2016), they all take their roots from anthropogenic activity and impacts that act both in continental and marine environments and hit all the biological stages of eels locally (direct mortality and habitat degradation) and/or globally (global warming, oceanic regime shifts) (Adam et al. 2008; Prouzet et al. 2010; Bonhommeau et al. 2008; Miller et al. 2016; Drouineau et al. 2018).

This situation likely results from the fact that eel management has been taken up by fishery experts. Indeed, traditionally in Fishery biology and management, for a reason of simplification, the value of the natural mortality (M) is considered, for a given stage of life, as a constant. F, the fishing mortality, is then regarded as an adjustment variable to ensure that the target population is not overexploited (Gros and Prouzet 2014). Thus, the (M) parameter of the catch equation is deemed as a black box in order to reduce the complexity of the system by considering that the other pressures (natural or anthropogenic), apart from fishery, are constant or negligible.

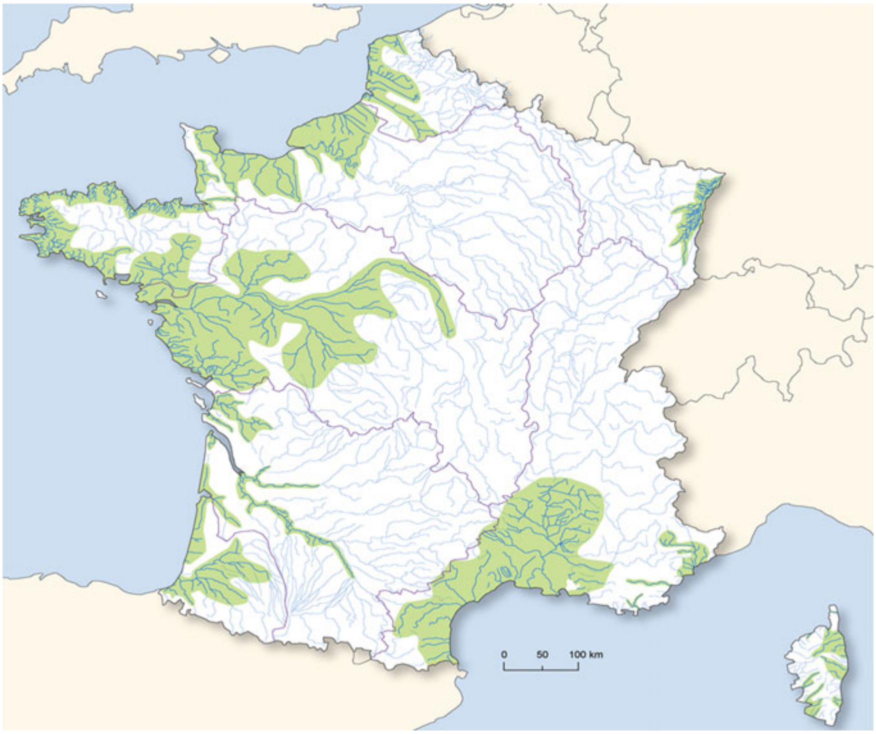


**Fig. 8** Map of the priority zones for Eel (from Onema/AFB 2015)

Unfortunately, this is no longer the case for most fish species, of which some of the essential habitats are located in the interface environments between the continent and the ocean (estuaries, lagoons, bays and coastlines), which are subject to many pressures from terrestrial environments and especially for diadromous species such as eel (Gros and Prouzet 2014).

For most commercial marine species, fishing mortality is thought to be the main driver of population dynamics (Gulland 1969; Laurec and Le Guen 1981). Conversely, this is not the case for coastal-dependant species and more particularly for diadromous species that depend on the quality and integrity of littoral, estuarine and riverine habitats and on the quality of the water. Eels have a particularly complex life cycle, and the success of the management of their population is strongly dependent on the restoration of quality of their continental habitat and connectivity that has strongly been impacted at least since the middle of the twentieth century (Feunteun 2002; Adam et al. 2008; Miller et al. 2016; Prouzet 2010).

Table 2 summarizes the history of European eel awareness and management. The first alarm bell on the decline of the eel stock was pulled in 1984 by the French working group on eels, but it took more than 14 years for ICES to state that eels were outside biological limits and that it was necessary to reduce fishing mortality

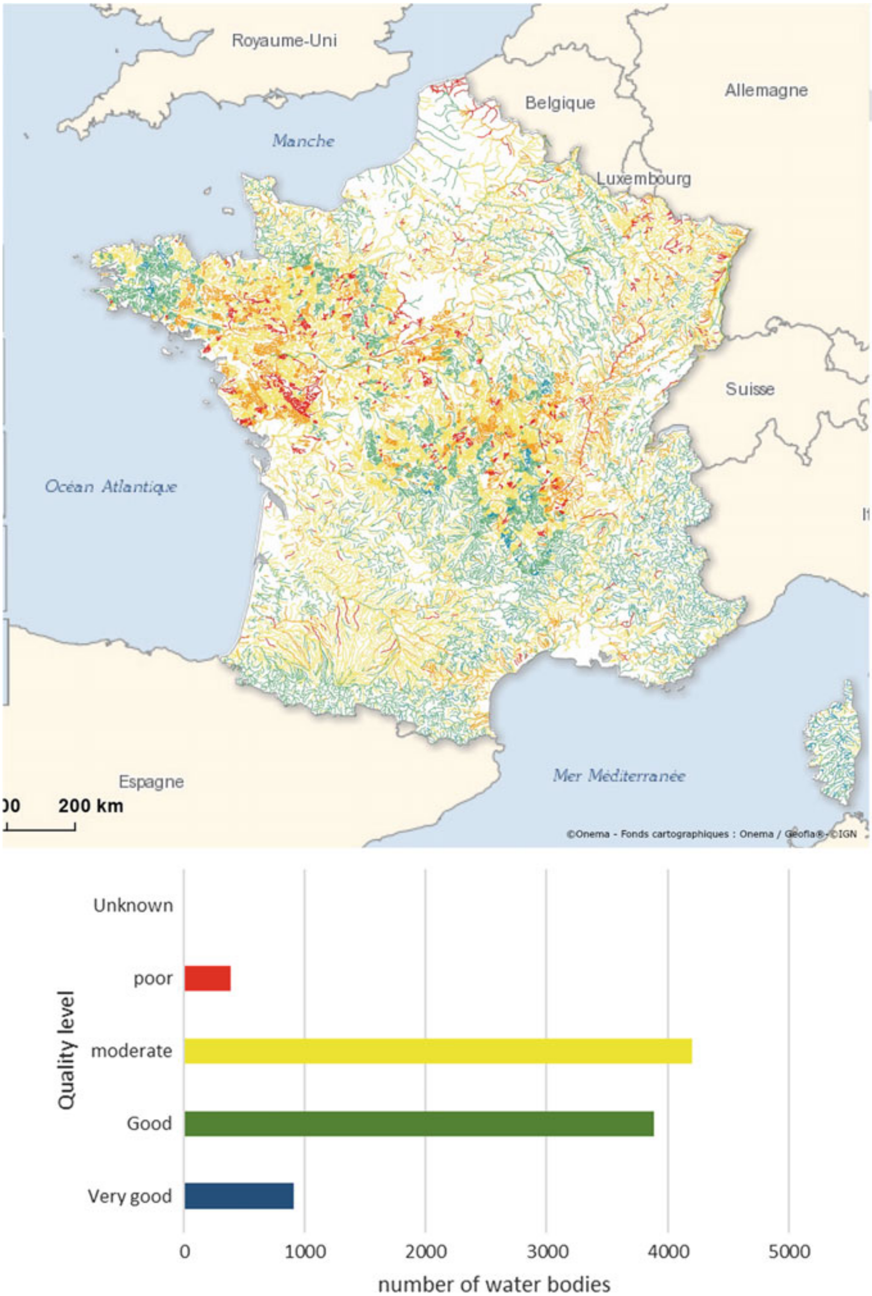


**Fig. 9** Ecological status of French waters in 2015 (from Eau France)

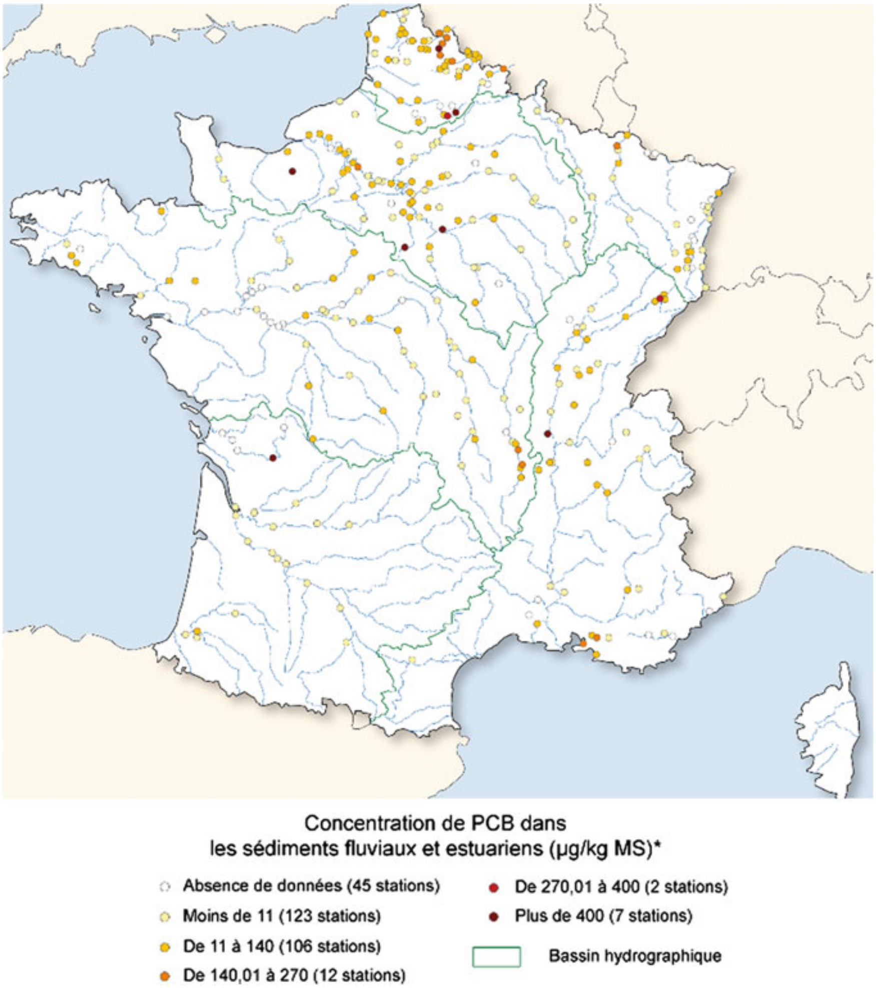


**Fig. 10** PCBs concentration in the sediments of estuarian and continental water bodies in µg/kg of dry matter (from Eau France)

to the lowest possible level (EIFAC ICES working group on eels 1998, Silkeborg). A year later, the EIFAC/ICES WGEEL confirmed the decline, but recognized that all anthropogenic mortality sources should be reduced to the lowest possible level implicitly and explicitly admitting that the causes of the decline were multiple and not solely due to overfishing. Since then, a number of studies and two European projects (INDICANG,[3] see Adam et al. 2008, EELIAD,[4]) showed that the hierarchy of the causes still remains controversial. All the stakeholders involved in the exploitation,

[3] http://www.ifremer.fr/indicang/.

[4] https://www.eip-water.eu/projects/eeliad-european-eels-atlantic-assessment-their-decline.

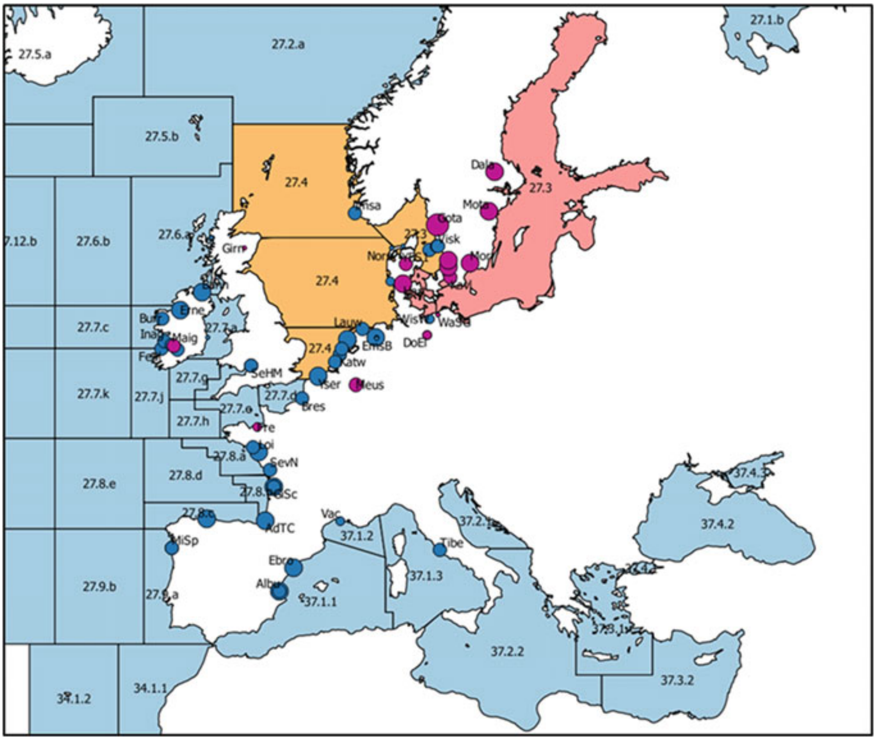


**Fig. 11** Geographical locations on all the data used to estimate the trend of the eel recruitment. North Sea corresponds to the areas 27.3 and 27.4. The others areas correspond to "Elsewhere Europe" (from ICES/WGEEL 2018a)

management and studies of eel population agree that the pressures are very diversified: chemical pollution of waters, alien invasive species, loss and degradation of natural wetlands, limitation to the free migration of the fish, fishery exploitation at all the stages of the eel biological cycle. In addition, there are a number of marine pressures, not yet assessed, on the marine phases of the European eel. For example, what are the effects and impacts of:

- Sublethal persistent organic pollutant and metallic contaminations of the eels on their physiology, spawning migration and mortality of eggs and larvae
- Decrease of the productivity in the subtropical gyres on the production of marine snow, the main food of the leptocephali (refs) during their transoceanic migration
- Microplastic on the starvation and mortality of leptocephali when we observe high concentrations of microplastic along the Sargasso Sea and leptocephali migration routes
- Climate change on the migration speed of the leptocephali through the North Atlantic Ocean circulation

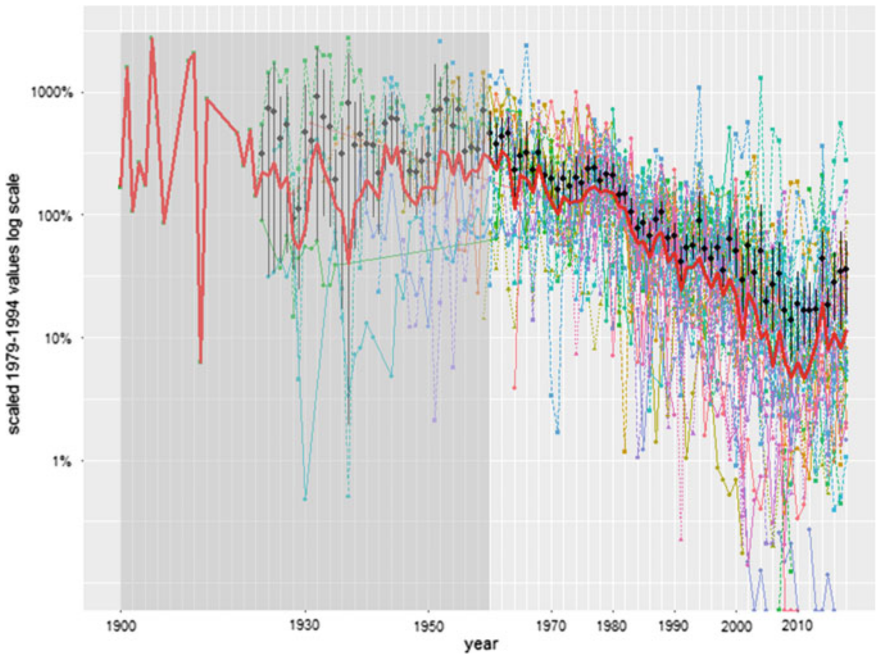


**Fig. 12** Times series of glass eel or glass eel + yellow eel (46 time series) and yellow eel (14 time series) recruitment in European rivers. Each time series has been scaled to its 1979–1994 average. Black dots and bars represent the mean values and their bootstrap confidence interval (95%). The red line is the geometric means. (From ICES WGEEL 2018b)

## 4 Definition and Implementation of the UE Eel Restoration and Management Plan

In order to restore this depleted eel population, UE defined an internationally based eel recovery plan in 2007 (EC 1100/2007[5]), which was progressively implemented by the member states starting from 2010.

Table 2 defines the main benchmarks for the definition and implementation of the UE eel restoration plan and shows the time lag between the first observation of the depleted level of the eel resources and the reaction of the member states.

This time lag is not due to the disinterest of the member states but mainly to the difficulty to implement such an Eel Management Plan at the European scale with different social, economic and environmental contexts (Fig. 6—the eel tree).

This figure gives an idea of the extreme complexity of the management of eels with schematically three geographical groups of fish with different growth characteristics and habitats. The northern group (Baltic sea, North Sea, North of the British Islands and Ireland) with a slow growth, low arrivals of glass eels or elvers and a large part

[5]Council regulation 1100/2007 establishing measures for the recovery of the stock of European eel.

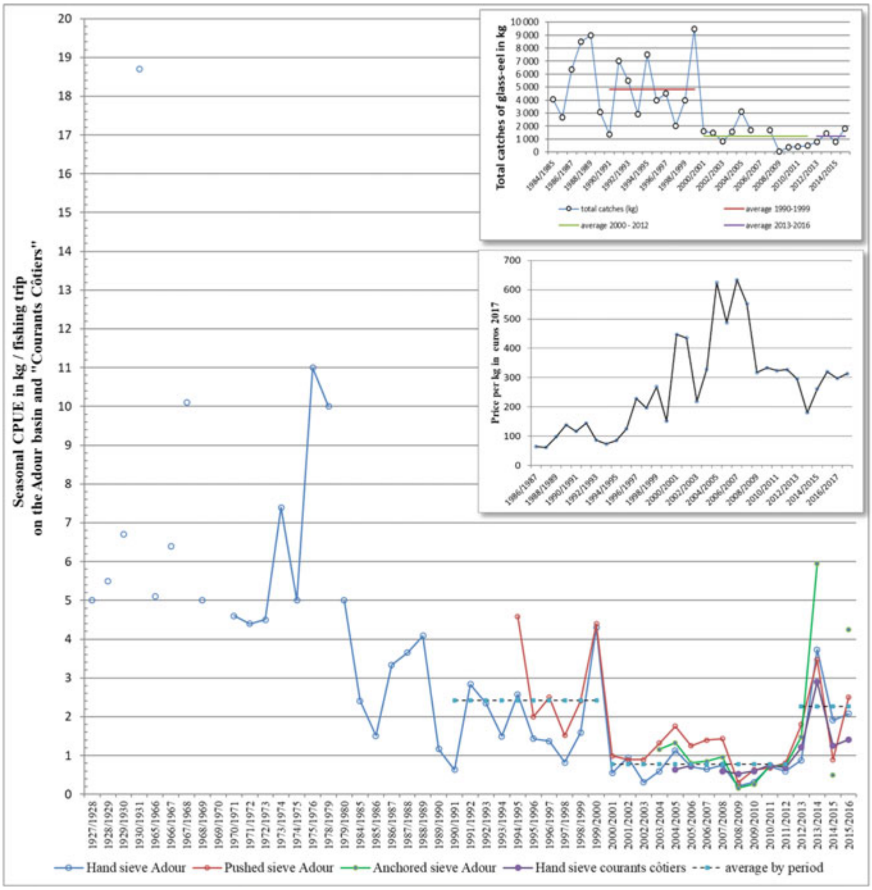


**Fig. 13** Time series of marine glass eel catches on the Adour basin expressed in kg per fishing trip in the main graph on the period on the period 1927–2016 and in kg for the whole season in the upper graph on the period 1984–2016 and the mean price per kg of glass eel in the middle graph on the period 1986–2018

of the eel population growing at sea; the southern group (Mediterranean sea, South of the Iberian Peninsula and North Africa) with a high growth rate with a part of the eel population living in transitional waters such as Mediterranean lagoons and a central group (Southern part of the British Islands, Atlantic coast of France and Northern part of the Iberian peninsula) with a wide range of growth rates and a large diversity of habitats mainly in inland and estuarine waters. In addition, the use of the eel resources is different: exploitation of glass eels in the central area (mainly from the South of the British Islands to the North of the Iberian Peninsula) that represented one of the most valuable commercial fishery of the Bay of Biscay before the export ban to Asia in 2010 (Léauté et al. 2002); exploitation of yellow and silver eels in the two others geographic areas with a large development of eel culture in the northern

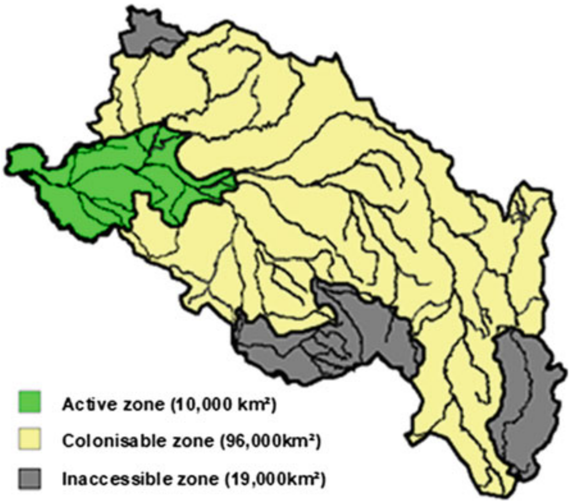


**Fig. 14** Active, colonisable and inaccessible zones for eel in the Loire catchment (from Laffaille and Rigaud 2008)

**Table 2** Main actions for the implementation of the European eel international regulation

| Years | Actions |
|---|---|
| 1984 | The French Working Group on Eel declared eels are steeply declining |
| 1998 | ICES considered European eel outside "safe biological limits" and advised to reduce fishing mortality to the lowest possible level |
| 1999 | ICES recommended to reduce all the anthropogenic mortalities to the lowest possible level |
| 2007 | UE defined an Eel regulation plan (1100/2007) for the recovery of the European eel |
| 2008 | European eel is included in the IUCN red list (critically endangered) |
| 2009 | CITES listed the European eel at the Annex 2 (threatened species with a necessary control of its international trade) |
| 2010 | Definition and implementation of a UE Eel Management Plan |
| 2011 | Ban of the eel export outside Europe |
| 2012 | First assessment of the national Eel Management Plans |
| 2014 | First assessment by ICES of the national Eel Management Plans |
| 2018 | French assessment of the Eel Management Plan |

area completely dependent on the glass eels catches (availability and price) landed in the central area.

As a consequence of the drastic depletion of the eel population, the Scientific Review Group (SRG) of the EU CITES management authorities concludes in December 2010: "It was not possible for the SRG to consider that the capture or the collection of European eel specimen in the wild or their export will not have a harmful effect on the conservation status of the species".

Thus from 2010, the eel export ban outside Europe (and of course Asia) is the background of the national Eel Management Plan that has to include:

- A reduction of commercial and recreational fishing activities.
- Restocking measures.
- Improvement of river habitats and of free movement of migrating fish (including measures to reduce the mortality linked to the hydro-electric power turbines).
- Transportation of silver eels from inland waters.
- Control of the predators.
- Aquaculture for restocking purposes.
- And other measures for the achievement of the target defined by the EU for the European eel resource: 40% of the pristine biomass.

In addition, the EU Member States that allow the fishing of glass eels (less than 12 cm in length) have an obligation to reserve 60% of their glass eel catches for the restocking of European waters.[6]

Article 4(2) of the Eel regulation establishes that a member state that has not submitted an eel regulation plan is forced by default to implement a fifty per cent reduction in their eel fisheries.

According to Article 9(1) of the Eel Regulation, each member state have to report every 3 years on progress in the implementation of their Eel Management Plans (EMPs).

## 5 What Has Been Done to Achieve the Target: In France

The objective defined by the EU for the eel resource is a long-term target if we consider the slow turn-over of that population between 5 and 30 y for a first spawning (Aoyama and Miller 2003). The objective of the EU EMP is defined in Article 2(4): "the objective of each Eel Management Plan shall be to reduce anthropogenic mortalities to permit with high probability the escapement to the sea of at least 40% of the silver eel biomass relative to the best estimate of escapement that would have existed if no anthropogenic influences had impacted the stock". This kind of pristine biomass ($B_0$) is very difficult to define accurately for most of the EU member states and the way of defining it differs among countries (ICES 2018a, b).

The 2018 French eel management report describes the actions that have been deployed to restore the eel population (Anon. 2018). However, these 168 pages mainly focus on fishery-dependant actions as restrictions and control of fishing effort and restocking. A significant effort has been paid to restore river continuity. Finally, this report implicitly acknowledges that little has been done to reduce sublethal contamination of eels by metallic and organic pollutants, and other anthropogenic impacts on water and ecosystem quality.

[6] Article 7(1) of the Eel regulation, by 31 July 2012 60% of the national total catches.

### *5.1 A Reduction of the Fishing Pressure in Line with the EU Eel Management Plan*

For France, since the beginning of the implementation of the Eel Management Plan, a reduction of the fishing pressure on all the Eel biological stages occurred:

- 51% decrease of the number of glass eel licences for the professional marine fishers and 71% decrease for the professional inland fishers (Table 3)
- 28% decrease of the number of yellow and silver eel licenses for the professional marine fishers and 25% decrease for the professional inland fishers (Table 4).

The number of fishing enterprises in the Mediterranean Sea also declined from by 33% between 2009 and 2018.

- A quota is also defined annually by a commitee formed by scientists, managers, and fishermen. Then, the annual quota is shared according to a key of dispatching in the different eel management units and between marine and inland groups of fishers (Table 5).

The consumption quota (human consumption) was largely exceeded during the fishing seasons 2012–2013 and 2013–2014, the first two years when 60% of the total quota was reserved for restocking purposes. The restocking quota is never reached, direct result of a slack European restocking market (see Fig. 5).

- A precise record of the glass eel catches is made according to a very strict framework. For the professional marine fishers, according to the regulation (CE) 1224/2009, the masters of fishing vessels have to declare their catches in a logbook as soon as the first one hundred grams of glass eels have been caught. The logbook must be completed when the glass eels are landed. These catches have to be declared to FranceAgrimer[7] directly by the fisher within the 24 h following the landing. For the inland fishers, the reporting requirement is analogous, but the logbook has to be sent to the French Biodiversity Agency.
- The fishing of glass eel (eels < 12 cm) is not allowed for the amateur fishery. Presently, there exists no scheme of prior administrative authorization to regulate the fishing activity in the French maritime area. The implementation of a licence regime is not made as there is no quota defined for yellow eel. For the recreational fishery in continental waters, there exists, since 2010, a decree defining the administrative conditions to deliver a fishing authorization for yellow eel fishing in freshwater with eel pots and lines. From 2011 to 2017, à 82% decrease of the numbers of amateur fishers has been recorded (from 5224 in 2011 to 931 in 2017, Anon. 2018). For the rod fishery in inshore waters, no authorization scheme has been defined and no obligatory catch reporting system. So as in most of the European waters (ICES 2018a), it is very difficult to know with accuracy the amount of yellow eel caught by the recreational fishery.

[7] French Office for farm and fishery products.

**Table 3** Evolution of the number of glass eel licenses on the period 2006–2018 in France

| | 2006 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | Trend 2006–2018 (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Marine fishers | 853 | 643 | 573 | 500 | 475 | 457 | 413 | 420 | 437 | 417 | −51 |
| Inland fishers | 371 | 180 | 158 | 147 | 145 | 129 | 126 | 112 | 109 | 109 | −71 |
| Total | 1224 | 823 | 733 | 647 | 620 | 586 | 539 | 532 | 546 | 526 | −57 |

**Table 4** Evolution of the number of the yellow and silver eel licences on the period 2009–2018 in France (Mediterranean area non-included)

| | | 2009 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | Trend 2009–2018 (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Yellow eel | Marine fishers | 309 | 236 | 224 | 248 | 222 | 228 | 229 | 216 | −30 |
| | Inland fishers | 169 | 169 | 172 | 146 | 143 | 134 | 135 | 128 | −24 |
| | Total | 478 | 405 | 396 | 394 | 365 | 362 | 364 | 344 | −28 |
| Silver eel | Inland fishers | 44 | 34 | 34 | 34 | 33 | 34 | 34 | 33 | −25 |

**Table 5** French glass eel quota (in kg) on the period 2010–2018 shared between consumption and restocking

| Fishing seasons | Consumption quota (kg) | Restocking quota (kg) | Total quota (kg) | Use level of the consumption quota (%) | Use level of the restocking quota (%) |
|---|---|---|---|---|---|
| 2010–2011 | 26,800 | 17,866 | 44,666 | 109 | 31 |
| 2011–2012 | 20,349 | 16,649 | 36,998 | 105 | 75 |
| 2012–2013 | 17,000 | 17,000 | 34,000 | 140 | 45 |
| 2013–2014 | 17,000 | 25,500 | 42,500 | 145 | 63 |
| 2014–2015 | 30,000 | 45,000 | 75,000 | 81 | 26 |
| 2015–2016 | 22,290 | 34,485 | 56,775 | 94 | 74 |
| 2016–2017 | 25,780 | 38,970 | 64,750 | 91 | 51 |
| 2017–2018 | 25,940 | 38,914 | 64,854 | 94 | 78 |
| Mean | 23,145 | 29,298 | 52,443 | | |

## *5.2 Restocking*

The objective of the French Eel Management Plan planned to keep 5–10% of the yearly catches of glass eels to restocking on the French catchments of the Bay of Biscay and the coasts of the Channel (Tréguier et al. 2015). A total of 21,800 kg (approx. 77 million) of glass eels have been restocked between 2011 and 2018 in 74 operations (Fig. 7). Restocking is funded by a national grant following a protocol that gives clear recommendations on the selection of restocking sites and density that can be applied. The efficiency of this measure is still been assessed by a national monitoring programme, but and no strong conclusions are yet available (Tréguier et al. 2015; Anon. 2018).

## *5.3 A Slow but Significant Restoration of the River Continuity*

Figure 8 shows the location of the priority zones for the eel restoration defined in the French Eel Management Plan in 2010.

The priority zone for Eel is a river or a part of a river where priority is given to eliminating obstacles that prevent the free migration of eels. In 2018, 9564 obstacles have been counted on the areas colonized (or potentially colonized) by eel, 2950 of which are in the priority zones for eel.

By 1 January 2018, 1882 (19.6%) of obstacles, 515 (17.5%) of which in the priority zones have been aligned with the environmental policy. So, a considerable amount of work still remains to increase the Eel available habitat. Restoration of the river continuity is one of the main critical factors to recover the eel resource and increase the potential eel habitat. In Spain, according to Clavero and Hermoso (2015), the amount of eel habitat lost since the nineteenth century surpasses 82% and explains in that country the collapse of the species the range of which is currently restricted to a coastal fringe (see Fig. 3 of the communication of Clavero and Hermoso 2015).

## 6 What Has not Been Targeted by the Management Plan

### *6.1 Eel Habitat Restoration*

The Water Framework Directive (2000/60/CE) has set the objective to achieve good ecological status for all waters in the European Union by 2015 (unless exception in 2021 or 2027).

In France, as in many European countries this objective is far from being achieved (Fig. 9).

The joint analysis of Figs. 8 and 9 shows that eels are mainly concentrated in areas where the ecological status of the water bodies is very often moderate (yellow colour) or poor (red colour). It is a major impediment to the achievement of the European Eel restoration programme.

According to the European Environment Agency (EEA 2012), "more than half the surface of the water bodies in Europe are reported to be in less than good ecological status or potential, and will need mitigation and/or restoration measures to meet the WFD objective". In addition, the EEA observed that river bodies and transitional waters have the worse ecological status compared to water bodies in lakes and coastal waters. The EEA concludes that "the worst area in Europe concerning ecological status and pressures in freshwater are in central and north-western Europe, while for coastal and transitional waters, the Baltic Sea and Greater North Sea regions are the worst" (EAA 2012).

### *6.2 Limiting Contamination by Organic and Metallic Pollutants*

The effects of contamination by pesticides have been suspected and proven to be one of the major causes of the eel species declines worldwide (Robinet and Feunteun 2002; Feunteun 2002). The difficulty is to fix sublethal thresholds to target management options. Given that eels are semelparous and that they spawn in remote oceanic habitats, it is practically impossible to measure reaction norms and contamination thresholds beyond which transoceanic breeding migration, breeders survival, and larval survival are compromised (Robinet and Feunteun 2002).

According the European Environment Agency (EEA), "the chemical quality of water bodies has improved significantly in the last 30 years but the situation as regards the priority substances introduced by the Water Framework Directive (WFD) is not clear" (EEA 2012). In addition, that Agency observed "Monitoring is clearly insufficient and inadequate in many Member States (MS), where not all priority substances are monitored and the number of water bodies being monitored is limited".

In its last report (EEA 2012), the Agency reports the poor chemical status of the transitional water of 6 MS: Netherlands, Sweden, Belgium Flanders, Germany and France, water bodies of an extreme importance for the future of the eel resources.

Pesticides are the predominant cause of poor chemical status in Luxembourg, France, Belgium, Czech Republic, Germany, Spain, Hungary, Italy, Netherlands and Romania.

Heavy metals are identified as problematic by 21 MS and 15 MS highlight cadmium as a cause of poor status.

TBT (tributyltin), powerful biocide, now banning in Europe, remains found at high levels in the aquatic ecosystems. It is a particular issue in Belgium, France and UK.

In France (Fig. 10), as in many European countries (ICES 2018a), polychlorinated biphenyls (PCBs) have a great impact on the quality of the environment (Tchilian 2010). Between 1930 and 1980, about one million metric tons were produced worldwide. PCBs are mixtures of chlorinated biphenyl congeners and cause a wide range of toxics effects across species from mammal to fish (Monosson 1999). They are known to affect the hypothalamic-pituitary-gonadal-liver (HPGL) axis at almost every point (Thomas 1990). The liver serves as reservoir for PCBs as for many lipophilic chemicals, and many of these contaminants are incorporated into the vitellogenin and are taken up by the developing oocyte. It is an important way of exposure for developing embryos or larva (Monosson 1999).

In 2006, UE defined a maximum acceptable concentration of PCBs in products for human consumption.

In 2008, a French action plan was set up and took into account new health standards such as 12 pg/g fresh weight for eels.[8] That level is often exceeded in several eel populations living in the vicinity of industrial and urban areas as shown in Fig. 10: Northern and Eastern France in industrial areas, Paris Basin, Rhône river downstream Lyon. In some European countries, the sale of eels from some areas is forbidden (ICES 2018a). It is the case in France for eels caught in some rivers or part of the catchments impacted by urban and industrial activities. Through biological magnification, PCBs as chemicals or heavy metals concentrations increase with each trophic level of food chain. Eel, after a given size, is a carnivorous species and accumulates high level of contaminants, especially in its fat content. Some biological investigations have shown that pollutant accumulation is related to head dimorphism in eel (De Meyer et al. 2018). These authors found that broad-headed eels contained higher concentrations of mercury and several lipophilic organic pollutants, compared to narrow-headed ones, irrespective of their fat content: with increasing head width the trophic position of the individual increased.

[8] Picogram equals $10^{-12}$ g.

### 6.3 *Marine Stages and Habitats*

It is well accepted that global change has provoked severe oceanic regime shifts that have deeply changed the food web structure, temperature, currents and other parameters of the epipelagic intertropical marine habitats where the eel larvae live. In turn, this has very likely impeded larval growth, transport to continental habitats and survival (i.e. Miller et al. 2016 for a summary). This is completely outside the objectives of the management plans because the actions are way outside the control of regional or national staff in charge of eel management. Indeed, all the global changes issues are to be dealt with at the international level. To that end, eels could and should be considered as ambassador species for the Conference of the Parties (COP) on climate change.

## 7 What Happened 10 Years After the Implementation of the Eel Management Plan?

### 7.1 *Trends in Glass Eel Recruitment: The Syndrome of the Broken Thermometer*

Glass eel recruitment series are estimated from a mixture of observations from fishery-dependant and independent surveys focusing on different stages: glass eels, elvers, young yellow eels in estuary, lakes or rivers (Fig. 11).

The two separate areas: "North Sea" and "Elsewhere Europe" correspond to two geographical groups of eels (see Fig. 6): the Northern group on one hand and the Central and Southern groups on the other hand characterized by different types of eel habitats and irrigated by different branches of the North Atlantic Current: Azores Current in the South; the main branch of the north Atlantic drift in the central part of the eel colonization area and the northern part of the North Atlantic drift for the Northern group. Moreover, the time series that are used are highly variable, fishery dependant or not. The fishery-dependant series may either report total catches or CPUE, which provide a very different view of the trends, especially when under a quota and price controlled by CITES regulations (see § 2, Figs. 4 and 5). This certainly impacts the robustness and the meaning of the time series since the eel management has been implemented in 2010 and may lead to the impossibility to detect clearly short-term variability. This is the syndrome of the broken thermometer.

Figure 12 shows the extreme variabilities of time series allowing however to emphasize a declining trend of the recruitment at least since the seventies. But the question is: can we detect, from the implementation of the European Eel Management Plan, a significant increase of the glass eel recruitment at least in the central part of the colonization area that receives the main arrivals of glass eel?

As mentioned previously, the trend of total catches, especially after the implementation of the European Eel Management Plan,[9] makes it difficult to detect a potential increase of the glass eel recruitment (see Fig. 3 for example), hence the need to take into account the variation of the fishing effort and use some relative index as the catch per unit of effort. The example taken into account is the glass eel fishery of the Adour river where a long time series of marine glass eels catches is recorded by Ifremer and IMA (Institut des Milieux Aquatiques). The catches are splitted according to the fishing gear used: pushed sieve since 1995, anchored sieve since 2003 and hand-sieve since 1970. The trend of the hand-sieve time series is, as previously mentioned (see § 2), less influenced by the different regulation regimes and economical contexts before and after the implementation of the EU Eel Management Plan.

When comparing CPUE and total catches in a same river, the steepness or even the significance of the decline is not the same as shown in Fig. 13.

The total catches reported on the Adour river since the eighties do not allowed to detect an increase of the glass eel landings after 2013 (3 years after the beginning of the decrease of the fishing pressure on yellow and silver eel in Europe). The average catches on the period 2013–2016 is similar to the average in the previous period (2000–2012) and much lower than the average in the period 1990–1999. This is not the case for the CPUE (main graph Fig. 13): the average CPUE in the period 2013–2016 is similar to the average observed in the period 1990–1999 and much higher than that observed in the period 2000–2012. This difference between total catches and CPUE is explained mainly by the fact that the total catches in France are limited by quota since 2010 in each Eel Management Unit (EMU) (see § 5.1).

In this context, Bornarel et al. (2018) considered four different types of time series to estimate absolute recruitment variations using GEREM model (Drouineau et al. 2016) and following an upscaling design from rivers, to regions and finally Europe. As expected, their model showed a decline of the recruitment since the 1980s until 2009, with a significant variation among regions. The steepness of the decline decreased globally from northern to southern latitudes. However, this study did not discuss the effect of the Eel Management Plan on the significance of the fishery-dependant series since 2009. The authors however concluded that there is a need for additional data to properly characterize the glass eel recruitment trends.

## *7.2 Trends in Colonization of River Catchments*

As mentioned by Adam et al. (2008), the estimation of the eel biomass in a whole catchment (especially a large one) is presently nearly impossible to achieve. To address this objective, a modelling approach has been developed to predict the abundance of eels according to information derived from the national freshwater fish

[9] Decrease of the fishing effort, limitation of catches, constraint of the eel market, …

survey (RCS[10] et RSA[11]) (Briand et al. 2018). This model has been applied to Ireland (de Eyto et al. 2016). It is also used to assess the abundance of silver eel potential per catchment unit and confronted to "real data" that are available from eel index rivers in France (Anon. 2018). However, the limitations of this model are numerous because the data set is mainly based on electrofishing and skews the results to shallow waters and does not properly take account of deep waters (large rivers, lakes) and to saline habitats (lagoons and estuaries).

Therefore, as quoted by Laffaille and Rigaud (2008): "Hence, observing the occurrence of the species or of some size groups can be useful at least in a first stage to visualize the current state of the resource and the way in which the situation is tending to evolve". The absence of eels from an eel suitable area or the absence of young eel stages from the lower part of the estuary or a lower part of a river is sufficiently explicit of the depletion of the eel resources. Seeing the reappearance of eels in the upper part of the rivers or the increase of the active zone (Fig. 14) characterized by the presence of individuals <15 cm[12] or between 15 and 30 cm[13] is a positive signal for the restoration of that species in a given catchment.

For example, on the Loire catchment, Canal et al. (2013) observed an increase of the eel abundance in the lower part of the Loire axis, increase mainly due to the important number of young eels inferior to 15 cm in size. The consequence is an increase of the presence probabilities of eels smaller than 30 cm at the tidal limit[14] in the Loire axis and an increase of the distance between the $D_{0.5}$ limit[15] and the tidal limit in 2013 compared to 2010. This shift of the $D_{0.5}$ limit upstream is confirmed in 2016 (Dufour 2016). Fig. 15 shows the evolution trend of $D_{0.5}$ limit for small yellow eels (size inferior to 30 cm) in the Loire axis.

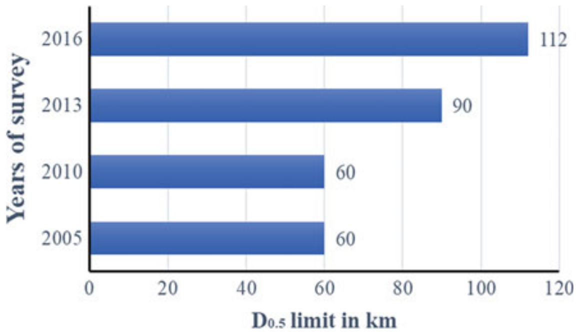


**Fig. 15** Evolution trend of the $D_{0.5}$ limit for the young yellow eels on the period 2005–2016 in the Loire axis (from LOGRAMI data http://www.migrateurs-loire.fr/front-de-colonisation-de-languille/)

[10]RCS: Réseau de contrôle et de surveillance de l'état écologique des eaux.

[11]RSA: Réseau spécifique anguille.

[12]This size is a size limit for the young individuals newly recruited that begin the process of the catchment colonization.

[13]That size category corresponds to older individuals aged 2–5.

[14]Tidal limit: the maximum upstream location at which a tidal variation of water level is observed.

[15]$D_{0.5}$ limit: which corresponds to the distance from the tidal limit where the probability of observing eels less than 30 cm is equal to 0.5. It is a colonisation and accessibility index.

It is an encouraging sign and a positive result obtained after the reduction of the fishing effort on silver eel in Europe and consistent with the increase in glass eel CPUE reported by the marine fishers and observed in the Adour river (see Fig. 13).

## 8 Conclusion

The implementation of the UE Eel Management Plan in 2010 and the Member States operational measures derived from that plan show that important efforts have been made, since 2010, to control and decrease the fishing pressure on all the stages of the Eel biological cycle. However, further substantial efforts are required to improve the quality of eel habitats, the free migration of individuals towards and from some of their potential habitats. In many countries, the loss of surface becomes irreversible and the remaining surface is just a small part of the pristine eel habitat (ICES 2018a, b) making difficult, if not impossible, the achievement of the long-term objective of the UE management plan: 40% of the pristine biomass.

There exists also, due to a change of the fishing regulation regime: export ban to Asia, adoption of quotas associated with a slack market for glass eel restocking, a real difficulty to estimate the variation of the recruitment after 2010 compared to that of the previous period and consequently the impacts of fishing regulation from 2013. The significance of the total catches is not the same before and after the implementation of the UE Eel Management Plan. Even, the CPUE time series after 2010 have to be interpreted carefully and taking into account the gear used. So, a need to reinvent surveys and to deeply re-examine significance of the series to unravel effects of the change of fishing habits from those of the recruitment variability and recovery.

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# The Management of Mediterranean Coastal Habitats: A Plea for a Socio-ecosystem-Based Approach

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**Abstract** Biodiversity is often defined erroneously as the number of species. The higher the number of species, the better the status or the health of a habitat is considered to be. Managers, stakeholders and environmentalists worldwide often prioritize the 'species approach'. The protection of an iconic and endearing species is obviously easier than that of tiny zooplankton species, although the latter may play a far more important role than the former in the functioning of healthy ecosystems. The species approach has been widely favoured compared to the ecosystem approach. However, 'species-by-species' management is unrealistic. The problem is that the management of natural habitats is often driven by environmentalist lobbies on the basis of taxonomy (e.g. mammals, turtles, birds, iconic fish, flowering plants, etc.) and disciplinary lobbies (biology, benthos, pelagos, contaminants, currents, etc.). Ecosystems are units of biological and spatial organization that include all the organisms, their interactions, the functional compartments they belong to, along with the components of the abiotic environment. The concept of the socio-ecosystem is useful insofar as it emphasizes the fact that man is part of ecosystems. Here, the authors make use of

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four case studies, in the Mediterranean Sea, in an attempt to demonstrate the interest of a comprehensive, socio-ecosystem-based approach in the field of environmental management. They also highlight the importance of tackling the coupling between benthic and pelagic ecosystems and between terrestrial and marine ecosystems.

**Keywords** Biodiversity · Environmentalist lobbies · Management · Mediterranean · Socio-ecosystem

## 1 Introduction

Biodiversity is often defined erroneously and in a simplistic way as the number of species. The higher the number of species, the better the status or the health of a habitat is considered to be. Disturbances are wrongly thought to reduce the number of species, while in reality they often increase it. In most cases, the highest number of species is reported for intermediate levels of disturbance (IDH—intermediate disturbance hypothesis and DEM—dynamic equilibrium model) (e.g. Lubchenco and Menge 1978; Huston 1979; Valdivia et al. 2005; Svensson et al. 2009). In fact, biodiversity is a complex multidimensional concept, defined by at least five scales (evolutionary, functional, organizational, spatial and heterogeneity scales) and more than a hundred metrics. These metrics can give apparently contrasting responses, when they are in fact complementary (Sala and Knowlton 2006; Boudouresque 2014; Boudouresque et al. 2017a).

Humans have always sought to structure, organize and control the environment they are living in, exploiting or protecting. Terrestrial or marine management practices have of course been adapted to these aims and to the epoch, with an outcome ranging from effective to mishandled and to counterproductive (Hardin 1968; McNeely 1996; Watson-Wright 2005). 'Management' is the buzzword for the proactive, modern aspect of this multi-millennial trend. Doing nothing also constitutes a management strategy.

Environmental issues have been addressed by man through three different approaches: the 'human-centred', 'species-centred' and the 'ecosystem-centred' approaches. The significance of the first, the human-centred approach, is today not solely historical (the eighteenth and nineteenth centuries), since is still followed today in other forms. The second, the species-centred approach, characterized the twentieth century and remains the current approach adopted in many countries and for several international agencies; it is supported by groups of experts working on a given taxon (hereafter 'taxonomic lobbies'). Finally, the ecosystem-centred approach has made its appearance recently, and it remains weakly established under the strong pressure of 'taxonomic lobbies'. Yet the ecosystem-centred approach is the only one that can meet the challenges driven by global change and ensure the proper management of natural habitats.

The social-ecological system-based approach is based on the principle that humans have been part of ecosystems for hundreds of thousands of years, first as top predators, and then as farmers, in the context of mutualistic symbioses. Humans are part of the ecosystems, as a key species or as ecosystem engineer, and they have to a greater or lesser extent shaped all the ecosystems of the planet, including within national parks (Redman et al. 2004; Folke 2006; Ostrom 2009).

## 2 The Age of the Human-Centred Approach

The French naturalist Buffon (1707–1788) felt only contempt for the environments that we now refer to as 'natural'. In his 'Histoire Naturelle', he speaks of '(…) *a congested space, clogged up with old trees laden with parasitic plants, lichens, mushrooms, impure fruits of corruption* (…), *dead and stagnant waters, for lack of being led and directed* (…); *swamps covered with aquatic and foul-smelling plants, that feed only venomous insects and serve as a haunt for disgusting animals. Between these filthy marshes which occupy the low places, and the decrepit forests which cover the high lands, extend some sorts of moors, savannahs which have nothing in common with our grasslands; there, weeds overcome, oppress the good grasses*' (Buffon 1764). Later, he wrote that '*The raw nature is hideous and dying* (…); *let us animate these dead waters, making them flow; let's form streams, canals (…); set fire to these old forests, already half-consumed; let us destroy with iron what the fire could not have consumed* (…)'[1] (Buffon 1767). It is clear that, for Buffon, the ideal nature was depicted by the royal gardens of Versailles, its fountains and canals.

It is easy today to smile at this vision of nature: it was the one that prevailed until the nineteenth century, based on a human-centred approach. During the first two-thirds of the nineteenth century, the philosophy of Saint-Simon, by promising the happiness of humanity through the scientific domestication of nature, helped to reinforce this vision. More recently, in a report to the US Congress dated 1948 that recommended draining the Florida wetland, we can read: '*The Everglades are now suitable only for the haunt of noxious vermin, or the resort of pestilent reptiles*' (Fudge 2001; Hollander 2008; Faget 2011).

The human-centred vision of nature persisted until the twentieth century, in the form of the dichotomy between useful species (for man) and pests (competitors of humanity); official lists of pests, the destruction of which was recommended, were published by European administrations (De la Blanchère 1878; Faget 2016). Thus, birds of prey were on the pest lists, being considered competitors with an impact on the availability of commercially valuable or emblematic species for farmers and hunters. This approach was very simplistic. In fact, predators have a positive impact on their prey, directly or indirectly (healthy herd hypothesis). For example, the Japanese authorities accused marine mammals for competing with fishers for fish resources, thus justifying hunting them; but actually, from the perspective not of a species-by-species approach, but of an ecosystem-based approach (see below), marine mammals

[1] Translated by the authors from the original French text.

favour fisheries (Gerber et al. 2009). The Japanese Satoumi approach, based on traditional use of the coastal waters by local people in the Edo period (1600–1868 CE) and still in use, may, in a way, be considered as the modern form of the human-centred approach. Satoumi is defined as the human use and management of coastal seas for high productivity, while maintaining high biodiversity and sound marine environments, via human-shaped seascapes (Yanagi 2013; Berque and Matsuda 2013; Henocque 2013; Komatsu et al. 2017). The point of view of western fishery scientists is another human-centred approach, with roots in the late nineteenth century; to embrace the overwhelming size of the ocean, fishery scientists turn towards mathematics, considering the catches as a compound effect of firstly fishing mortality and secondly natural mortality (see Fedor Baranov's equation; Baranov 1918). Many generations of fishery scientists followed this pioneer, developing production models and refining their equations using population demography properties, until the need for an ecosystem-based approach to fisheries prevailed.

It is worth noting that the interest for humans is today taken into consideration as ecological goods and ecosystem services: the natural processes and components that benefit human needs (Costanza et al. 1997, 2014; Nordlund et al. 2016).

## 3 The Age of the Species-Centred Approach

From the nineteenth century on, and especially during the twentieth century, with the development of environmental NGOs (non-governmental organizations), e.g. the IUCN (International Union for Conservation of Nature in 1948), the WWF (World Wildlife Fund in 1961) and Greenpeace (in 1971), a species-centred approach was developed. Species were divided into two broad categories: on the one hand, outstanding species, including species with heritage value (iconic species), which deserve particular attention, and on the other, the 'ordinary' species. The notion of outstanding species is a fuzzy concept (Gauthier et al. 2010; Astruch et al. 2012; Brambilla et al. 2013) that covers threatened species, rare species, species with protection status, charismatic species, ecosystem engineers and key species, and finally indicators of environmental quality.

### *3.1 Threatened Species*

Species are classified, according to the IUCN (2017), into nine categories: EX (extinct), EW (extinct in the wild—can survive in zoos or botanical gardens), CR (critically endangered—facing an extremely high risk of extinction in the wild), EN (facing a risk of extinction in the wild), VU (vulnerable—e.g. a population size reduction >30% over the last 10 years), NT (near threatened), LC (least concern), DD (data deficient) and NE (not evaluated). The categories EW, CR, EN and VU are grouped under the name of 'threatened species'. The classification of species within these categories is carried out by panels of experts, is regularly updated and can be considered reliable, according to current knowledge. For example, the seagrasses *Posidonia oceanica* and *Cymodocea nodosa* are ranked as LC, which is consistent with Boudouresque et al. (2009).

At the national and regional scales, species are classified within these categories, 'according to the IUCN methodology and approach' but, perhaps because of greater pressure from the specialists of certain taxa (e.g. birds, bats, mammals, vascular plants), the classification is sometimes less rigorous. For example, in the Provence and French Riviera region (France), *P. oceanica* and *C. nodosa* are ranked as EN and NT, respectively (Noble et al. 2015), which seems very exaggerated (*P. oceanica*) or even wrong (*C. nodosa*); the latter species is rather expanding, taking advantage of global warming and the decline of *P. oceanica* (Boudouresque et al. 2009; Montefalcone et al. 2011; Pergent et al. 2012).

In some cases, expert judgment is probably more relevant, or better supported, than the IUCN Red List. For example, the Mediterranean brown algae *Cystoseira crinita*, *C. squarrosa* and *Laminaria rodriguezii* are listed as 'not evaluated (NE)' in the IUCN Red List, while *C. crinita* is regarded as CE, near to regionally extinct, in French Catalonia and Languedoc (France) (Blanfuné et al. 2016a), *C. squarrosa* is regionally extinct along the French coast, with its last record in 1929 (Thibaut et al. 2015), and *L. rodriguezii* is endangered in the Adriatic Sea (Žuljević et al. 2016).

## 3.2 *Rare Species*

Rare species can be either threatened or not, for example, the deep-dwelling needle-spined sea urchin *Centrostephanus longispinus* in the north-western Mediterranean; this species is not endangered, just naturally rare in the area, especially at depths accessible to scuba divers. It is quite abundant in some other areas (e.g. Eastern Mediterranean, Atlantic coast of Morocco, Senegal) (Francour 1991; Templado and Moreno 1996). Surprisingly, in the north-western Mediterranean Sea, one of its densest populations has been sighted on a wastewater pipe, near Marseilles (western Provence, France) (Bonhomme et al. 2014). Despite the lack of known threats or any clear decline in its population, the species is listed as threatened in French Red Lists and is strongly protected.

It is worth noting that, in some cases, the extreme rarity of a species constitutes per se a threat. For example, the brown alga (kingdom stramenopiles) *Laminaria ochroleuca*, is only known, in the Mediterranean Sea, from four localities: Alboran Island (Spain), Al Hoceima (Morocco), Banc de Matifou (Algiers, Algeria) and Straits of Messina (Italy) (Feldmann 1943; Giaccone 1969; Araùjo et al. 2016); its IUCN status is 'non evaluated (NE)'; it is clear that a small number of highly localized events (e.g. contamination and coastal development) could lead to local extinction of the species. A further and more worrying example is that of the mollusc *Gibbula nivosa,* endemic to Malta Island. Although no warning signs were detected, it was considered extinct (EX) in 2000–2002, before the discovery of a small relic population at Marsamxett, in 2006–2007, thus becoming a critically endangered (CE) species (Schembri et al. 2007; Evans et al. 2010).

### 3.3 Protection Status

Some species are protected by national or regional legislation. The protection status is highly dependent upon the visibility of the species (e.g. size), the sympathy it arouses (e.g. dolphins) and especially the influence of 'taxonomic lobbies' (e.g. birds, bats and sea mammals). In France, the seagrass *Cymodocea nodosa*, the sea urchin *Centrostephanus longispinus* and the dolphin *Stenella coeruleoalba* are strictly protected, while none of their populations are actually threatened or even in regression.

### 3.4 Charismatic Species

Lovable species (or charismatic species) are species that enjoy a coefficient of sympathy from the general public (whether threatened or not). Dolphins are the perfect example, even if they entered this category very late, after World War II (Faget 2016). In the Mediterranean Sea, the short-beaked common dolphin *Delphinus delphis*, although listed as LC (least concern) worldwide, is considered as vulnerable (significant decline). In contrast, the common bottlenose dolphin *Tursiops truncatus* and the striped dolphin *Stenella coeruleoalba* are far from being threatened in the Mediterranean; their populations are in no way declining and may even benefit from human impact (e.g. overfishing and elimination of their competitors, such as sharks) to proliferate (Cagnolaro and Notabartolo di Sciara 1992; Gannier 1995). Whatever their actual population status, national legislations fully protect all Mediterranean dolphins.

In Italy, the appeal of bird species better predicts their conservation status than the threats that are actually hanging over them (Brambilla et al. 2013). Some species are charismatic due to their role in enhancing seascapes, such as the gorgonians *Paramuricea clavata* (Fig. 1), *Eunicella singularis* and *E. cavolini* (Astruch et al. 2012).

Courchamp et al. (2018) drew attention to a perverse effect regarding charismatic species: the massive cultural and commercial visibility of some of them in the public sphere encourages the public to think that they are still common while some of them may be on the brink of extinction.

**Fig. 1** Dusky grouper *Epinephelus marginatus* in a coralligenous habitat. On the left, the gorgonian *Paramuricea clavata*. Port-Cros Archipelago marine protected area (MPA), eastern Provence. Photograph © Sandrine Ruitton

### *3.5 Ecosystem Engineers and Key Species*

Ecosystem engineers are '*organisms that directly or indirectly modulate the availability of resources (other than themselves) to other species, by causing physical state changes in biotic or abiotic materials*' (Lawton 1994). Key species are species that '*have effects on ecosystems out of all proportion to their relative abundance*' (Bond 2001). Within the scope of the ecosystem-based approach (see below), the ecosystem engineers and the key species are undoubtedly those most worthy of consideration.

### *3.6 Indicators of Environmental Quality*

In the Mediterranean Sea, the red alga (Rhodobionta) *Lithophyllum byssoides*, the brown alga (Stramenopiles) *Cystoseira* spp. and the seagrass (Magnoliophyta) *Posidonia oceanica* (Fig. 2) are usually regarded as indicators of good environmental quality; in contrast, most species of the genus *Ulva* (including Enteromorpha-like *Ulva*) are linked to environmental stress (Gobert et al. 2009; Blanfuné et al. 2016b, 2017). Finally, some species displaying sensitivity to positive or negative thermal anomalies are indicators of global warming, e.g. the Chlorobionta *Caulerpa prolifera,* the expansion of which is favoured by warmer temperature, and in contrast the gorgonians *Paramuricea clavata* and *Eunicella singularis*, which are negatively impacted by warm episodes (Perez et al. 2000; Garrabou et al. 2002; Boudouresque et al. 2017b).

**Fig. 2** A *Posidonia oceanica* seagrass meadow. Bagaud Island, Port-Cros Archipelago marine protected area (MPA), eastern Provence. Photograph © Sandrine Ruitton

## 3.7 Species-Centred Management

Managers, stakeholders and environmentalists worldwide often prioritize the species-centred approach. The protection of an iconic and endearing species is obviously easier than that of tiny zooplankton species, or of parasites, although the latter may play a far more important role than the former in the functioning of 'healthy' ecosystems (Combes 2001). Within the framework of the Habitat Directive (1992) and of the Natura 2000 network of nature protection areas of the European Union (EU), the species-centred approach has been widely favoured compared to the ecosystem-centred approach, despite the name given to the Directive. Beyond this Directive, the 'species-by-species' approach can be found at all levels of the environmental management process, including fishery management, before ecosystem-based fishery management (EBFM) came to the fore (see below). However, 'species-by-species' management is unrealistic, particularly when the emblematic species are either predators or prey. Obviously, the protection measures cannot lead to the increase in numbers of both predator and prey populations. The problem is that the management of natural habitats has often been driven by environmentalist 'lobbies' on the basis of taxonomy alone. As every taxonomist specialist group is focusing on its specific type of organism (e.g. marine mammals, turtles and tortoises, birds, iconic fish such as the grouper *Epinephelus marginatus*, flowering plants) (Fig. 1), the management of natural habitats often results in a layering of taxon-focused protection measures. Disciplinary (e.g. biology, benthos, pelagos, contaminants, currents, modelling) groups of specialists also drive the management of natural habitats. All in all, the management of natural habitats is often reminiscent of the tale of the blind men examining the elephant.

## 4 The Revolution of the 'Ecosystem-Centred' Approach

With the ecosystem-centred approach, we move from the notion of species, which of course play a role in an ecosystem, to that of an ecosystem in which species participate. The distinction may seem tenuous. However, it is a true revolution, as important as the shift from the human-centred approach to the species-centred approach.

Humans are often rightly viewed as a disturbance by ecologists and environmentalists. However, at least in some cases, social-ecological systems including humans could be closer to 'natural' ecosystems than ecosystems excluding humans, such as the no-take zones (NTZs) of marine protected areas (MPAs). A good example is the Mediterranean monk seal *Monachus monachus* and artisanal fisheries. Until the 1950s, the archipelagos of Port-Cros and Porquerolles (eastern Provence, France) hosted a monk seal colony. Taking into account the mean daily food ration of the species, mainly fish (Marchessaux 1989; Ballesteros 2012), the possible size of the colony and the tightly restricted way fishing is practised in the Port-Cros MPA (Cadiou et al. 2009; Astruch et al. 2018), it has been suggested that artisanal fishers may contribute to mitigating the ecological impact of the local extinction of this top predator, making the social-ecological system closer to a 'natural' one than a NTZ deprived of both top predators and fishers (Boudouresque et al. 2004; Le Diréach et al. 2018). Ideally, the return of the top predators (e.g. monk seal and sharks) would of course be preferable; but the size of MPAs is almost always much smaller than their home range. Further examples are provided by ecosystem-based fishery management and the ecosystem approach to management (see, e.g., Tudela and Short 2005; Halpern et al. 2010; Kincaid et al. 2017).

The ecosystem-centred approach has several strong points. (i) It allows the integration of humans in the functioning of the ecosystem, in a natural way, thus passing from the notion of ecosystem to that of social-ecological system. Humans are no longer set aside from a number of species, the system, but are within the system. (ii) While the species-centred approach often just considers a collection of remarkable taxa, the ecosystem-centred approach requires the construction of a framework, a conceptual model of the ecosystem. In this model, there are grounds for including even the unremarkable species (i.e. species that are not rare, or threatened, or iconic). (iii) The conceptual model makes it possible to link the species together, following a network of interactions, and to better interpret the possible fluctuations in their numbers. In addition, the conceptual model, within the framework of the vertical diversity hypothesis (VDH), takes into account top-down and bottom-up processes within the ecosystem (e.g. Wang and Brose 2018). (iv) The conceptual model can be a stepping stone towards analytical or numerical modelling, where flows (e.g. C, N, P) between compartments are quantified (Pethybridge et al. 2018). (v) The ecosystem-centred approach also highlights the importance in tackling the coupling between adjacent ecosystems (including benthic and pelagic, terrestrial and marine ecosystems). In addition, the life range of many species, e.g. spawning areas, nurseries, feeding and resting areas, spreads over several adjacent ecosystems (Cheminée et al. 2014). (vi) The ecosystem-centred approach makes it possible to build environmental quality indices that are much more significant and reliable than indices based on one or a few species (generally belonging to the same higher taxon, e.g. teleosts or Magnoliophyta). For example, the Ecosystem-Based Quality Index (EBQI) of the *Posidonia oceanica* seagrass ecosystem, based on the whole ecosystem, distinguishes well between sites located in marine protected areas (MPAs), such as the Port-Cros Archipelago MPA (Provence, France) and the Nature Reserve of Medes Islands (Spanish Catalonia), and those located in areas profoundly altered by human activities, such as overfishing. Interestingly, there is no congruence between the EBQI and the indices (ecological quality ratios—EQRs) which are based solely on the seagrass species and some affiliated species; a high value of the latter indices may simply reflect the health of the seagrass and the clearness of the water column, rather than the health of the ecosystem (Fig. 3) (Personnic et al. 2014; Ruitton et al. 2014; Boudouresque et al. 2015; Rastorgueff et al. 2015; Thibaut et al. 2017). (vii) Invasive species constitute one of the most worrying aspects of global change (Maxwell et al. 2016; Boudouresque et al. 2017a). The Mediterranean Sea is the area worldwide most hit by non-indigenous species, with 500–1000 introduced species (Ribera and Boudouresque 1995; Galil 2008; Katsanevakis et al. 2013). Invasion issues are

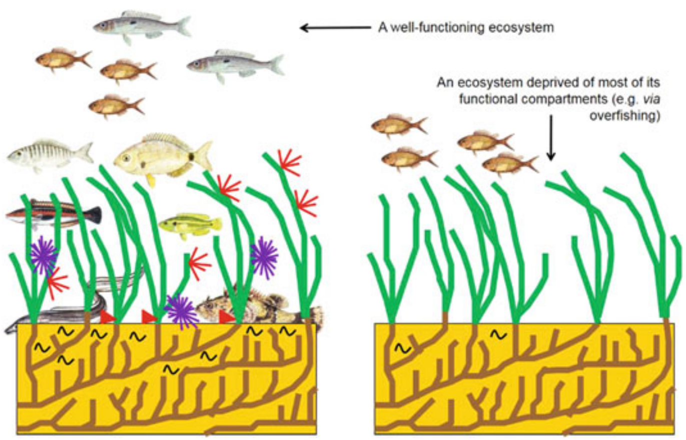


**Fig. 3** *Left*. A pristine *Posidonia oceanica* ecosystem, with species belonging to all functional compartments: the seagrass in *brown* (rhizomes) and *green* (leaves), leaf and rhizomes epibionts in *red* (primary producers); infauna in *black* (detritus feeders); the sea urchin *Paracentrotus lividus* in *purple* (herbivores) and teleosts (predators, top predators and planktivores). *Right*. A *P. oceanica* meadow deprived of most of its functional compartments (e.g. *via* overfishing), which could be considered as healthy on the basis of EQRs based on seagrass descriptors, such as shoot density and meadow coverage. From Boudouresque et al. (2015, modified)

usually studied and managed in a single-species context: interaction between an invasive species and a native one, the impact of an invasive species on point or alpha species diversity, etc. In fact, invasive species rarely act in isolation, but in packs; invasive species rarely have an impact on a given species, but on entire communities; therefore, understanding their role and impact can only be achieved in the context of the whole ecosystem (Boudouresque et al. 2005, 2011). (viii) Human activities (e.g. fisheries and contamination) do have an impact on particular species; however, it is only within the framework of the whole ecosystem, and within its functional compartments, that these effects can be understood, managed and if possible mitigated (e.g. Halpern et al. 2010; Sala et al. 2012; Giakoumi et al. 2015; Ourgaud et al. 2015; Kincaid et al. 2017). Ecosystem-based fishery management (EBFM) is obviously part of the ecosystem-centred approach (e.g. Rice 2005; Tudela and Short 2005). (ix) By definition, the concept of ecosystem services can only be understood, assessed and managed at ecosystem level.

Obviously, the ecosystem-centred approach requires a diversity of data to be really operational. Their non-availability could be a weak point of this approach, a major impediment to its use. In fact, for most ecosystems, the available data are considerable, though scattered in thousands of publications, old and recent, and often un-synthesized. In the absence of properly integrated data, and despite the 'gaps', 'expert judgement' is a powerful tool, which is much more effective than some managers think (see, e.g., Muxika et al. 2007; Murray et al. 2016).

## 5 Case Studies

Hereafter, we will use four Mediterranean case studies to demonstrate the interest of a comprehensive, social-ecological system-centred approach in the field of environmental management and the sustainability of fisheries. These case studies are: (i) the salt marshes of Hyères, where the management is mainly species-centred or more specifically bird-centred; (ii) the Biguglia lagoon, a nature reserve, where the conservation should be planned not only at the scale of the lagoon, but also at the scale of the adjacent wetland and the watershed, through an ecosystem-centred and integrated approach; (iii) a coastal pelagic social-ecological system (the Gulf of Lion), where modelling has been developed, within the aim of the sustainable management of fisheries, and (iv) the MPA of the Archipelago of Port-Cros (National Park), where the aim of a social-ecological system-based management process is clearly proclaimed (Fig. 4).

### *5.1 The Salt Marshes of Hyères*

Salt marshes and brackish lagoons are part of an ecological continuum, a functional unit, that corresponds well to the concept of a social-ecological system. Between

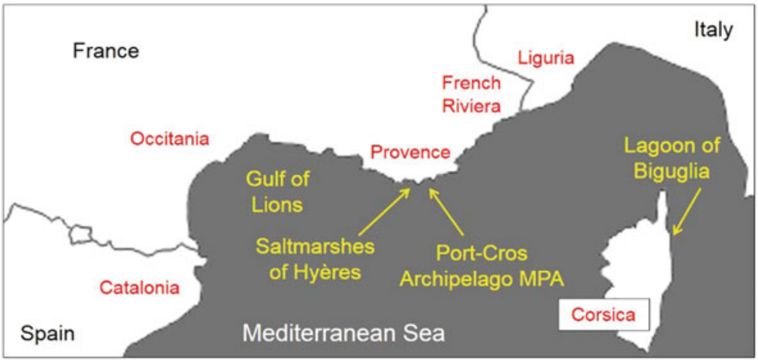


**Fig. 4** Localization of the four case studies: Gulf of Lion (Occitania), salt marshes of Hyères, Port-Cros Archipelago MPA (Provence) and lagoon of Biguglia (Corsica)

the sixteenth century and 1995, the salt marshes of Hyères (Figs. 4 and 5) (900 ha, eastern Provence, France) were profoundly altered by humans for the exploitation of salt, turning them into salt evaporation ponds: ensembles of canals and of shallow pans used to evaporate brine. Evaporation ponds and canals are still in place, so that even after salt production was discontinued, the Hyères salt marshes remain typical of a social-ecological system. Since 2001, the salt marshes of Hyères have belonged to the Conservatoire du littoral (CL), a French public sector organization (inspired by the British private charity National Trust NT; Legrain 2000). The objectives of the CL are not to manage its territories as national parks, nor as natural areas (which would not make sense in the case of the salt marshes of Hyères, which are man-made), but to protect them from urbanization and to make them accessible to the

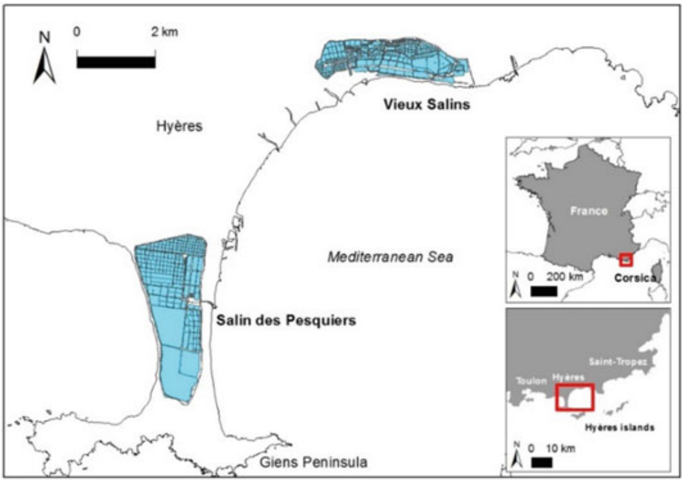


**Fig. 5** Salt marshes of Hyères (Salin des PESQUIERS and Vieux Salins) location

**Fig. 6** Salins des PESQUIERS salt marshes (eastern Provence, France). Left: general view, with a canal. Centre: a lock. Right: the pump that lowers the water level in the pans and discharges the water into the belt canal, and from there into the sea. Photographs © Charles F. Boudouresque

public. These zones are therefore managed on a case-by-case basis, in cooperation with the municipalities (here, Toulon Provence Méditerranée) and local institutions (here, the Port-Cros National Park), without any general doctrine.

In the case of the salt marshes of Hyères (Figs. 4 and 5), the main aims are to conserve the heritage of the salt industry and preserve ‘biodiversity’. Regarding biodiversity, it is clear that management policy is focused on birds, with a vision of biodiversity that is that of the twentieth century: How many species? How many individuals? According to this vision of biodiversity, the more species and the more individuals, the better.

The circulation of water, the management of locks and canals, the water level, everything is mostly managed to favour the maximum number of waterfowl species and to match the specific needs of each of them. A pump has even been built to lower the water level, below the mean sea level, according to the needs of each bird species (Fig. 6). Artificial nests are set up to promote waterfowl reproduction. Since foxes are predators of eggs and waterfowl chicks, chickens have been used as bait, being raised and placed in traps to capture foxes which are then killed. Of course, foxes in particular, but predators in general, are part of a natural ecosystem, but the goal here, otherwise perfectly acceptable, is not to favour the wilderness of the salt marsh ecosystem, but to turn the salt marshes of Hyères into some sort of bird-centred animal park or zoo.

Finally, the rise of the sea level and its consequences have not been considered. During the Last Glacial Maximum (LGM), ~20,000 years ago, the sea level was ~120–130 m below its current level. Since then, it has never stopped rising (Lichter et al. 2010; Faivre et al. 2013). Glacial cycles last about 100,000 years, with oscillations between cold glacial maximum and warm interglacial periods. The interglacial period we are in is not finished. At the end of the last interglacial episodes, the ice cap of Greenland completely melted, which led to a rise of the sea level of 6–9 m above the current one (DeConto and Pollard 2016). So we can expect the same increase to occur within the next millennia (2–3 millennia?), without taking into account any human impact. But greenhouse gases should accelerate this natural rise of the sea level and even aggravate it, with the melting of the Antarctic ice cap. The management strategy for the Hyères salt marshes, which does not take into account their future flooding, may well turn out to be a very short-term strategy. A number of taxa have been studied and monitored. However, no attempt has been made to integrate them into functional compartments within an ecosystem-based approach.

## *5.2 The Biguglia Lagoon*

Biguglia is a shallow, brackish, 1460 ha coastal lagoon located close to Bastia city (Corsica) (Figs. 4 and 7). The lagoon is linked to the Mediterranean Sea through a long natural channel; marine water inputs are limited because the sea channel tends to close (due to the accumulation of sand). It receives freshwater from the rivers draining its 180 $km^2$ watershed and from old artificial channels and pumping stations draining the agricultural plain, sewage plants and rainfall; freshwater inputs dominate the water budget, and lagoon renewal is rapid (Garrido et al. 2016; Pasqualini et al. 2017). Biguglia lagoon was recognized as a very important site for waterfowl and was included in the Ramsar List of wetlands of international importance. This lagoon

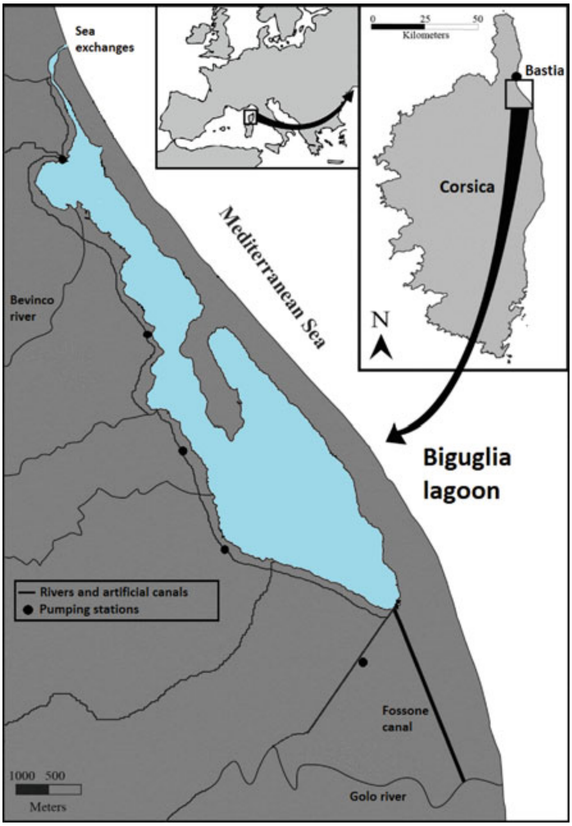


**Fig. 7** Location of Biguglia lagoon (Corsica) with rivers, artificial canals and pumping stations

has been classified as a nature reserve since 1994 and in the EU Natura 2000 network since 2006 (Special Protected Areas of the Bird Directive).

Biguglia lagoon has a single owner (Haute-Corse department) with a specific service dedicated to its management. Since 2006, the whole lagoon area and a small part of the fringing wetlands are no-entry zones with the exception of a small number of artisanal fishers who are allowed in for this traditional use. For 40 years, this confined ecosystem has increasingly been disturbed by eutrophication associated with an intensification of agriculture and an increase in the density of urban settlements in the watershed; the degradation of the water quality in Biguglia lagoon is reflected by a shift from a dominance of aquatic magnoliophytes in the 1970s to varying dominance of phytoplankton and opportunistic macroalgae in the early 2000s (Souchu et al. 2010; Pasqualini et al. 2017).

The deterioration of the water quality led the managers of the Biguglia lagoon nature reserve to take action to improve the water quality; however, this has resulted in the progressive desalination of the lagoon, with in particular the marked development of freshwater species. Similarly, the alterations in the ecosystem have drastically facilitated the successful installation of opportunistic and invasive organisms, such as the phytoplankton *Prorocentrum minimum* and the ctenophore *Mnemiopsis leidyi* (Cecchi et al. 2016; Garrido et al. 2016). Such management actions can weaken the entire ecosystem and have a significant impact on fish resources and bird populations, which play a key role in the conservation of the lagoon. Ecological restoration efforts undertaken to improve the hydraulic management of the nature reserve must be accompanied by the reduction of nutrient inputs in the watershed, calling for a perspective of the regional and local authorities that goes beyond the boundaries of the lagoon nature reserve to include the adjacent salt marsh and the watershed. In addition, lagoon conservation requires an integrated and multidisciplinary approach where the natural and social scientists work together (Robert et al. 2015).

## *5.3 The Gulf of Lion*

The Gulf of Lion (GOL) is an important feeding area for many fish, seabird and marine mammal species (Fig. 4). It is a highly productive system because of high nutrient inputs coming mainly from the Rhone River, upwelling activity, bottom morphology and water circulation (Agostini and Bakun 2002; Petrenko et al. 2005; Hu et al. 2009). Many fish species of commercial interest have been intensively exploited on the GOL continental shelf for decades by the French and Spanish fleets, using multispecies gear such as trawl nets, purse seines and gillnets (Farrugio et al. 1993).

Current analyses of the status of Mediterranean marine ecosystems suggest that most demersal and pelagic fish stocks are fully exploited or overexploited (Papaconstantinou and Farrugio 2000). Fishing is one of the major drivers of ecosystem alteration in coastal areas (Jackson et al. 2001). It has various kinds of direct and indirect impact that interact with the impact produced by changes in natural and anthropogenic oceanographic features and disturbances (Hall 1999; Christensen et al. 2003). The achievement of effective marine ecosystem-based management implies the regulation of the use of the living resources based on the understanding of the structure and dynamics of the ecosystem of which the resource is a part. Ecosystem modelling has been proposed as a tool to inform management decision making for marine fisheries (Cochrane and De Young 2008). Ecosystem models facilitate the analyses of ecosystem structure and functioning. For a long time, fisheries have been gradually replacing top predators, e.g. sharks (Ferretti et al. 2008). In the GOL, fishery impact analysis is particularly difficult as there are many types of gear catching many species. The effects of fishing gear are complex, according to the number of target and accessory species and the catch biomass (Bănaru et al. 2013). The highest impact on ecosystem functioning is caused by large benthic trawls.

Multiple controls (bottom-up, wasp-waist, top-down) interact in marine ecosystems, and only an ecosystem approach may highlight their complex effects. Fisheries have a higher top-down effect on the system's vitality, resilience and organization, and finally ecosystem health, than pollution and terrestrial inputs from agricultural activities discharged by river inputs. Fishery impact on the ecosystem should be related to socio-economic activities as fishers are a usual predator, in the framework of a social-ecological system, and the factors related to socio-economic constraints (market fish price, fuel price, international exchanges, competition from recreational fisheries and illegal fisheries, regulations, etc.) may not be predicted by ecological models alone. In addition, the problem is made more complex by the fact that most of the coastal species have their productivity reduced by the deterioration of the marine environment, so that the solution is not a sectoral management system with only fishery regulation, but also an improvement of the quality of coastal ecosystems (Patrick Prouzet, pers. comm.).

## *5.4 The Port-Cros Archipelago*

The Port-Cros National Park (PCNP) was established in 1963 in eastern Provence (France) (Figs. 4 and 8). It was the second marine and terrestrial national park in Europe, only preceded by the Mljet National Park, in Croatia. Originally, the PCNP, with its marine protected area (~1300 ha), was restricted to the Port-Cros Archipelago, ~8 km off the eastern Provence mainland (France) (Barcelo and Boudouresque 2012; Astruch et al. 2018). Subsequently, the PCNP was given the responsibility for managing a variety of island (e.g. Porquerolles Island), mainland (e.g. Cap Lardier) and marine (e.g. the Pelagos sanctuary for marine mammals) territories (Barcelo and Boudouresque 2012; Barcelo et al. 2013). Finally, a reform substantially modified the status of French national parks (Law of 14 April 2006), involving an innovative approach to governance and management, with a more effective balance between protection of the environment and sustainable development and a more important role for the local authorities. Since 2012, the PCNP has been then strongly extended; the new Port-Cros National Park (N-PCNP) includes two

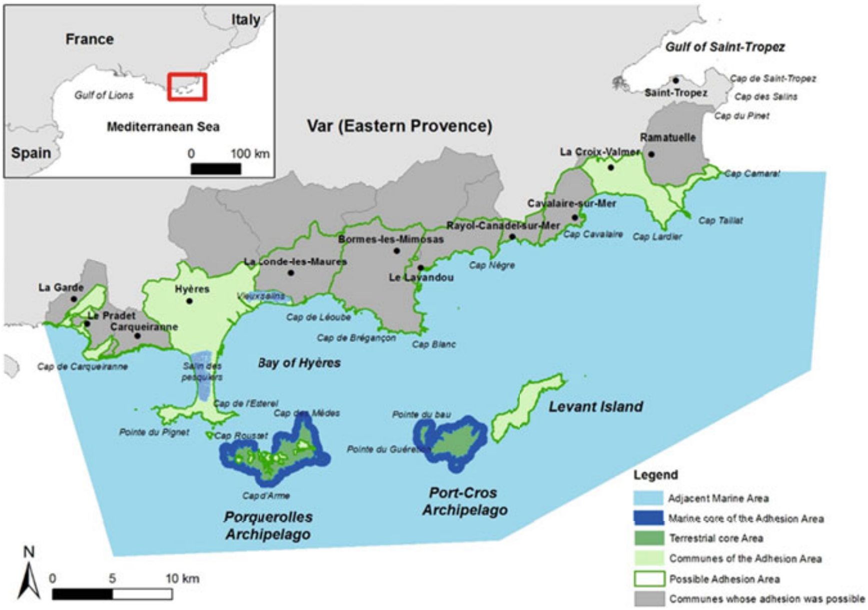


**Fig. 8** Port-Cros National Park (PCNP; 1963–2012), restricted to the Port-Cros Archipelago MPA, and the New Port-Cros National Park (N-PCNP), between La Garde and Ramatuelle, established between 2012 and 2016. © Adrien Goujard

core-protected areas, the Port-Cros Archipelago and the Porquerolles Archipelago (both terrestrial and marine), a terrestrial adhesion area (AA, buffer zone) and a vast adjacent marine area (AMA, buffer zone) (Fig. 8; Hogg et al. 2016; Astruch et al. 2018).

Within the Port-Cros Archipelago MPA, the legislation is strictly respected, in contrast to the vast majority of Mediterranean MPAs, which are ‘paper parks’, the announced regulations being in no way enforced (Sala et al. 2012; Meinesz and Blanfuné 2015). During the first decades following its establishment, the management of the PCNP was focused on iconic species, such as the seagrass *Posidonia oceanica* (Fig. 2), the giant mollusc *Pinna nobilis* and the teleosts *Epinephelus marginatus* (Fig. 1) and *Sciaena umbra* (Harmelin et al. 2007; Harmelin and Ruitton 2007; Astruch et al. 2012; Rouanet et al. 2015). Subsequently, an original management system, the so-called Multi-Use Management (MUM), was implemented gradually, based on a social-ecological system approach. In contrast to most MPAs, which are based on the dichotomy between areas where all fishing is prohibited (no-take zones, NTZs; the core area) and areas where the ‘ordinary’ legislation of the country is implemented (the buffer zone), artisanal fishing is not only authorized but even welcomed (Boudouresque et al. 2004; Cadiou et al. 2009; Astruch et al. 2018). The Port-Cros Archipelago MPA is characterized by a complex zoning system, to avoid user conflicts involving different human activities, while making them compatible with healthy ecosystems close to what is supposed to be ‘pristine’ (the baseline); for example, trawling, spear fishing and recreational fishing have been banned, while artisanal fishing was allowed, provided it fell within a restrictive framework (fishing charter, mesh size of nets, length of nets, size of boats, etc.), adjusted each year and intended to adjust catches, stock and quality of ecosystems (Boudouresque et al. 2004; Cadiou et al. 2009; Boudouresque et al. 2013; Barcelo et al. 2013; Astruch et al. 2018). Overall, the management of the marine part of the PCNP nowadays is quite in phase with a social-ecological system approach.

## 6 Conclusion

In the past, only physical, chemical, biogeochemical and microbiological variables were considered to measure the status of the marine environment in EU marine waters. They were assessed in isolation and set against thresholds; if the values were below the thresholds, the state of the environment was regarded as very good or good. However, as stressed by Boero (2016), these stressors can act in synergy: all values can be below thresholds, but acting together, they might alter the functioning of the ecosystem. The Marine Strategy Framework Directive (MSFD) of the EU corresponds to the ecosystem-centred revolution; the Good Environment Status (GES) is assessed on the basis of the state of biodiversity and ecosystem functioning. Most of the eleven descriptors prescribe that each of them should not impair the functioning of ecosystems (Boero 2016).

It is important to emphasize that the three approaches: the human-centred approach, the species-centred approach and the ecosystem-centred approach, are not contradictory, but complementary. Over time, they accumulate and they operate in parallel, rather than replacing each other. In the same way, the radio did not replace printed documents, television did not eliminate the radio and the Internet did not eliminate printed documents, radio and television. In addition, the ecosystem approach cannot exist without knowledge of the species. As far as the knowledge of the species is concerned, it cannot exist without the specialists of taxa (fish, birds, crustaceans, etc.), because nobody today can master the whole of the taxonomy of the living world. In this sense, the current decline, some say extinction, of taxonomists, is a central problem in ecology (Boero 2010; Hutchings 2018).

The ecosystem approach has become, within a few years, a trendy concept (Ostrom 2009). Dozens of publications mention it, implicitly or explicitly: an ecosystem-based approach to fisheries, an ecosystem-based approach to management, etc. Yet, reading some of these works, one wonders where the ecosystem is? The ecosystem approach is simply an imprecation, a kind of conceptual umbrella, a magic word. The same can be said of the social-ecological system approach. It is time today to give real meaning to the ecosystem-based approach and more particularly to the social-ecological system-based approach.

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# Effects of Ground Uplift, Construction of an Artificial Tidal Flat and Tsunami Seawalls on Marine Life and Local Residents Following the 2011 Great East Japan Earthquake

**Kenji Okoshi**

**Abstract** Eight years have passed since the Great East Japan Earthquake occurred. I divided the process of the earthquake into four main events—the initial earthquake including liquefaction, subsequent tsunamis, land subsidence and ground uplift—and examined the impact of each event on marine life. Under the influence of ground subsidence, the young oysters born in the summer of 2011 were attached 50 cm or more above where the parent generation was attached. However, in 2016, due to the influence of the subsequent ground uplift, oysters attached to the top of the rock began to die. Mass colonization of Manila clams occurred after the artificial tidal flat was created and the clam fishing industry was reopened. The new seawalls were constructed seaward of the previous seawalls; thus, the overall area of the tidal flat decreased. High seawalls also break the continuity of nature between land and sea. Plans are underway to separate the industrial area and the residential area bordering the seawall. From the point of view of disaster prevention, a high seawall is necessary, but it will cause great damage to tourism and residents' lifestyles because the sea is hardly visible. In addition to population decline and aging, revitalizing the industry after construction of the seawall is a very difficult task. Finally, I briefly discuss the differences in response to disaster prevention by comparing cases in Asia and Europe with those in Japan.

**Keywords** Mollusk · Oyster · Clam · Earthquake · Uplift · Artificial tidal flat · Tsunami · Seawall

## 1 Introduction

Eight years have passed since the Great East Japan Earthquake occurred on March 11, 2011 (Ozaki 2015). In my previous papers, I divided the earthquake process into three main events—the initial earthquake including liquefaction, subsequent tsunamis and land subsidence (Okoshi 2015, 2016)—and examined the impact of each event on

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marine life and local residents. However, the ground has recently experienced uplift. Around Oshika Peninsula at Ishinomaki, Miyagi Prefecture, northern Japan, land had risen by about 50 cm by 2019 (Geographical Survey Institute Japan, 2019). This value corresponds to half of the subsidence. Therefore, ground uplift has become a fourth event arising from the earthquake, and it will have an effect on marine organisms. In addition, land reclamation and the construction of seawalls have continued, affecting marine life, coastal residents and local industries. For instance, in Mangoku-ura Lagoon in Ishinomaki near Oshika Peninsula, clam fishing became impossible after the earthquake because the clam fishing ground subsided. Therefore, sediment was poured into the sea to raise the clam fishing ground. The artificial tidal flat was partially completed in 2013. Several years after the earthquake, it is necessary to study the effects of ground elevation changes and artificial structures rather than the effects of the initial tsunamis (Suzuki 2011; Miura et al. 2012; Okoshi 2012a, b; Seike et al. 2013; Takami et al. 2013; Urabe et al. 2013; Kanaya et al. 2014; Okoshi 2015, 2016).

In this paper, I focus primarily on the effects of ground uplift on oysters, the new recruitment of clams in the artificial tidal flats and the resumption of clam fishing. Then, I describe the high seawall constructed on the coast of the Tohoku district in comparison with the previous seawall. Finally, I also briefly discuss the differences in response to disaster prevention by comparing cases in Asia and Europe with those in Japan.

## 2 Influence of Ground Uplift on Oysters

Land subsidence results in a downward displacement of the intertidal zone. It is unclear how the sudden occurrence of land subsidence damages marine organisms, but organisms adapted to living within specific vertical zones are disrupted by such changes. At Oshika Peninsula, the land subsided as much as 1 m due to the earthquake. At Mangoku-ura Lagoon near Oshika Peninsula, land subsidence of ~80 cm was observed after the earthquake, and the intertidal zone was shifted to the subtidal zone. I examined species that have disappeared and those that have successfully colonized the transition area of Mangoku-ura Lagoon in the eight years after the earthquake. My observations showed that the ecological effects of land subsidence varied among species and locations. As expected, the impact of land subsidence was more severe for sessile organisms compared with mobile organisms (Okoshi 2016). Although many bivalves were damaged by liquefaction and tsunamis (Okoshi 2012a, b, 2015, 2016), recruitment of juveniles was observed after July 2011 within the tidal zone of the Mangoku-ura Lagoon. Typically, larval oysters are known to attach to the parental adhesion layer on intertidal rocky shores. Due to land subsidence, rocks and some of the roots and trunks of cedar trees that originally grew along the coastline sank under the seawater level were used as settlement substrata by larval oysters and barnacles (Okoshi 2016). Accordingly, although adult oysters found within the subtidal zone had originally occupied the intertidal zone, juvenile oysters have been able to colonize substrates that were originally supratidal and/or land. Thus, adult and juvenile oysters exhibited an unusual separated distribution in the growing season of 2011. We selected one rock on Setojima Island in Mangoku-ura Lagoon and observed in detail the recruitment, growth and death of oysters attached to it from 2011 (Okoshi 2016). Details will be given in a separate report (Okoshi 2016; Okoshi et al. submitted), but in September 2011, new juveniles were observed on the rock (Fig. 1; Okoshi 2016). The oysters born before 2011 continue to grow in the subtidal zone around Setojima Island. Because the settlement position of the parent oysters born before 2011 and the oysters born after 2011 was different by 80 cm to 1 m due to ground subsidence, their distributions did not overlap. The newly attached oysters grew steadily, and the oyster coverage on the rock surface increased (Fig. 1). However, since 2016, oysters attached to the upper part of the rock have begun to die (Fig. 1).

This phenomenon was common across the whole Ohama area, including Setojima Island. Figure 2 shows the data on ground subsidence and uplift after the earthquake in the Tohoku region, published by the Geographical Survey Institute Japan. It was found that a 50-cm uplift had occurred in the area around Mangoku-ura Lagoon by

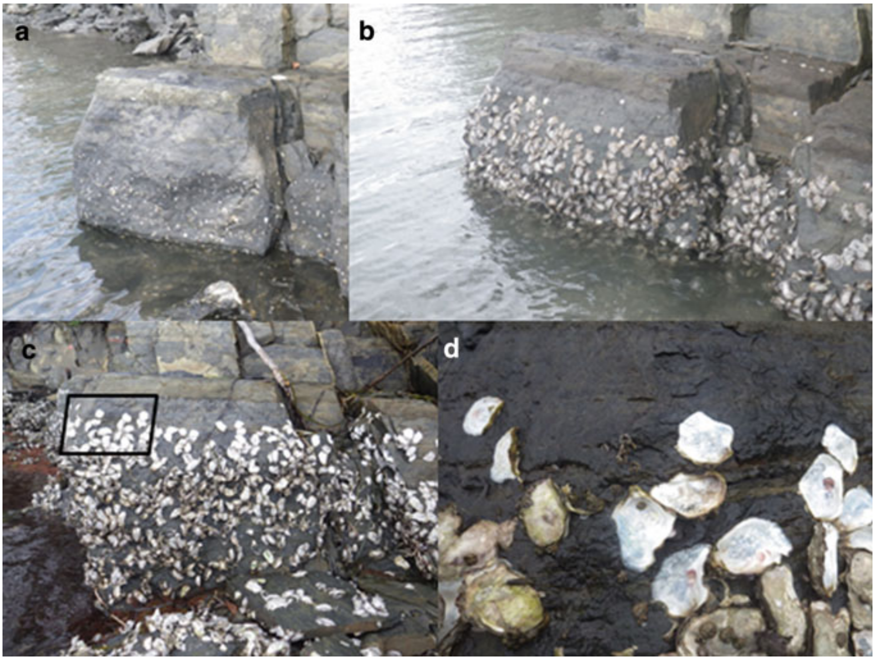


**Fig. 1** **a** Newly attached spat oysters (white dots on the rock) in September 2011. **b** The oyster coverage on the rock surface increased in September 2012. **c** Rock surface in September 2016. Some of the oysters attached to the top of the rock died, the right valve disappears and only the white left valve is visible. **d** Higher magnification of the frame in (**c**). The attached position of dead individuals was limited to the upper part of the rock in 2016

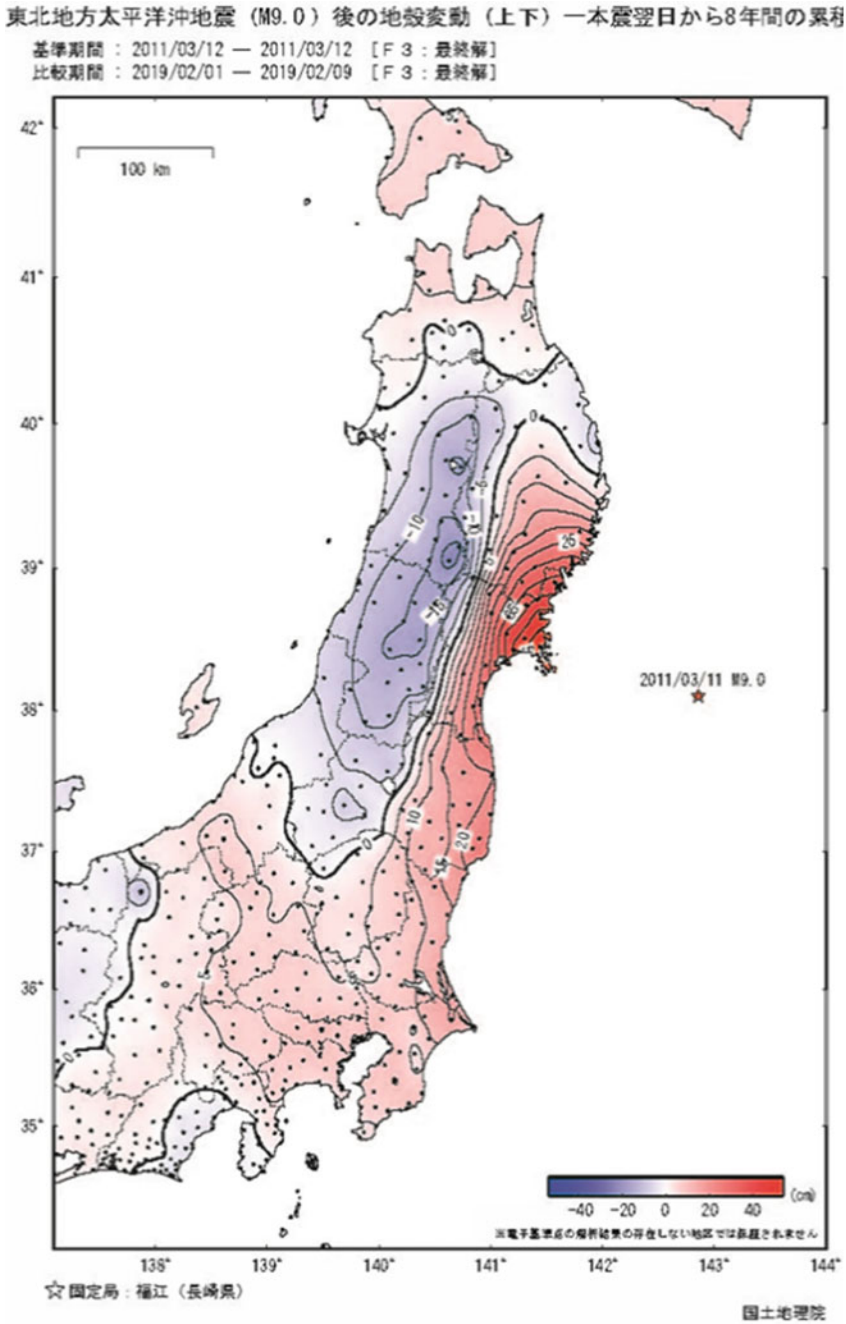


**Fig. 2** Crustal deformation during the 2011 Tohoku earthquake. Up (red) and down (purple) fluctuations accumulated for eight years from the day after the earthquake. https://www.gsi.go.jp/common/000211359.pdf

2019 (Geographical Survey Institute Japan, 2019). It is presumed that the death of individual oysters on the upper area of the rock is due to the increase in the ebb time at low tide because of ground uplift. If the uplift continues, new juveniles on the upper part of the rock will disappear, and the number of dead individuals will increase in the upper part compared with the lower part. Continuous monitoring is needed to determine the fate of individuals growing on the new substrata.

## 3 Clam Fishing in the Artificial Tidal Flat

In Mangoku-ura Lagoon, sediments from the mountains have been added artificially to the seafloor since October 2013 to maintain a shallow littoral zone and create tidal flats, where the Manila clam *Ruditapes philippinarum* population could colonize and develop (Okoshi 2015, 2016). Mass colonization of Manila clams, which are an important fishery resource for fishermen, occurred after creating the artificial tidal flat. We examined population dynamics such as the growth and survival of clams on the artificial tidal flat and provided the information to the fishermen's cooperative association (Okoshi 2018). The fishermen's cooperative association decided the opening day of the clam fishery based on our information. The news of the first catch of clams in the artificial tidal flat after the earthquake was on the front page of two local newspapers in May 2017 (Fig. 3) and was also reported on the NHK news. *Laguncula pulchella* (formally known as *Euspira fortunei*), a clam-eating alien mollusk (Okoshi 2004; Okoshi and Sato-Okoshi 2011; Suzuki and Okoshi 2018), was also found in the artificial tidal flats. In addition, a mat formation of the zebra mussel *Musculista senhousia* was found. The fishermen's cooperative continuously removes alien moon snail, seaweed and zebra mussel that have colonized the tidal flat surface. For a sustainable clam fishery, continuous environmental management and clam resource management are required (Okoshi 2018).

## 4 Effects of Man-Made Structures on Coastal Ecosystems and Coastal Residents

The construction of tsunami seawalls has begun along the Pacific coast of the Tohoku region. For example, new seawalls have been created by reclaiming the shoreline of Matsukawa-ura Lagoon in Fukushima Prefecture (Okoshi 2016). It is common for the new seawalls to be higher and wider than the previous ones. Seawalls around the Udagawa Estuary, which flows into the Matsukawa-ura Lagoon, are larger than before. The new seawalls have been constructed on the seaward side of the previously existing seawalls; thus the area of the tidal flat around the Udagawa river mouth has decreased. The reed beds that were once there have almost gone. The tidal area was infilled to a width of ~30 m around the mouth of the Tsugaruishi River in Miyako City,


**Fig. 3** First fishery of Manila clams after the earthquake at the artificial tidal flat in May 2017. The two local newspapers both reported on the front page

Iwate Prefecture (Fig. 4). Ten-meter-plus seawalls are not rare in this region. In the Taro area, in Miyako City, a 14.7 m high tsunami breakwater has been constructed. This blocks local residents' view of the sea unless they go up to the hill. In this area, plans are underway to separate the industrial area and the residential area bordering the seawall (Fig. 5). Before the earthquake, houses and shops were located near the beach. It has been proposed to site daytime working locations on the seaward side of the seawall and has residents return to the residential area on higher ground after work is completed (Fig. 5). There will be no people on the beach at night. Construction of evacuation routes in case of emergencies is also being carried out. The seawalls to be maintained in Iwate, Miyagi and Fukushima prefectures total 400 km, at about 600 locations, of which the sections that are 10 m or more in height span 50 km. The total cost of the seawall construction is estimated to be approximately 1 trillion yen.[1]

There is a precedent for similar seawall construction in Japan. A magnitude 7.7 earthquake occurred in 1993 near Okushiri Island, southwest of Hokkaido, northern Japan. The Aonae area on Okushiri Island was devastated by the tsunamis and fire. After the earthquake, seawalls were constructed on the coastal side of the road that goes around the island. Before the earthquake, coastal vegetation was continuous until the beach. After constructing the tsunami seawalls, there was no vegetation

[1] 82,000,000 euros or 92,000,000 US $.

**Fig. 4** A huge seawall constructed in Miyako, Iwate Prefecture. The tidal land area was infilled to a width of 10–30 m

at all on the coastal side of the seawalls (Okoshi 2015). High seawalls break the continuity of nature from land to sea. At the Aonae fishing port, the Bokai Bridge ("Bokai" means "seeing the sea") was built for emergency evacuation. This bridge also serves as a parking lot and an event plaza. Twenty-five years after the earthquake, the key fisheries industry is decreasing, and the tourism industry, which was growing before the earthquake, is now flat. When I visited the Bokai Bridge, there were no people in the fishing port, and there were no cars in the parking lot (Fig. 6).

Rishiri Island and Rebun Island located north of Okushiri Island, which were designated as a national park, have two to three times as many tourists as Okushiri Island. These two islands have not been affected by major earthquakes or tsunamis, and the high seawalls have not been extended to the coastline. From the viewpoint of disaster prevention, a high seawall is necessary, but it will cause great damage to tourism and affect residents' lifestyles as the sea is hardly visible. The core industries of the towns along the coast of the Tohoku district are fisheries and tourism similar to Okushiri Island. In addition to population decline and aging, revitalizing the industry after the construction of the seawall is a very difficult task, which leads to the question: what does the seawall protect? Given these significant natural and artificial alterations to the coastline of northern Japan, long-term monitoring is needed to evaluate the continuing changes that are expected following earthquake events. Such information is important to monitor the health of marine communities and the lifestyle of coastal residents along the coast of northeast Japan (Okoshi 2016).


**Fig. 5** Taro area in Miyako City, where a 14.7 m high tsunami breakwater has been constructed. Work activities will be carried out on the seaward side of the seawall during the day, and workers will return to the landward side of the seawall at night

## 5 Concept of Earthquake and Tsunami Disaster Prevention in Japan and Elsewhere in the World

The Great Sumatra–Andaman Earthquake occurred in December 2004 (Lay et al. 2005). The parts of Thailand and Indonesia facing the Andaman Sea were heavily damaged. The tsunamis in the Andaman Sea had a major impact on tropical reef organisms, while the earthquake in Japan had an impact on temperate species, but reports on the impact of earthquakes and tsunamis that occurred six years prior to the Great East Japan Earthquake on the coastal environment and marine life are very useful precedents. We are exchanging information and collaborating with Thai researchers. We also visited Thailand and attended a joint symposium and survey of the Andaman Sea coast where tsunamis occurred. During the joint survey, we aimed to clarify the differences and commonalities between the reef area and the rias coast area. A survey of the Phang-Nga coast in 2017 confirmed that large chunks of coral, moved by the tsunamis from the outer edge of the reef, were numerous in the shallow lagoon (Fig. 7).

Fifteen years after the Indian Ocean earthquake and tsunamis, land plants have not yet grown on the tops of coral clumps struck by the tsunamis (Fig. 7). In Japan, it is known that a large tsunami in Meiwa occurred in 1771 in the Nansei Islands area.

**Fig. 6** Bokai Bridge built for tsunami emergency evacuation in Okushiri Island after the earthquake and tsunamis in 1993

At that time, as in the case of the Indian Ocean earthquake, large chunks of coral were moved not only into the lagoon, but also onto land. Even after 250 years, many coral blocks (commonly known as "tsunami stones") are seen on Miyakojima Island, as shown in Fig. 7. Land plants are growing on some of the large coral outcrops that were struck. The case of Miyakojima Island indicates that it may take a long time for corals to weather and to deposit sediments in coral hollows, and it serves as a reference for estimating future changes in Thailand. In the case of the tsunamis in Japan in 2011, there have been cases where small rocks with creatures living in the subtidal zone have been damaged (Okoshi 2012), but no large rocks of several meters have been moved. It is necessary to examine whether the coral is lighter than the rock, or whether the movement is due to the steeply deepening coastal structure of the rias coast.

The difference between the two countries is clearly seen in the seawalls built after the earthquake. In Thailand, instead of creating tsunami seawalls, tsunami evacuation towers were built along the coast of the Andaman Sea (Fig. 8). Buddha statues and monuments describing the victims of the tsunamis were also built on the beach (Fig. 8). There have been few major earthquakes in countries in Europe. Because of its exposed northern mid-Atlantic location, morphology and plate tectonics setting, the Azores Archipelago off the coast of Portugal is highly vulnerable to tsunami hazards (Andrade et al. 2006). The Azores are known as a tourist destination, but there are

**Fig. 7** Massive coral boulders moved by the 2004 Indian Ocean earthquake and tsunamis at Phang-Nga coast in Thailand (upper) and by the 1771 Meiwa earthquake and tsunamis at Miyako Island in Okinawa, Japan (lower). Land plants were growing on some of the large chunks of coral that had been damaged in Miyako Island. There were no land plants at all on the coral stones in Thailand

no tsunami seawalls on the coast, and facilities for tourists such as boardwalks have been created, while tsunami hazard maps are used to prepare for disasters (Andrade et al. 2006). In the United Kingdom and France, there is almost no large tsunami, but there is a large amount of coastal erosion caused by strong storms. Coastline conservation is a growing problem in these areas. The basic idea of coastal erosion in the UK is that it is impossible to protect all coastal erosion. Therefore, it is important to make effective use of the limited budget and create a system for making decisions. There has never been a tsunami in Arcachon Bay in France, but there are various stakeholders such as tourism, oyster farming and villa owners (Okoshi et al. 1992). Consensus building in the case of building something on the beach is often difficult in France. The institutional framework for coastal zone management in France has progressed considerably in the 1990s through the development of Integrated Coastal Zone Management (ICZM) strategies in the European Union (Deboudt et al. 2008). In Japan, where natural disasters occur frequently, the idea that land conservation and protection of human lives are the top priority is the mainstream. Under the three slogans of disaster prevention, disaster reduction and land resilience, the Japanese government has significantly increased its budget to maintain the functions of important infrastructure that protects and supports life, economy and living in the event of


**Fig. 8** Evacuation route, evacuation tower, buddha statues and monuments describing the victims of the tsunamis at Phang-Naga coast in Thailand in 2017

a disaster. When large cities such as Tokyo and Osaka become sites of earthquake and tsunami disasters in the future, it will be extremely difficult to reach agreement on the types and priorities of reconstruction projects with many stakeholders.

## 6 Creation of "Tsunami Biology"

Earthquakes and tsunamis associated with earthquakes occur all over the world. However, large earthquakes such as the Great East Japan Earthquake occur only once every several hundred years; thus, there has been no accumulation of scientific knowledge so far. The recent earthquakes and tsunamis in Thailand and Japan have increased our knowledge of the effects on coastal life. In 2020, ten years after the earthquake and tsunamis, major research projects will be completed, and many researchers will leave the Tohoku area. It is important to summarize what we have understood, what is still unexplained and what to look for when the next earthquake comes. Most approaches from fields such as physics and geology have been related to earthquakes and tsunamis, but with the accumulation of biological knowledge, I would like to propose that "tsunami biology" be established as one research field.

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# Climate and Culture of Kesen-numa

**Hiroyasu Yamauchi**

**Abstract** People in Kesen-numa area have roots in its native climate since long ago and have lived deeply contacting with the sea. Since the modern age, especially 1945 after the World War II, a human-centric development of coastal zone has been promoted there and changed the relation between local people and the sea greatly. This chapter discusses on the problem that the huge tsunami in 2011 left: an answer to a question on "what is to live with the sea?" from the viewpoint of local people who experienced the East Japan Great Earthquake and also from the viewpoint of a curator who recorded damages by the disaster.

**Keywords** Kesen-numa · Tsunami · Sanriku · Culture · Museum · Curator · East Japan Great Earthquake

## 1 Introduction: Kesen-numa City

Kesen-numa City is located[1] in northeastern Honshu Island, Japanese Archipelago facing the Pacific Ocean (Fig. 1). The Kesen-numa area, at the southern end of the mountainous area continuing from north, is a hill with a narrow flatland. Its coastal area is characterized by rias-type bays with capes and complex coves like sawtooth. Thus, we have very diverse landscapes.

Kesen-numa Bay which is a doorway of Kesen-numa City is a deep bay with a complicated shape. Kesen-numa Oshima Island is situated at the mouth of this bay, close to Karakuwa Peninsula (Fig. 1). Since the island and the cape protect Kesen-numa Bay from the Pacific Ocean, Kesen-numa Bay is very calm. Due to its protected location, Kesen-numa became a leading fishing port in Japan with one of the world's good fishing grounds distributed in offshore waters off Kesen-numa Bay. Catch of skipjack tuna (*Katsuwonus pelamis*) is particularly high there, and most of the catch

[1] Longitude and latitude are 141.6° E and 38.9° N.

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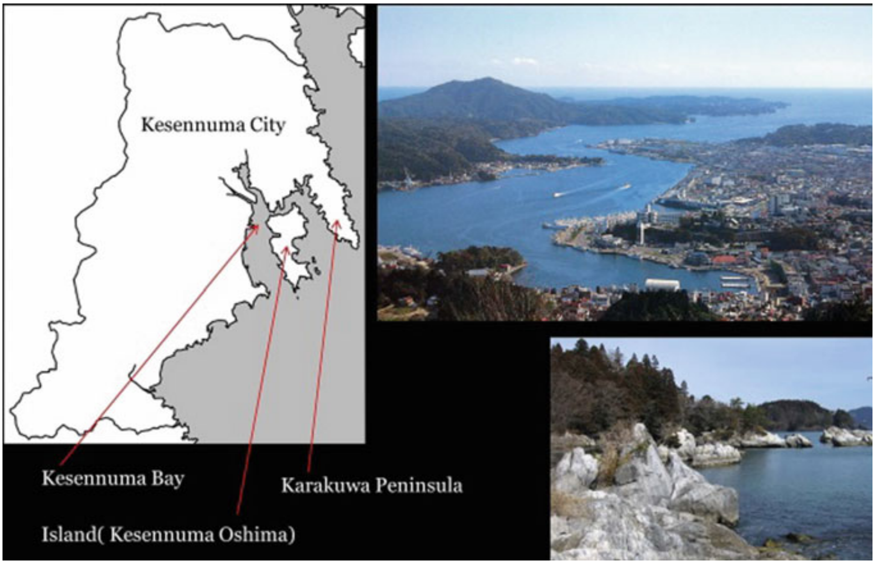


**Fig. 1** Map showing Kesen-numa City, Kesen-numa Bay, Karakuwa, and Kesen-numa Oshima Island (left), picture of Karakuwa (lower right) and Kesen-numa Bay (upper right) and picture of the rocky coast of Kesen-numa Bay

are landed on Kesen-numa fishing harbor (Fig. 2). Aquaculture is spread widely in calm bays and coves (Fig. 2). At present, the population of Kesen-numa City is about 65,370 people. Since about 70% of the population are related to fishing or fishery industries in any way, it can be said that Kesen-numa City cannot live without the sea.

## 2 Nature of Kesen-numa: Its Geography and Climate

In general, an area facing the sea is influenced by the water temperature and humidity of the sea. However, the climate in Kesen-numa area is first influenced by the mountain rather than the sea (Fig. 3).

In most cases, wind blows from the northwest mountainous region. This wind is called "Narai no kaze" (winter monsoon wind from the northwest) in Japanese in Kesen-numa area. In winter, the cold and strong wind transports snow from the mountain (Fig. 3) dancing even during a fine weather. The wind makes Kesen-numa area colder and drier than surrounding areas in winter although Kesen-numa area is along the sea. So, for Kesen-numa area, the mountain is geographically and climatically as important as the sea.

**Fig. 2** Pictures showing the fish market of Kesen-numa Port (upper left), skipjack tuna sold at the market (lower left), cultured oyster (upper right) and buoys of aquaculture facilities in Kesen-numa Bay (lower right)

## 3 Characteristics of Local Culture of Kesen-numa Area

When talking about the culture of Kesen-numa area, the sea is central. However, the sea is the "place to go" for local residents. In other words, the sea is "another world" or "the world on the other side." People do not live on the sea nor under the sea. They come from the mountain as mentioned above.

Kesen-numa area is not suitable for rice cultivation because flatland is narrow. In old ages, people living in Kesen-numa area had been to fishing on the sea and exchanged fish catches for rice as staple food with farmers in inland areas. They had made salt pans utilizing tidal flats and also exchanged salt for rice.

Thanks to wind from the mountain ("Narai no kaze" in Japanese), Kesen-numa developed as a big port since the sailboat period (Fig. 4). A deep and complex cove produces a natural and excellent shelter. In addition, "Narai no kaze" blowing from land to the sea permits sailboats to go easily offshore from the port. During the sailboat period, a good port needed such wind. From this background, traditional culture, "Tora mai" (tiger dance) relating to the tiger who is a god of wind in Japan, has been established in Kesen-numa area (Fig. 5).

The production of shark's fins is representative of food culture developed and established by the wind. In old ages, fishermen used sharks caught as tuna bycatch to

**Fig. 3** Kesen-numa area is mainly influenced by the mountain rather than the sea, especially during winter when the northwest wind blows from the mountain

**Fig. 4** Picture showing old Kesen-numa Port around the 1900s. The port has developed since the sailboat period thanks to wind from the mountain that is "Narai no kaze" blowing from northwest mountain areas

**Fig. 5** Pictures showing traditional culture, “Tora mai” (tiger dance), relating to the tiger who is a god of wind in Japan, has been established in Kesen-numa area

process goods. Knowing the high value of sharks’ fins, they have started to produce them. Dry wind blowing down from the mountain in winter is the best for dry matter production. Therefore, the world’s highest quality shark’s fins began to be produced. Kesen-numa area has originally produced dry matters of fish and shellfish that became important products to support its local economy in winter.

In addition, abundant wood and bamboo materials obtained from the mountains served to produce various things such as boats, fishing gears, and aquaculture rafts indispensable for fisheries and aquaculture. Moreover, firewood and charcoal from the mountains near Kesen-numa area were used to make salt, conserve fish and process them.

Long ago, people in Kesen-numa were used to live with what existed there, caring for their natural resources they lived upon. However, such a life began to change from just over 100 years ago. And, in 2011, it was quite different from what it was then.

## 4 Relationship Between Tsunami and Local Culture Till 2011

Since the end of the World War II in 1945, Japan has changed in a completely different country. Thought, culture, industry, education changed deeply, as the environment.

**Fig. 6** Pictures showing landscapes before the end of World War II (upper pictures) and those in recent years (lower pictures)

Among them, topographic and landscape changes due to exploitation for industrial development are remarkable (Fig. 6). The relationship between people and nature built by the predecessors for hundreds of years has changed thoroughly.

The offshore area of Kesen-numa is one of the most exposed areas to earthquakes in the world. Once a big earthquake occurs there, it always generates massive tsunamis. Kesen-numa area is a place hit by massive tsunamis once in about 40 years on average and is inseparable from a disaster. The coast, which forms a calm inner bay, is an excellent topography for fishing. However, the land topography in front of the ocean and its V-shaped valleys magnify the tsunami damage. The tsunami invading a narrow valley from offshore to coast loses its escape place and increases the height of flooding according to its progress into land. The tsunami that runs up the side of the mountain becomes a receding wave and takes all things to the sea. Such massive tsunami damages have been repeated many times since long ago (Fig. 7).

The Meiji Sanriku Tsunami in 1896 lost approximately 22,000 people with a tsunami wave of more than 10 m high (Fig. 8).

A part of the affected villages was relocated to a hill where the tsunami does not reach. In 1933, again the Showa Sanriku Tsunami struck and lost about 3000 people (Fig. 8). The villages which had been relocated to the hill 37 years ago were safe, but all the villages which did not relocate were swallowed by the tsunami waves (Fig. 8).

**Fig. 7** Block prints of massive tsunami damages in 1896. The tsunami has been repeated many times since long ago

Fishermen who thought "We cannot live away from the sea" again became victims of the tsunami (Fig. 8).

In response to this tsunami damage, the relocation of the villages to the hill was considered again. On the other hand, there were many people who insisted "We still cannot leave the sea." Then, a seawall was built along the coast there. However, everyone knew that the seawall was intended to earn evacuation time and not completely prevent the tsunami.

In 1960, 27 years after the Showa Sanriku Tsunami, the Chile Earthquake Tsunami that occurred off Chile of South America hit the Pacific coast of Japan with a loss of about 140 people throughout Japan. About 100 of them were around Kesen-numa area. There had been a legend "Don't build houses on the ground which was hit by the tsunami in 1933" and a law to prohibit constructing buildings including houses there. However, Japanese Government has promoted a policy to develop industries since 1945 neglecting this wisdom, changing the law, digging the sea, reclaiming the shallow sea, and changing river flows with a pretext for reconstruction of Japan after the World War II. The low land constructed with this policy was damaged by the tsunami of the Chile Earthquake in 1960.

On the other hand, there were less damages by the tsunami of 1960 where coastal seawalls have been constructed after 1933. Based on this experience, many seawalls and water gates against tsunamis have been constructed since then (Fig. 9).

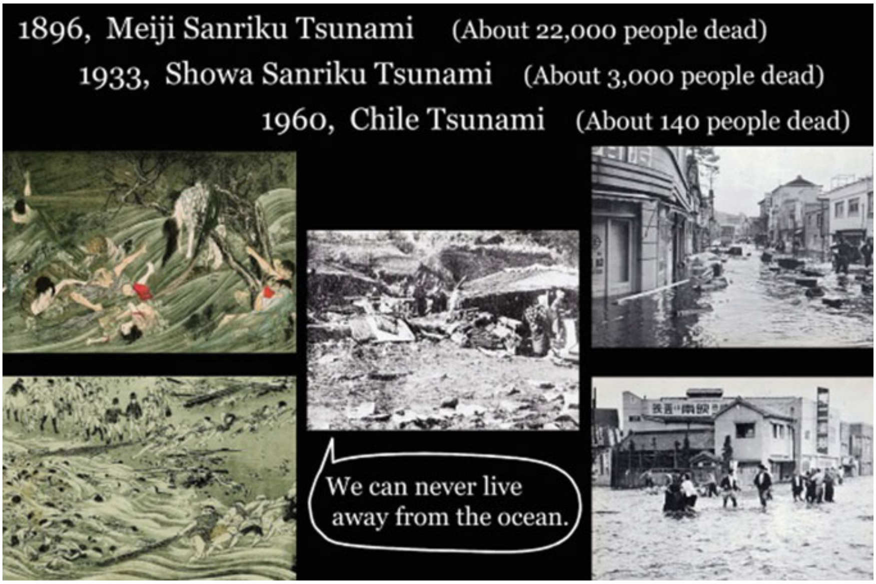


**Fig. 8** History of tsunami disasters in Kesen-numa. Block prints on Meiji Sanriku Tsunami in 1896 (left column), picture on Showa Sanriku Tsunami in 1933 (center column) and pictures on Chile Tsunami in 1960 (right column)

**Fig. 9** Picture showing seawall after the Chile Tsunami in 1960

This was a very good project for constructing public infrastructures. Nevertheless, new seawalls constructed by the project were low and weak against tsunamis.

The tsunami of 1896 was greater than 10 m high. Seawalls that were constructed since 1933 were designed to resist such tsunamis. Thus, they could stand the tsunami of the Chile Earthquake. On the other hand, seawalls that were constructed after the tsunami of the Chile Earthquake was designed to resist tsunamis with a height of 3 m because the height of its tsunami was 3 m. Residents who did not know past tsunamis started to live believing and depending on feeble seawalls that were constructed on the ground hit by the tsunami with a height greater than 10 m to resist tsunamis with heights smaller than one-third of that of 1896. It was the first step of residents' mistake.

Since then, sand beach and tidal flats have been reclaimed to enlarge a flat-land for industries and houses under the wrong conviction that safety for life was achieved only by construction of seawalls. Shallow sea bottom areas in bays were channeled, and docks were constructed for landing of big ships. Tidal currents entering and exiting the bay have changed because of waterways and reclamation. Pollution of seawater and habitat loss have led to loss of marine biodiversity in the bay. The coastal ecotone, which is "the intermediate region between land and the sea," composed of a variety of habitats such as beaches, rocky reefs, and tidal flats has nearly been lost (Fig. 10). Then, coastlines consisting of dykes and seawalls made of inorganic concrete have cut off the land from the sea. The cultural relationship with nature that our predecessors built over years and centuries has been destroyed in a short period of time.

**Fig. 10** Picture showing the scenery of Kesen-numa Port and the waterfront built on landfill that have destroyed the coastal ecotone between land and the sea

## 5 How Should We Build the Relationship Between Tsunami and Local Culture? Present Status and Problems

We have looked for “What is not there,” ignoring “What is there,” and created “What should not be there.” The relationship between the sea and the mountain, which used to have a close relationship once, has also collapsed. Wood and bamboo are replaced with metal and plastic. Firewood and charcoal are replaced with oil and electricity. Then, mountain resources are no longer needed.

People of Kesen-numa area, who had lived in the mountains and lived on the sea, became those who now live on landfill and only use the sea. While the number of fishermen has decreased, the number of intermediate buyers and fishery processors has increased. Landing fish and shellfish have become products to be distributed to large cities. Local residents did not see the sea, but they saw only resources obtained from the sea from a viewpoint of the economy. Annual events and entertainment that had passed through generations in the area have also became obsolete. Their necessity and need as a cultural background have gradually been lost.

In 2011, a huge tsunami swallowed the Kesen-numa area that was in such a situation (Fig. 11). Most of the reclaimed land forming the center of the city was devastated. The artificial coastline of the bay collapsed in many places (Fig. 12). There

**Fig. 11** Kesen-numa City swallowed by the tsunami on 11 March 2011

**Fig. 12** Seawalls along the coast of the Kesen-numa Port broken by the tsunami on 11 March 2011

were 1214 deaths and 220 people missing. By now, the population has decreased by about 8120 people.

Today, more than nine years have passed since the occurrence of the tsunami, restoration and reconstruction projects are proceeding in Kesen-numa area. The basic idea of the project is to build larger seawalls and further increase landfill sites. It is done in the same way as before the disaster. There are not a few local residents who are wondering about such a project policy. However, it is inevitable to obey the policy indicated by the government.

## 6 Conclusion: Thinking to Live Together with the Sea Based on a Developmental Idea from Prevention of Disasters to Their Reduction

In 2011, we learned that we should not trust any seawalls built by humans. Although we call out a disaster prevention, we learned that we cannot prevent it. Then we have to accept it. After accepting it, we must consider reductions of its damages and disaster reductions. We do not want to invest a huge expenditure to build bigger seawalls and raise a ground level artificially.

We hope to increase the sound coastal ecotone, the intermediate area between the sea and land which had lost, restore the biodiversity like the past, and regain the rich landscape (Fig. 13). We must reevaluate what is there and what should be there, and review what should not be there. We want to restore the relationship between the sea and the mountain, put ourselves in the cycle of nature, and want to culturally reconstruct the right way of living as a living organism.

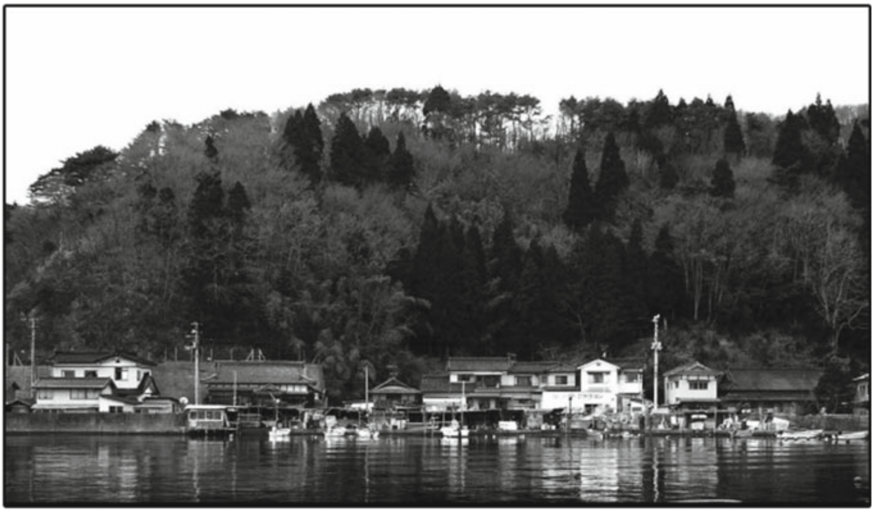

**Fig. 13** Picture indicating people's life with the sound coastal ecotone; the intermediate area between the sea and land which had lost has to be restored to increase the biodiversity like the past and to regain the rich landscape

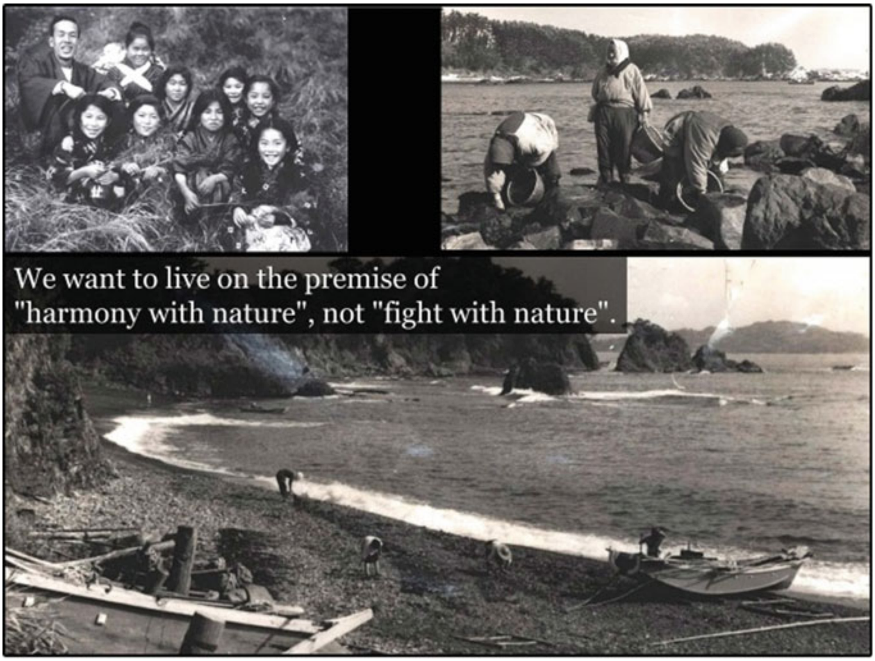


**Fig. 14** Pictures showing life on the premise of harmonious coexistence with nature and accumulate experiences of daily life leading to reductions of disasters, rather than talk about disasters on the premise of a battle against nature

What we must prioritize is regional culture education. How did the predecessors live? What kind of mistakes did we make? We have to learn history and protect our future. I believe that we need to live on the premise of harmonious coexistence with nature and accumulate experiences of daily life leading to reductions of disasters, rather than talk about disasters on the premise of a battle against nature (Fig. 14).

In a few years, the Kesen-numa area will be attacked again by a huge tsunami. It is an inevitable destiny. I am a curator at a museum in such a place. I opened the permanent exhibition summarizing the 2011 tsunami disaster record and the history of the tsunami disaster in the Kesen-numa area at Rias Ark Museum of Art, where I work. Why did the 2011 tsunami cause such damages? I am trying to find the answer not in the scale of the earthquakes and tsunamis, but in the culture and the people's life that have been accumulated. Therefore, I opened the permanent exhibition to share such ideas with local residents (Fig. 15).


**Fig. 15** Pictures showing the permanent exhibition summarizing the 2011 tsunami disaster records and the history of the tsunami disaster in the Kesen-numa area at Rias Ark Museum of Art

We cannot control the nature with the power of human beings. It is impossible to prevent the occurrence of earthquakes and tsunamis (Fig. 16). It is also impossible to jump over huge tsunamis that occur. However, it is possible to change our way of life and way of thinking. I hope to share this idea, “We must change ourselves to protect our future” which we learned from the 2011 tsunami, with people in the world.

**Fig. 16** Symbolized picture on the lesson learned from the disaster by the tsunami on 11 March 2011, "We must change ourselves to protect our future" because we cannot control the nature with the power of human beings

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# Integrated Approaches and Communities Restoration Processes

# Prospects for Practical "*Satoumi*" Implementation for Sustainable Development Goals: Lessons Learnt from the Seto Inland Sea, Japan

**Takehiro Tanaka and Keita Furukawa**

**Abstract** "*Satoumi*" is defined as an enhanced coastal zone in terms of biodiversity and productivity with human interactions. The authors conducted literature surveys, hearings with local people, and organized their governmental work experiences as fisheries, port and harbor, and ocean policy experts. The results were used to reveal a basic framework of fishery rights and management rights of foreshore areas. Hinase, at Bizen city, Okayama prefecture, in Japan is known as the leading "*Satoumi*" case study site; it was studied from the perspective of its history and progress with insights on the integration of industries and services with fisheries (called the 6th industrialization), eelgrass bed restoration, and establishment of governance. Throughout the study, key issues to implementing "*Satoumi*" was organized and discussed. Furthermore, a proposal for designing a support mechanism for "*Satoumi*" implementation regarding global and local contexts was put forward.

**Keywords** *Satoumi* · Integrated coastal management · Sustainable development goals · Coastal-based management

## 1 Introduction

"*Satoumi*" or "*Sato-Umi*" is defined and proposed by Yanagi (1998) as "an enhanced coastal zone in terms of biodiversity and productivity with human interactions." In Japan, *Satoumi* has already been addressed in various ocean policies, e.g. the Basic Act on Ocean Policy (enacted in 2007) and the Basic Plan on Ocean Policy (Cabinet decision made on 15 May 2018). Especially, within the Plan, it is explicitly recommended to "Use '*Sato-Umi*' experience of maintaining high productivity and biodiversity to implement comprehensive management of coastal areas."

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*Satoumi* was born in the Seto Inland Sea and made known to the world at EMECS7 (2006 at Caen, France) as "Sato-Umi." Since the conference, "*Satoumi*" and "*Sato-Umi*" and other related expressions have been standardized as "*Satoumi*," and the first international "*Satoumi* Workshop" was held at EMECS8 (2007 at Shanghai, China). *Satoumi* workshops have been held annually somewhere in the world in succession since then. Thus, *Satoumi* is gaining worldwide recognition. *Satoumi* is considered another example of Integrated Coastal Management (ICM) led by fisheries communities based on their given rights for fishing and management of foreshore areas inherited from ancient times in Japan. It is also thought of as a special strategy for the Ecosystem-Based Approach (EBA), enabling a sustainable Socio-Ecological Balance. Nevertheless, process designs and implementation support mechanisms are not yet explicitly described nor determined.

Furthermore, international concerns for planetary survival resulted in the Sustainable Development Goals (SDGs) at the United Nations High Level Political Forum in 2015. This was followed by an international action plan, the "Call for Action," which was adopted at the UN Ocean Conference in 2017, a world assemblage for implementation of SDG 14: to conserve and sustainably use the oceans, seas and marine resources for sustainable development. Within the Action Plan, ICM is referred to as a tool for local implementation and the importance of "Blue Economy" concept is mentioned by various domestic and international stakeholders (UNSDKP 2014; World Bank 2017; The Economist Intelligence Unit 2015), regional bodies (EU 2014; PEMSEA 2015), at the national level (e.g. Indonesia and FAO 2014), and at the local level (OPRI 2018).

Targets and methods of this manuscript are as follows: At first, developments of Japanese fisheries have been summarized by legislative perspectives by literature survey (Sect. 2). It is followed by a case study at Hinase, Okayama, prefecture based on hearing from stakeholders and authors' experiences as a person in charge at local government, national government and NGOs. The case study was described viewpoints of historical background (Sect. 3), eelgrass restoration (Sect. 4), and *satoumi* governance (Sect. 5). It revealed key issues to implementing "*Satoumi*." Finally, a proposal for designing a support mechanism for "*Satoumi*" implementation regarding global and local contexts was put forward (Sect. 6) to clarify the relation of the *Satoumi* concept, SDGs, and the Blue Economy.

## 2 Japanese Fishery Rights and Management Rights of Foreshore Areas

Japanese fishery rights and the Fisheries Act are rooted in more than 2,000 years of history and tradition, making them unique in the world. While there are many countries and states with Fisheries Acts as their legal basis for securing fishery rights, Japanese fishery rights are based on our unique traditions. In the Edo era (1603–1868), major fishing villages were already settled, and almost all kinds of coastal fisheries were well established. Exclusive ownership of fishing areas and their associated licenses and governance were implemented by each municipality independently. This was based on the *Buke-sho-hatto* (basic rules for samurai families) enacted by the Tokugawa government in the Edo era. It made *Sanya-kaisen-iriai* (the shared use of mountains, fields, seas and rivers) the principle for fisheries administration. The most important part of the rules, *Isowa-netsuki-okiwa-iriai*, specifically stated that reefs are land based and offshore is shared based. It meant that reefs, as coastal fishing grounds, should be used exclusively by the local fishing village; and offshore areas, as beyond local jurisdiction, should be open areas accessible to other fishermen. Furthermore, borders between neighboring villages were determined by extending the village border on land in the offshore direction, making fishery rights borders determined by village borders.

Traditions of local fishing cooperatives managing and determining use of foreshore water areas as their own sea are based on these rules established in the Edo era. They were known as *Isson-senyo-gyojo* (the designated exclusive fishing area for the village) and the villages had *Chisaki-ken* (management rights over foreshore areas). The *Chisaki-ken* has clearly existed in Japanese coastal use up until now; it is well recognized as a management tradition rather than dictation of water surface, and it has the same validity as legislative acts and regulations.

In the Meiji era (1868–1912), government officials of the Department of Fisheries codified the relations between fishing villages and fishermen of the village to sustain the *Isson-senyo-gyojo* in the Fisheries Act (enacted in 1901) based on vast research of villages and complicated negotiations. For example, the *Chisaki-senyou-gyogyouken* (the exclusive fishing rights in the foreshore areas) could not be granted directly to the fishing village because they did not have a body as an objective entity. Thus, fisheries cooperatives were established as corporate entities to be able to grant fishing rights in the Act. Until then, fisheries cooperatives had been only private organizations to preserve order in the fisheries. It made fisheries cooperatives the sole entities to receive exclusive fishing rights for the foreshore fishing area by transforming the tradition of *Isson-senyo-gyojo* to the written right of the *Chisaki-senyou-gyogyouken*.

Traditional knowledge and governance of Japanese fishermen for managing their fishing area is outstanding. Makino (2016) pointed out "Japanese coastal area has been voluntary managed by local fishermen for sustainable use of fishery resources, and it has contributed to conserve bio-diversity as a result." Tsurita (2017) described outstanding points of local fishermen's mechanisms for managing their fishing are as a local common. They (1) define clear boundary of management, (2) manage the area by relevant group's discussion and coordination, (3) monitor it's prosecution, and (4) implement social measures when the case happens. These are based on their vast knowledge and experience with climate, tidal currents, bottom topography, sediment quality, etc. One of their most impressive expressions is, "fisheries are the sea's leftovers." Some in the younger generation object to the word "leftovers," as it implies, they are beggars. Nevertheless, not only fishermen in the Seto Inland Sea, but those in the Pacific and in the Sea of Japan also use the same expression. It expresses their deep appreciation and awe for the sea that made it possible for them to raise their families. These attitudes reflect a stewardship of the sea based on the traditional *Chisaki-ken*, which incubated the thought that "we conserve our fishing area by ourselves" and crystalized an awareness of themselves as "guardians of the sea." There is a high compatibility between this awareness and *Satoumi*, as it is active human interaction that maintains optimal conditions in the sea, which is the reason why *Satoumi* were soon to be found throughout Japanese fisheries communities.[1]

## 3 Historical Background of Fisheries at Hinase-Town

Hinase-town in Bizen City, on the eastern edge of Okayama prefecture, has been recognized as a top runner in *Satoumi* implementation. Hinase extends over a part of the mainland and 13 islands. It is called *Hinase-Sengen-Ryoshimachi* (Hinase as a fishing village with a thousand fishermen's houses). They widely operate fisheries of small vessel bottom trawlers, small set nets, drift gillnets, and oyster culture. Okayama prefecture is ranked the third biggest oyster culture area in Japan in both product volume and value (2015), and Hinase is one of the major contributors.

In the Muromachi era (1338–1573), Hinase developed as a fishing village to supply fish to the major western cities of Kyoto and Osaka. In the Meiji era (1868–1912), 90% of the 830 households in the village worked as fishermen. There was remarkable passion for fisheries among Hinase fishermen. They explored and expanded their fishing area all over the nation, as well as in the seas around the Korean peninsula, Taiwan, Manila, and Singapore from the 1880s. The small set net called "*Tsubo-ami*" is a typical fishing technique invented by Hinase fishermen, and they have broaden the technique many fishing villages throughout the nation.

In 1958, they cultured 400 thousand yellowtail snapper (*Hamachi*), due to their early decision to switch their major fisheries to aquaculture of yellowtail snapper and Japanese pufferfish and the tourist fisheries, as they foresaw the future of inland sea fisheries as a dead-end.

Fish culture and resource management also became an object of their enthusiastic concern. In 1971, they were awarded the 10th Emperor's Prize for Agricultural Festivals for their work on prawn culture. They had been playing an important role as an implementer for the Seto Inland Sea area resource rehabilitation plan for Japanese Spanish mackerel since 2002. They had been leading pilot exercises on net size control, fertile egg discharges, and intermediate breeding.

Since 1967, a locally operated market named "*Gomino-ichi*" has been in operation. It utilizes an operation yard of the Hinase-town fisheries cooperative's auction, and originally targeted local residents. In the late 1970s, however, it shifted its target consumers to tourists from the major western cities of Kyoto, Osaka, and Kobe.

[1]Descriptions on this section based on Japanese literatures e.g. "the History of the Tokyo Inner Harbour Fisheries (Committee for Publishing the History of the Tokyo Inner Habrour Fisheris 1971)" and "the Commentary for Fisheries Act (Kaneda 2017)", and personal communications with local fishermen in various occasions.

Efficient resource use is realized by close communication among market operators who are fishermen’s wives. Furthermore, oyster houses have been set up in “*Michino-eki-Shioji*,” where a direct sales store has become a major tourism draw in the area.

Countermeasures for marine debris that were long implemented in Hinase led to national movements. Since 1982, recovery and treatment of marine debris trapped by bottom trawlers have become established practices. It has co-benefits for resource management in the re-discharge of small fish and maintaining freshness of the catch. Recently, used bamboo rafts for oyster culture have been recycled as bamboo charcoal for the local pottery, “*Bizen-yaki.*” This challenging project was named “*Bizen-yaki* born from Hinase oyster rafts,” and has been implemented with collaboration between fisheries and local pottery artists.

As shown above, the Hinase area has always been a leader and pioneer in environmental conservation of fisheries areas and fisheries resource management, including conservation and restoration. Its collaboration between fisheries and tourism has also made it a prime example for promoting the sixth industrialization.[2]

## 4 Eelgrass Restoration in Hinase Area

Until the 1950s, the coastal area of Okayama prefecture was dominated by tidal flats and seagrass meadows. The area of each ecosystem is 4,100 ha and 4,300 ha, respectively (Fig. 1). It is more than 10% of all the sea area of about 800 $km^2$. It was a perfect hatching ground and nurseries for many kinds of fish and shellfish. 90% of the

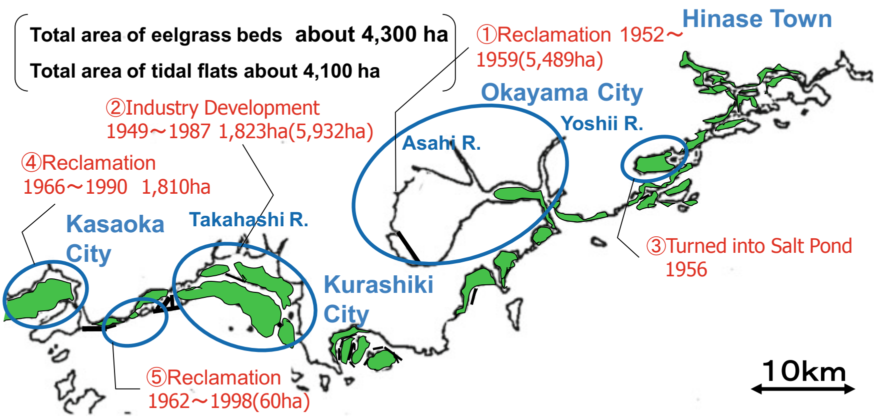


**Fig. 1** Area of eelgrass beds and tidal flats in Okayama prefecture in the 1950s

[2]Descriptions on this section based on hearing and literature search at Hinase-town fisheries cooperative, Bizen city and Okayama prefecture.

area had been lost due to land reclamations, landfills, and water and sediment quality degradation caused by high-growth period in the 1980s. It is Hinase's fishermen who are trying to reverse this situation.

In early summer of 1985, 19 set net fishermen and a few young group members of the Hinase-town fisheries cooperative started eelgrass restoration at three predetermined sites. They took flower shoots carefully from an existing eelgrass bed, kept the seeds until autumn for maturing the seeds, rinsed them again and again in seawater, got 150,000 seeds at last, and sowed them in the sites. The number of sowed sites amounted to 16. Nevertheless, successful restoration of eelgrass was seen in only one site.

Their provisional experiments revealed the effectiveness of sediment remediation by oyster shells. During 1994–1996, they were continuing the restoration project by fishermen sowing the seeds and others carrying out field research for establishing eelgrass restoration techniques. It took 5 years of public–private partnership between researchers and experts to compile the "Technical Guidelines for Eelgrass Bed Restoration," published by the Marino Forum 21 (2001). It was not an easy journey. The members of the project were often delighted at the apparently successful growth of the beds, only to be repeatedly disappointed by their disappearance. In 2005, about 38 ha of stable eelgrass beds had been restored. In 2006, "Guidelines for Utilization of Oyster Shells" was published by Okayama Prefecture (2006), and sediment remediation has since been promoted accordingly. The area of restored eelgrass beds had expanded to about 80 ha in 2008. In 2009, the Hinase Promotion Council for Seagrass Bed Restoration was formed with 83 members of the Hinase-town fisheries cooperative. From 2010 to 2015, the restored area expanded to 250 ha. More than 100 million seeds have been sowed during 30 years of restoration efforts. In 2013, floating breakwaters and artificial reefs were set to stabilize the eelgrass beds and secure calm fields for oyster culture under the infrastructure implementation project (2002–2013 Tobi area regional fisheries ground improvement project). It realized a form of "*Satoumi* with oyster and eelgrass" (Fig. 2).

Furthermore, "Guidelines for holistic sediment rehabilitation by oyster shells" was published in 2013 by Okayama Prefecture (2013), and the project for improvement of biodiversity including deeper areas was started in 2015. Oyster shells can be a potential habitat for benthic and sessile animals. The project was facilitated using mosaics of oyster shell beds in areas of more than 10 m depth. They became habitats for small size fauna. The incubation of these animals can be the starting point of a detritus food web, continuing on to a higher-order food web. These links will help to achieve "implementation of smooth, sustainable and firm material circulation" in the field.

The eelgrass habitat restoration work that had been implemented solely by fishermen expanded in 2012 when the general public joined the activities. Since 2013, about 200 local Hinase junior high school students have joined as part of their new curriculum in ocean education. Since 2015, it has been expanded to primary schools, junior high schools, high schools, and university students. Interaction with *Satoyama* (village-based forest management system) type activities has also been started with Maniwa city and Kagamino town. Fisheries villages were connected

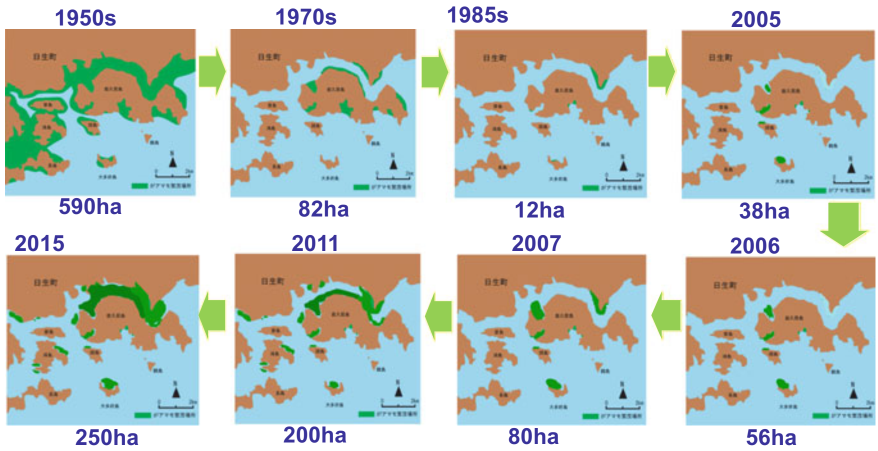


**Fig. 2** Thirty years efforts for restoring eelgrass beds in the Hinase area

with each other, and eelgrass bed restoration actions were widely promoted among fishermen, citizens, and children of Seto city, Okayama city, Tamano city, Asakuchi city and Kasaoka city, as well as all of Okayama prefecture. In 2015, "*Satoumi* rice" was merchandized as part of a brand campaign of the *Zen-Noh* (National Federation of Agricultural Cooperative Associations: JA). It became popular and qualified year after year, spurring stakeholders of agricultural fields to join in eelgrass bed restoration as "forestation of the sea." It is a remarkable turning point in the local history, since Okayama prefecture experienced tragic conflicts between farmers and fishermen more than 400 years ago. It was initiated by the Ukita tidal barrier seawall construction in 1584 to promote reclamation for new agricultural fields. The local fishermen using the area upset and destructed the seawall in 1722, and debate on it continued for more than 100 years.

More than 30 years of activities have extended eelgrass beds up to more than 250 ha from a drastically diminished state. In recognition of their achievements, the Hinase-town fisheries cooperatives were awarded the 9th National Maritime Award in 2016 from the prime minister.[3]

## 5 *Satoumi* Governance in Hinase-Town

Coastal management in all states around the world is framed by basic concepts such as ecosystem-based management (EBM), community-based management (CBM), and integrated coastal management (ICM). *Satoumi* is a subset of ICM combining in a

[3]Descriptions on this section based on the eelgrass restoration project implementation and its records of the Okayama prefecture, Hinase-town fisheries cooperative and the Satoumi Research Institute in relation with various local stake holders.

holistic manner *Satoyama* (management of mountain sides)—*Satochi* (management of land)—and *Satoumi* (management of coasts) (UNU 2011).

In Bizen City, where Hinase-town is located, the Ocean Policy Research Institute of the Sasakawa Peace Foundation (formerly the Ocean Policy Research Foundation) initiated and participated in the ICM Model Sites Project, which began with the establishment of the ICM Study Group, a collaborative effort among Bizen City, Okayama prefecture, the Chamber of Commerce, the Tourist Association and academia. From 3 to 5 June 2016, the 9th National Eelgrass Summit 2016 in Bizen was held in Hinase-town. Its theme was “Starting with Bizen! Creation of the *Satoumi-Satoyama* Brand—Networking with regions and generations.” About 2,000 participants from all over Japan, from Hokkaido in the north to Okinawa in the south, gathered together to launch the ICM modality in Bizen City (Fig. 3).

The concluding declaration of the National Eelgrass Summit 2016 in Bizen was, “We promise to further expand the network recognizing the links among forests, land, rivers, and seas, through towns, academia and NPOs nationwide, and continue our efforts to realize an ideal coexistence between people and nature and to promote such activities both domestically and abroad.” As a process for implementation, the “Bizen *Satoumi-Satoyama* Branding Committee with ICM” was established on 6 February 2017. It consists of four special committees (branding strategy committee, merchandise development committee, tourism strategy committee, and community storytelling committee). One and a half years after its establishment, there are steady achievements regarding reexamination and development of local resources, new merchandise developments, and planning and practicing of eco-tours. Stakeholders who had heretofore been fighting alone in their field have begun to collaborate on shared goals and are making enthusiastic efforts for realization of a more hopeful future. These stakeholders include fisheries cooperatives, agricultural cooperatives, forestry cooperatives, community fostering teams, chambers of commerce, tourist associations, pottery artists, chefs, cultural museum organizers, researchers, and educators.


**Fig. 3** Snapshots from the 9th National Eelgrass Summit 2016 in Bizen

"*Satoumi* with Oyster and Eelgrass" is aiming to establish a holistic and truly circulatory local society of *Satoumi*, *Satoyama*, and Community, through interaction of people and materials based on the water circulation linkages among forests, land, rivers, and sea.[4]

# 6 Issues to Be Considered for Realization of *Satoumi*

## *6.1 Under Global Contexts*

Above, we discussed implementation of the three pillars for sustainable development in Hinase-town's experience, namely (1) economic, (2) environmental, and (3) social aspects. Let us clarify the heart of the *Satoumi* concept of interaction between people and nature by re-visiting Hinase-town's experience. It will be helpful to understand the *Satoumi* achievement of high biodiversity and productivity by human intervention.

From organizing aspects of the Hinase-town fisheries cooperative as a private sector, it is important to consider ESG investment, which is being encouraged globally and nationally. The action of the Hinase-town fisheries cooperative for eelgrass restoration is in line with ESG investment. ESG investment stands for investment in Environment, Social and Governance issues based on the principles for responsible investment concept proposed by Hon. Kofi Atta Annan, the former UN Secretary-General.

The Sustainable Development Agenda for 2030 enacted by the United Nations in 2015 is also in line with the Hinase-town fisheries cooperative action, especially as regards the following:

- Sixth industrialization of fisheries at Hinase: SDG 9 and 12, (1, 2, and 7)
- Eelgrass restoration in Hinase area: SDG 14 and 15, (4, 6, and 13)
- *Satoumi* governance in Hinase-town: SDG 11 and 17, (3, 5, 10, and 16).

As to the implementation of *Satoumi*, it is important to establish a worthwhile model of economic growth (in line with SDG 9), and for producers and consumers to build responsible and close links (SDG 12). Also, a feasible model is needed to co-organize the conservation of land-sea biodiversity and sustainable fisheries, and an inclusive and integrated *Satoumi* governance should be built up, with citizens, governments, educational parties, private citizens, and academia in cooperation (in line with SDG 11 and 17). The fishery rights and management rights for foreshore areas that fisheries society long maintained is key for implementation. Since it is based on their pride in being "Guardians of the *Satoumi*," it can be considered their

[4]Descriptions on this section based on the ICM project implementation and its records of the Bizen city, and organizing committee of the eelgrass summit.

Voluntary Commitment. This means it is important to maintain proper and open links between the fisheries community and society, and that a code of conduct based on the sustainable development concept be followed.

## 6.2 Under Local Contexts

In previous eras, when fisheries were the basis of their livelihoods, fishermen's voluntary management was able to maintain foreshore environments in a healthy condition. However, with a four-fifths decrease in the number of fishermen from 1953 to 2016, from 790 thousand to 153 thousand, combined with the aging problem, it has become difficult for fishermen to manage their foreshores by themselves alone. In the midst of these conditions, the government published a revolution in fisheries policy on May 24, 2018. It includes abolishment of prioritized fisheries rights to the local villages. It is aiming to invite new investors to raise the Japanese fisheries industry out of its long decline. This could mean the withdrawing of historical rights of fishermen and fisheries villages, which made possible their care of the area since the Edo era. We are very concerned if this revolution destroys the unique system of "Sea Guardians" that proudly operated for so long in Japan. There are doubts whether the profit-based private companies can become the new "Sea Guardians" for our seas under the new initiatives for boosting fishery economics.

Furthermore, global environmental changes are affecting coastal environments drastically. According to the Nereus Program (Nereus 2018), by 2050, global-based climate change will have an effect on seawater temperature rise, decreasing the fish catch and downsizing the fish size in the tropics, increasing the fish catch in Arctic areas, with rises and declines in the temperate zone depending on the species, along with complex changes in distribution patterns. In Japan's case, it will affect migratory species such as salmon. When the migration route changes, the homing rate of salmon will change. Bumper harvests of Spanish mackerel are already appearing on the Japan seaside. Even in the Seto Inland Sea, northern fish such as fat greenling and flatfish are decreasing, and southern fish such as sea bream and red-spotted grouper are increasing. Serious degradation of reefs is occurring nationwide. Oligotrophication in coastal areas such as the Seto Inland Sea is also a big problem. Fishermen are claiming that there is "no smell of living creatures in the sea," "no smell of reefs," and "no see sea slaters on reefs." When bivalves such as short neck clams disappear, related benthos and sessile also decrease. It means the bearers of nutrient cycling are decreasing. This will result in the collapse of primary production in the ecosystem due to lack of nutrients to be circulated. These are fundamental problems for fishery resources.

### *6.3 Concluding Remarks*

Ocean and coasts are the indispensable and precious common heritage of mankind. The *Satoumi* concept and action will be a clue for tackling the question of "how should humans interact with the ocean?" Nevertheless, the situation of each local coast depends on actual use, including fisheries, the structure of industries, culture, and historical backgrounds, resulting in different goals. In 2013 and 2014, the official journal of the Japan Society of Fishery Science devoted two issues to "My Idea, Sense, and Approach to *Satoumi*" (Uchida 2013, 2014). Twelve experts, including the author, presented their definitions of *Satoumi* therein. One of the common themes was how we should sustain the fish catch as an important nutrient source for humans. Our definition was "nearby seas are to be conserved and developed in a sustainable manner with the compilation of human knowledge." This was our conclusion after participating in Hinase-town's experience and *Satoumi* activities on site. Coastal management in Japan has been based and relies on local fisheries cooperatives and their fishermen with fishing rights and management rights of foreshore areas. It is the tradition of being the "Guardian of the Sea" alive in their hearts. The succession of this attitude has continued up to now. *Satoumi* activities are ongoing in more than hundred sites in Japan. The most important stakeholders are fishermen and their affiliates. The number of fishermen will continue to decrease, but they will continue to be key persons and main actors in *Satoumi* activities as experts of the ocean. Nevertheless, common recognition for their role perhaps ought to shift from one based on fishing rights and management rights of foreshore management to one of being guardians for *Satoumi*.

The *Satoumi* activities at Hinase-town in Bizen City can be a model for coastal management in future. As it is guarded by a network of fishermen, together with local and more distant school children, citizens, and people from forested mountains, it has a cheering section that goes beyond geographical areas, generations, and personal situations.

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# French Marine Nature Parks: An Innovative Tool for Integrated Management of Maritime Space

**Melina Roth, Kévin Leleu, Matthieu Cabaussel, Benoit Dumeau, and Magali Lucia**

**Abstract** Marine nature parks are amongst the 15 French MPA categories listed by the Law of April 14, 2006. Their aims are to contribute to the protection and knowledge of the marine environment, but also the sustainable development of maritime activities. Nine Marine nature parks were in operation as of 1 January 2019: six in mainland France, spread across all coastlines, and three in French overseas territories. The Marine nature park of Arcachon Bay (*Parc naturel marin du Bassin d'Arcachon*) was created on 5 June 2014 to preserve and sustainably manage this exceptional maritime area, considered as a "common good". It covers 435 km$^2$ of maritime space, with 144 km of coastline. The borders include almost all of the Arcachon Bay's maritime public domain, in addition to the mouth of the Bay up to three nautical miles west, up to the boundary between the municipalities of Lège-Cap Ferret and Le Porge in the north, and between the municipalities of La Teste-de-Buch and Biscarrosse in the south. The Marine nature park of Arcachon Bay Management Plan was approved by its Management Board on May 2017 and then by the French Agency for Biodiversity Executive Board in September. The document is a fundamental component of a Marine nature park, which structures its activity and serves as a basis for all decisions taken by the Management Board. The development of the Marine nature park of Arcachon Bay Management Plan required almost two years of work and mobilised a large number of stakeholders in various consultation phases. It contains a wide range of objectives related to natural and cultural local resources, as well as spatio-temporal coexistence between activities or contribution to the maritime economy. Knowledge is also an important component of the document. The implementation of the Management Plan is led by the Management Board, comprising representatives of all maritime stakeholders in the territory. Every year, the Management Board approved the Marine nature park's action programme to help meet the objectives set out in its Management Plan. For the Marine nature park of Arcachon Bay, the actions can be divided into four main categories: knowledge, protection, sustainable development and promotion. These actions involve a number of institutional, professional, non-profit and scientific partners, who provide a technical and/or financial contribution depending on their assignments and involvement on

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the topic. The Management Plan is also implemented through advices issued by the Management Board on proposed permits for activities located on the site or which could impact the marine environment. These advices are based on the impact of the project on ecosystems and also, where possible, on their contribution to meeting the goals of the Management Plan.

**Keywords** Marine nature park · Arcachon Bay · Management plan · Management board · Common good

## 1 Introduction: French Marine Nature Parks

"Marine nature park" Marine Protected Areas (MPAs) were created in France by the Law of 14 April 2006 relating to national parks, Marine nature parks and regional nature parks. Marine nature parks are one of the 15 categories of French MPA, which in January 2018, covered over 22.3% of French waters (ONB 2018). Marine nature parks are entities of the French Agency for Biodiversity (AFB), a public institution of administrative nature (*établissement public à caractère administratif*) created by the Law of 8 August 2016 for the reconquest of biodiversity. The French Environmental Code defines three fundamental missions for Marine nature parks: understanding marine heritage, preserving the marine environment and promoting the sustainable development of maritime activities. Marine nature parks are created by a ministerial decree that sets out the three indivisible components of every park:

- The perimeter of the Marine nature park;
- The management orientations and specific long-term orientations of each Marine nature park, on which the Management Plan and all initiatives led by the Marine nature park are based;
- The Management Board, the Marine nature park's governance body, represented by a President and several Vice-Presidents.

The creation of a Marine nature park is the completion of preparatory work involving consultation with users of the marine area in question to gather all available knowledge and diagnostic assessments and form the components of the future ministerial decree.

Nine Marine nature parks were in operation as of 1 January 2019: six in mainland France, spread across all four coastlines (English Channel—North Sea, North Atlantic, South Atlantic, Mediterranean Sea); and three in French overseas territories (Indian Ocean and Caribbean Sea).

## 2 Marine Nature Park of Arcachon Bay

The Marine nature park of Arcachon Bay (*Parc naturel marin du Bassin d'Arcachon*) was created on 5 June 2014[1] to preserve and sustainably manage this exceptional maritime area. Arcachon Bay was created through a continuous sequence of subtle geological, biological and human interactions over time, and has always been considered an exceptional site. Its form and function are unique in the world, and it is home to a diversity of fauna, flora, landscape and culture that sets the territory apart:

- The Dune du Pilat, the tallest sand dune in Europe;
- One of the largest dwarf eelgrass bed in Europe;
- The Banc d'Arguin, France's largest sandbank;
- A renown oyster farming bays in Europe (*Crassostrea gigas*);
- One of the first clam sites operated in France (Sanchez et al. 2018).

Humans settled early here to live and benefit from nature. Discoveries of sharpened flints witness to prehistoric human activity near Dune du Pilat, Eyrac and Les Bordes, dating back to the Late Neolithic Period (2800–2300 BC) (Gruet and Jacques 2013). After this, most signs of human settlements and agricultural and commercial activities were concentrated in La Teste-de-Buch, along the Eyre Valley and the eastern side of the Bay (Thierry, 2002). Various subsequent periods saw a number of commercial activities thrive: fishing reservoirs, shellfish and maritime fishing activities, followed by the rise of tourism, sea bathing and more recently, water sports and recreational activities. The Bay is therefore a crucial place with vital resources for a number of professional and recreational practices that contribute to the local economy and the residents' living environment.

The various processes supporting the ecological balance of Arcachon Bay are constantly interacting. There are numerous relationships between humans and the environment in the Bay, which help build its identity and make it more attractive. All work in the environment affects or contributes to these balances, which means that all levels of individual and collective responsibility need to be constantly taken into account to protect this common good.

### *2.1 Perimeter*

The Marine nature park of Arcachon Bay covers 435 km$^2$ of maritime space, with 144 km of coastline (Fig. 1). The borders of the Marine nature park include almost all of the Arcachon Bay's maritime public domain, in addition to the mouth of the Bay up to three nautical miles west, up to the boundary between the municipalities of Lège-Cap Ferret and Le Porge in the north, and between the municipalities of La Teste-de-Buch and Biscarrosse in the south. Two national nature reserves are included within the perimeter of the Marine nature park of Arcachon Bay: The National Nature

[1] Decree n°2014-588 establishing the Marine nature park of Arcachon Bay.

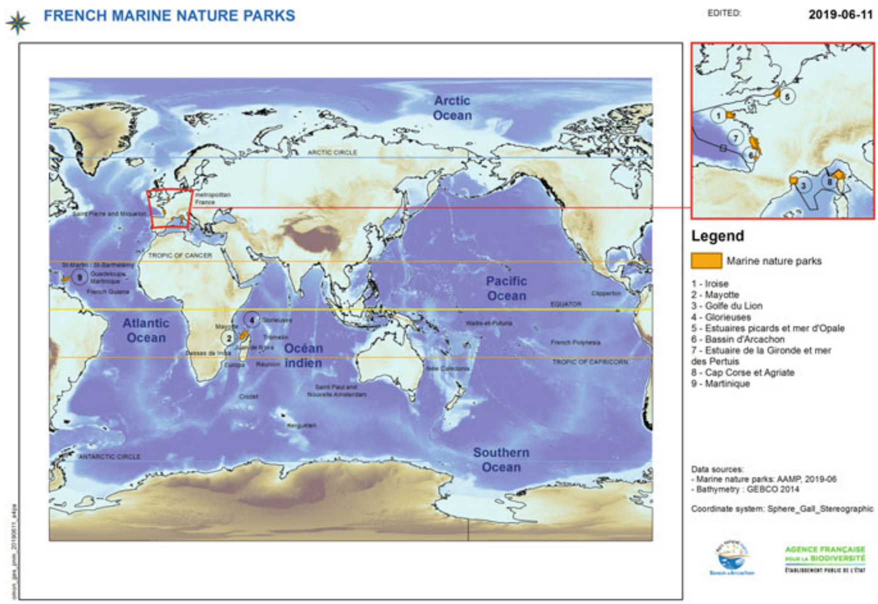


**Fig. 1** French Marine nature parks

Reserve of Banc d'Arguin and National Nature Reserve of the Salt Meadows of Arès and Lège-Cap Ferret. The Marine nature park of Arcachon Bay also operates two Natura 2000 sites under the Birds and Habitats Directives (Fig. 2).

## *2.2 Management Orientations*

Seven management orientations were set out in the Decree n°2014-588 creating the Marine nature park of Arcachon Bay. They cover all the remarkable ecological and socio-economic aspects of Arcachon Bay, including lagoon biodiversity and its attractiveness for birds, the ecological functions of salt marshes and their link to water quality, and the promotion and support of professional sectors and environmentally-friendly practices in water sports activities. Specific management orientations also cover promoting marine natural, cultural and landscape heritage, and helping all local people to take responsibility by raising awareness of the impacts of various uses on the environment.

Special attention was paid to these orientations when developing the Marine nature park Management Plan and defining the long-term objectives.

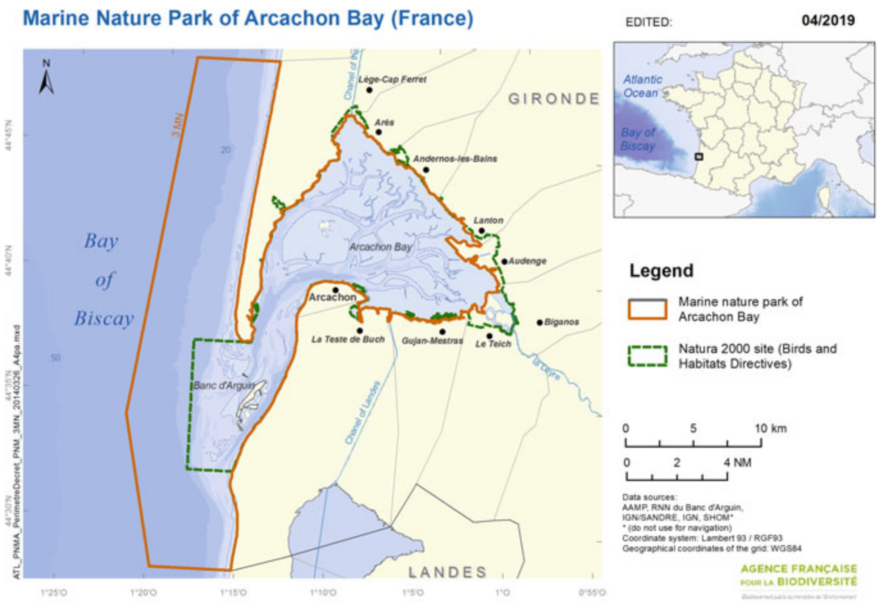


**Fig. 2** Perimeter of the Marine nature park of Arcachon Bay (Parc Naturel Marin du Bassin d'Arcachon, 2017)

## *2.3 Management Board*

The Marine nature park of Arcachon Bay Management Board comprises 56 members, including representatives of the following stakeholders and bodies:

- Local authorities: municipalities, Regional Council, *Département* Council, Inter-municipal Syndicate of Arcachon Bay (28.6% of members)
- Professional organizations representing fishing, shellfish aquaculture, boating industries, etc. (26.8%)
- A group including associations for the protection of the environment and cultural heritage, qualified individuals (scientists), the Regional Nature Park of Les Landes de Gascogne and the representative of a neighbouring MPA (21.4%)
- Government services (12.5%)
- Recreational sea users: sailing, boardsports, underwater diving, etc. (10.7%).

The role of the Management Board is defined by the French Environmental Code. Their assignments include developing the Management Plan, deciding what actions to carry out and making decisions to be implemented by the Marine nature park's technical team. It does not draw up regulations but can make proposals to the relevant prefects for any measures, including regulatory measures, required to meet the objectives defined in the Management Plan.

In order to facilitate policy implementation, the Marine nature park Management Board establishes an Executive Committee, with a small group of 14 members representing all groups comprising the Board. This Committee prepares the Management Board meetings and provides follow-up for the everyday actions for which the Board delegates its authority. For the Marine nature park of Arcachon Bay, the Executive Committee comprises 14 members, including the President and four Vice-Presidents.

## 3 Management Plan of Arcachon Bay

The Management Plan is a fundamental component of a Marine nature park, which structures its activity and serves as a basis for all decisions taken by the Management Board. This strategic 15-year document determines the protection, research, promotion and sustainable development measures to be implemented within the defined area, on the basis of the management orientations set out in the creation decree. The Management Plan must be developed within three years of the date of publication of the decree and is submitted for approval by the Management Board and then the French Agency for Biodiversity Executive Board. It must be revised at least every 15 years. The Marine nature park's Management Plan also serves as a "Document of Objectives" for the Natura 2000 sites it operates.[2]

A Management Plan is broken down into several chapters in line with the themes of each territory. For each theme, "aims" and "sub-aims" (equivalent to long-term objectives and sub-objectives) and "levels of requirements" are defined. Levels of requirements determine the 15-year target for each sub-aim depending on the various themes. An MPA dashboard including indicators and a reference reading grid is used to regularly assess whether these levels have been achieved.

Work on developing the Marine nature park of Arcachon Bay Management Plan began on 1 September 2015. The method used is based on consultation structured around six thematic committees, each chaired by a member of the Management Board:

- Management of natural resources,
- Sustainable development of activities, maritime identity and local culture,
- Management of maritime space,
- Knowledge,
- Awareness-raising,
- Governance.

This decompartmentalised approach to the themes discussed helped provide an overview of all issues in the territory during discussions, by avoiding the sectoral approaches inherent to the various topics. This co-building approach mobilised a large number of stakeholders in the various consultation phases (Fig. 3). A total of 350 people helped define the components of the Management Plan.

[2]Article L414-2 of the Environmental Code.

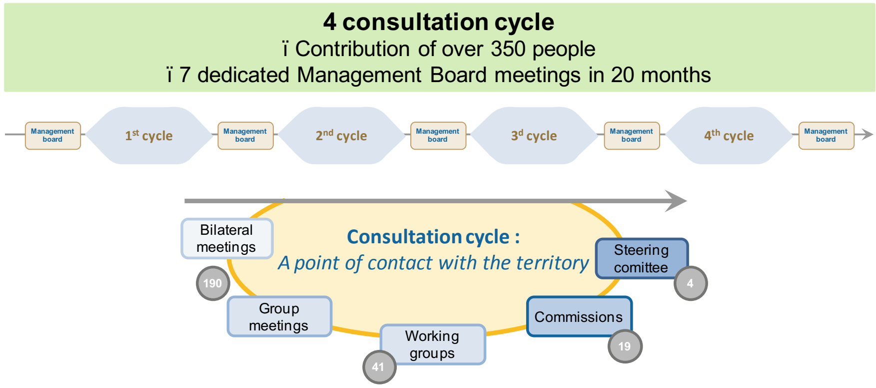


**Fig. 3** Consultation cycle used to draw up the Marine nature park of Arcachon Bay Management Plan (PNMBA 2017)

The Marine nature park of Arcachon Bay Management Plan was approved by its Management Board on 19 May 2017 and then by the AFB Executive Board in September. It is broken down into five main chapters (PNMBA 2017).

- Three chapters are structured around marine environment preservation, knowledge and the sustainable development of maritime activities.
- A fourth chapter focuses on the governance required to implement the Management Plan, its contribution to public policies and how the Marine nature park integrates into the local landscape.
- A fifth chapter looks at the map of vocations, a graphic required by the French Environmental Code as a means of grouping various purposes into major categories. This document has no regulatory weight and does not modify existing regulations.

### *3.1 An Exceptional Common Good*

The first chapter covers the "exceptional common good" used by the various stakeholders, residents and visitors, over time. Preserving the wealth of natural resources in Arcachon Bay and its mouth is the first section in this chapter. Its wealth of resources includes water quality, which is central to the entire ecosystem and the activities that depend on it. The Management Plan therefore aims to maintain in optimal conditions a number of characteristic parameters for water quality that promotes uses and ecosystems. The unusual morphology and hydrodynamics of Arcachon Bay have created an exceptional mosaic of habitats (Fig. 4), with a remarkable diversity of flora and fauna. The objectives aim to achieve the long-term sustainability of this

**Fig. 4** Salt meadows in the east of Arcachon Bay. Copyright: B Dumeau/French Agency for Biodiversity

living resource. More specific objectives target the conservation of several emblematic species, including eelgrass, seahorses and eels, and the preservation of resources subject to exploitation. Finally, a more general objective was identified for the overall attractiveness of the Bay for fauna and birds, primary production and ecological continuity.

The second section of the chapter on the "common good" covers passing on a living maritime culture in the Arcachon Bay. The many links between Bay residents and the ocean are expressed through the activities they carry out, the resources they use and the places they go. Although some characteristics of Arcachon Bay are shared with other territories, their combination within the Bay's own geographical, historical and socio-cultural context has created a unique maritime identity.

Over time, this maritime identity has encouraged the emergence of a tangible and intangible heritage and local memory unique to the Bay, and landscapes shaped by mankind that reflect the place's unique character. Some aspects of this local maritime identity are facing changes that demonstrate their fragility and underline the need to preserve, reaffirm and pass on the Bay's living maritime culture.

The third section of this chapter covers the space represented by Arcachon Bay, its dynamics and how it is shared. The morphology of Arcachon Bay is constantly changing, with significant differences over fairly short time periods. Tidal currents, swells and wind shape the loose sediments that form the Bay. This dynamic space provides a wealth of natural resources and supports the development of maritime

**Fig. 5** Dwarf eelgrass bed, oyster tables and pleasure boats. Copyright: A Garreau/French Agency for Biodiversity

activities, with interests that vary depending on whether they are practised professionally or for recreational purposes. The objectives of this section seek to adapt to maritime dynamics and strike a balance between the different purposes of the Bay and its mouth. These objectives are achieved through an overall approach to challenges, with a strong focus on taking into account the cumulated effects of developments and interventions in the marine environment, silting of the Bay bed, accessibility and the maritime purpose of port spaces, and the restoration of unfarmed oyster beds. They also call for reconciling the different activities practised in Arcachon Bay, in both space and time (Fig. 5).

Finally, the last section in this chapter defines the objectives for discovering and understanding Arcachon Bay in order to better protect it. Preserving the "common good" of Arcachon Bay is mainly contingent on residents and local stakeholders sharing the challenges facing the territory. Knowledge of the Bay's specific features, its natural and cultural resources, and opportunities for regular and/or long-term "encounters" with the marine environment are important levers for promoting collective and individual responsibility for preservation.

The Management Plan therefore sets the objective of promoting greater appropriation of maritime issues, particularly by residents and younger generations. It also aims to promote best practices for Bay protection and help users understand their advantages. At the same time, it aims to strengthen possibilities for discovering and practicing environmentally-friendly activities in contact with the marine environment. Finally, it proposes networking the full range of stakeholders working to raise awareness across the Bay, in order to collectively increase their added value for their various audiences.

### *3.2 Sustainable Development of Marine Activities*

The second chapter of the Management Plan focuses on the sustainable development of maritime activities, with a section on accounting for these activities and their practices with preservation of the marine environment, and a section on the territory's investment in a sustainable marine economy linked to its identity. The Marine nature park of Arcachon Bay is home to a broad range of professional and recreational activities that reflect the diversity of natural resources on the site. Fishing, oyster farming, boating and outdoor sports make the most of the many advantages offered by the lagoon and its mouth, with visitor numbers dependent on the tides, weather conditions and season. The sustainable development objectives for maritime activities differentiate between fishing and hunting activities, farming activities and water sports, bathing and outdoor activities (Fig. 6), in line with objectives for innovation and experimentation to ensure their sustainability. This chapter's socio-economic

**Fig. 6** Access to an oceanic beach in the mouth of the Arcachon Bay. Copyright: M Cabaussel/French Agency for Biodiversity

objectives seek to strengthen the role of the marine economy in the local landscape, by drawing on the diversity of economic sectors, environmental exemplarity and contribution to cultural heritage. This also involves supporting and promoting traditional sectors. Finally, the Management Plan seeks to strengthen industries of excellence and extend their influence beyond the territory.

### *3.3 A Multi-disciplinary and Shared Knowledge*

The third chapter of the Management Plan covers knowledge, with a focus on the need for a multi-disciplinary approach, the complementarity of data and information sources and the need for knowledge sharing. Targeted observation should improve data on all species and the dynamics involved in order to improve the warning capacity where required, and provide useful information for revising the document in 15 years' time.

### *3.4 Governance*

The fourth chapter of the Management Plan focuses on governance of the Marine nature park of Arcachon Bay. As mentioned above, the Management Board is the local decision-making body, and its composition is defined in the Decree creating the Marine nature park. The composition is designed to mobilise and empower local public stakeholders, professionals, users, the non-profit sector and scientists around a shared territorial project. None of the groups represented on the Management Board have a majority. Implementation of the Management Plan therefore requires significant consultation and the shared efforts of public and private stakeholders to achieve the long-term objectives that have been developed together. The objectives of this chapter set out the expected contributions of the Marine nature park of Arcachon Bay and its Management Board to the development and implementation of public, territorial and sectoral policies, by encouraging the various stakeholders to come together to implement the Management Plan. Objectives are also defined to ensure that the Marine nature park of Arcachon Bay works within a context of regional, national and international cooperation and discussion, in order to promote the understanding of larger-scale challenges and enhance the capacities of stakeholders working on this type of initiative.

### *3.5 Map of Vocations*

The fifth and final chapter of the Management Plan shows the map of vocations for the Marine nature park of Arcachon Bay (Fig. 7). This map of uses is a mandatory

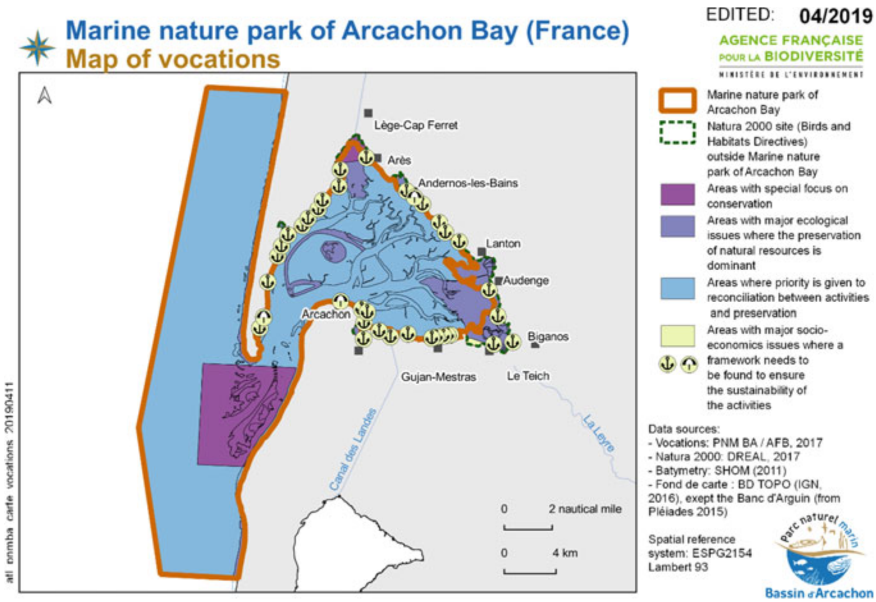


**Fig. 7** Map of the vocations of the Marine nature park of Arcachon Bay (PNMBA 2017)

component of a Marine nature park Management Plan. It must help identify the major orientations for the various geographical sectors within the park, depending on the objectives defined in the Management Plan. It gives the Management Board a key for understanding the management priorities for each sector identified. The priorities of the Marine nature park of Arcachon Bay were defined with regard to two major themes: preservation of natural resources and the sustainable development of activities. Four purposes were defined using information from the consultation and thematic maps of the challenges facing the Marine nature park of Arcachon Bay.

The first purpose seeks to strike a balance between the preservation of natural resources and the sustainable development of activities. In the sectors concerned, priority will be given to permanently reconciling practices with the sensitivity of environments. The second purpose focuses on spaces where major ecological issues have been identified. In these spaces, the preservation of natural resources will be dominant. The compatibility of these activities with preservation issues will be crucial for the Management Board when coordinating projects. The third purpose relates to spaces with major socio-economic issues, where a framework needs to be found to ensure the sustainability of activities. They will be given priority in these sectors, while ensuring that these activities remain compatible with the conservation challenges of the Marine nature park. A fourth purpose has also been set for national nature reserves that have a specific regulatory framework with a special focus on conservation.

# 4 Implementation and Coordination of the Management Plan

Implementation of the Management Plan is led by the Management Board. This local governance approach, comprising representatives of all maritime stakeholders in the territory, is central to the life of the Marine nature park. The coordination of this body is therefore essential for debate and consultation, for organising the stakeholder convergence and synergies required for concrete implementation of actions and achieving the long-term goals set by the territory. Management Board meetings will therefore provide key strategic leadership of Management Plan actions and implementation. Implementation consists primarily of actions led or supported by the Marine nature park of Arcachon Bay, financed by its own equity or in partnership with local or regional stakeholders. Every year, the Marine nature park's action programme is approved by the Management Board, which also votes on subsidies granted to partners. The Management Plan is also implemented through advices issued by the Management Board.

The Management Board is coordinated by the team at the Marine nature park of Arcachon Bay using the funding allocated to the project by the French Agency for Biodiversity. This funding can be increased through special technical or financial partnerships.

## *4.1 Advices*

In addition to the technical and logistical organisation of the Management Board and Executive Committee meetings, coordination includes the technical preparation of advices requested by French government services for projects planned within the Marine nature park. The Management Board is asked to issue advices on proposed permits for activities located on the site or which could impact the marine environment. These opinions are based on the impact of the project on ecosystems and also, where possible, on their contribution to meeting the goals of the Management Plan. These advices include a technical presentation, and are voted on by all members of the Board, after debate and discussion. Members are also entitled to request additional information.

## *4.2 Actions*

The actions led or supported by the Marine nature park of Arcachon Bay are included in annual or multi-annual action programmes that provide a framework for approval of the Marine nature park's contribution and the expected outcomes of the planned actions. The actions implemented can be divided into four main categories: knowledge, protection, sustainable development and promotion. Ongoing or previously implemented actions include:

- Mapping of marine habitats, in partnership with the local botanical conservatory.
- Following consultation, proposed changes to regulations to reduce conflicts of use between kayak mooring and protection of the environment and avifauna.
- Assessment of the state and dynamics of beds of mussels, variegated scallops and common slipper limpets in the lagoon, in partnership with professional fishermen and local oyster farmers.
- Support for experimental cleaning operations within the Maritime Public Domain (removal of abandoned oyster fishing structures and destruction of non-indigenous wild oyster reefs), in partnership with oyster farmers and the relevant government services.
- Support for best practices in migratory waterfowl hunting, in partnership with the local sea hunting association and the Gironde hunting federation.
- Experiments with innovative ecological moorings, in partnership with the municipality of Lège-Cap Ferret and a local maritime engineering firm.
- Characterising port heritage in the Bay, in partnership with the Architecture, Urban Planning and Environment Board.
- Creation of scientific mediation tools and media on "tides" phenomenon.
- Involvement in local events, especially those involving local resource persons, information and awareness-raising stands (e.g. on recreational seafood hand harvesting).

These actions involve a number of institutional, professional, non-profit and scientific partners, who provide a technical and/or financial contribution depending on their assignments and involvement on the topic. The actions led or supported by the Marine nature park of Arcachon Bay across the territory therefore help meet the objectives set out in its Management Plan. Furthermore, the Marine nature park helps mobilise stakeholders around implementation of the Management Plan and harmonise actions led by the various stakeholders themselves in their sectoral or territorial strategies.

The objectives of the Marine nature park of Arcachon Bay are monitored using an MPA dashboard that gives a summary of all metrics and reference reading grids selected for assessing the situation or trends observed with regard to the objectives set. The Management Board should be able to use these indicators to define and prioritise action programmes. The choice of indicators is therefore vital and especially complex, as they need to reflect a situation or dynamic trend within a multi-parameter context, and serve as a decision-making tool. Work is therefore ongoing to define these indicators at both a local and national level, with specific work involving various Marine nature parks on this subject.

## 5 Conclusion

Marine nature parks are an innovative tool for the conservation of natural environments in France. They link conservation of the marine environment to a dedicated local governance body responsible for coordinating action within a balanced local approach that reconciles the sustainable development of marine activities and the conservation of natural and cultural heritage. In the specific case of Arcachon Bay, the Management Board chose to build the future of local development on sustainable interference with ecosystems considered to be a natural and exceptional common good. This decision requires the continuous involvement of stakeholders in managing and preserving the various components of this heritage, and makes the governance body responsible for preventing and resolving conflicts of use and ensuring the local implementation and adaptation of public policies. The integrated and cross-cutting approach provides a multi-disciplinary and cross-cutting framework to tackle the issues. The advices issued by the Marine nature park support and guide local initiatives towards virtuous choices. Improving knowledge is an essential lever for innovation and changing practices as part of a continuous process. The long-term aim is to ensure the conditions for the renewal and preservation of resources that are vital for the quality of life and local economy, and support relationships between people and nature that encourage the protection of ecosystems and all their biodiversity, including human life.

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# Eel Restocking in France: An Emergency Measure to Save the European Eel

**Jacqueline Rabic and Déborah Gornet**

**Abstract** The European eel is a migratory species highly dependent on the continuity of its ecosystem. Declining for several years, it is threatened by multiple mortality factors including degradation of its habitat: fragmentation of rivers (dams, hydroelectric works, etc.), water pollution (chemical pollutants, endocrine disruptors, etc.). In addition, other factors contribute to the weakening of the eel stock such as poaching, the introduction of catfish (invasive predatory species) as well as professional and amateur fishing. This is why the European eel benefits from a management plan at the European level. In addition to the restoration of habitats and ecological continuity, restocking has been put in place by the European Member States as an emergency measure. Restocking is a transfer of glass-eels or elvers (young eels) from estuarine areas to host sites considered as the most favourable habitats. This transfer, which is the result of close cooperation between fishermen, fish traders, scientists and state services, avoids the mortality associated with migration towards the nursery areas. The goal is to help increase the number of healthy spawners returning to the sea. In France, this practice is conducted under strict and rigorous conditions and accompanied by scientific monitoring over several years. This is why, thanks to its experience, the French professional fishers initiate the creation of an association, on 17 June 2010, to ensure the coordination of the national restocking program: ARA France.

**Keywords** *Anguilla anguilla* · Restocking · Professional fishing · French Eel management plan (EMP))

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# 1 The Context

## *1.1 A Declining Heritage Species*

Formerly very abundant throughout Europe, the European eel (*Anguilla anguilla*) is experiencing an unprecedented decline in all French watersheds. The disappearance of wetlands, the fragmentation of habitats, channelization of rivers, parasitism (including *Anguillicola crassus*), contamination of sediments by heavy metals and persistent pollutants, water pollution by various chemical substances, some of which have effects of endocrine disruption, diseases, professional and amateur fishing, poaching, turbining, predation (including cormorant), introduced species with invasive potential (catfish) are considered as the main causes of this situation (Adam et al. 2008; Rabic et al. 2009; Feunteun 2012). Some of these causes could be amplified by others and synergistic cumulative effects would also be possible. Thus, it is likely that the deleterious impact of parasitism on the eel increases when the immunity of the eel is weakened by the many pollutants to which it may be exposed in the river (prevalence of external pathologies that can have a significant impact on survival of the species).

## *1.2 Eel Restocking: A Necessary Management Measure in Europe and France*

Among the management measures aimed at reversing the decline of the species and contributing to the recovery of the stock, the restocking (or more precisely the transfer of eels) in Europe consists to introduce glass-eels or young eels in natural habitats considered as good nursery areas, with a good carrying capacity and where the eel density is considered under the norm and ensuring an optimal survival rate of fish until their return to sea (sources of reduced mortality).

Restocking remains:

- an European obligation: Regulation EC No 1100/2007 requires EU countries to reserve 60% of their glass-eel landings for the purpose of restocking in European waters [Article 7 (1)];
- a national commitment: the French eel management plan (Eel French Management Plan 2010), plans to reserve between 5 and 10% of the eel national production to the repopulation on the French watersheds;
- an emergency measure (Eel French Management Plan 2010).

### 1.3 A National Structure: ARA France and Its Main Objectives

The Association for the Eel Restocking in France (ARA France[1]), created in 2010, under the law 1901, at the initiative of the eel professional fishermen, participates in the financing of restocking actions in France, coordinates the national program and ensures compliance with the eel restocking specifications (http://www.repeuplementanguille.fr/). It provides information exchanges among actors: professional fishermen, fishmongers, territorial and national State services, summarizes in an annual report the restocking activities in France (Anonymous 2014) and proposes evolutions and adaptations of the restocking program. As a technical partner since 2011, ARA France is also involved, at the local level, in the restocking activities.

To achieve optimum performance in its core tasks, ARA France's objective should be to connect stakeholders wishing to invest in the eel conservation and the restocking of that species in France. Mortality factors are multiple and restocking is considered as an emergency measure until eel restoration which is a long-term solution, becomes fully effective. By bringing together a maximum of actors involved in the Eel protection, ARA France wishes to respond to the urgency of the situation and actively contribute to the restoration of the species.

## 2 A Restocking Procedure Framed at Each Stage

### 2.1 Selection of Suitable Sites for Restocking

This selection is made by the Migratory Fish Management Committee (COGEPOMI). The goal is to choose favourable areas with good carrying capacity and allowing good growth, low mortality for the eel restocked and an optimal escapement to the breeding area at sea (Fig. 1).

### 2.2 The Best Fishing Practices Guide

In order to guarantee the good quality of glass eels for restocking and to optimize the effectiveness of the restocking actions carried out in France and across Europe, all French fishermen have to respect the charter of Best Fishing Practices (Anonymous 2012[2]). This charter defines the conditions of fishing practice:

- speed of the boat: 3 or 4 knots maximum dependent on the turbidity level and the strength of tide;

[1]Association pour le Repeuplement de l'anguille en France http://www.repeuplementanguille.fr/.
[2]http://www.comite-peches.fr/wp-content/uploads/GBP-Plaquette-V3.pdf.

**Fig. 1** An example of a restocking site chosen: Aureilhan Lake. (Copyright ARA France)

- duration of the fishing haul: not more than 10 or 15 min for each haul depending on the water turbidity, the mesh of the pushed-sieve and its length and shape;
- used on board a sorting device in order to reduce the by-catch (Fig. 2);
- used on board a fish tank (capacity between 100 and 500 L) in order to keep alive, the glass-eels caught until the sale of the fish to an approved fish-trading enterprise (Fig. 3).

**Fig. 2** Use of a sorting device to separate the glass-eels from other fishes or shrimps. (Copyright Ifremer)

**Fig. 3** Fish tank onboard a fishing boat and fed by running water and continuous renewal

## *2.3 Health Tests*

The health quality of glass eels (absence of lesions, parasites, viruses, etc.) is a determining factor in the success of the restocking program. The glass eels for restocking are subject to a thorough health examination. For each restocking operation (Fig. 4),

**Fig. 4** Glass-eels ready to be restocked on the Orne river in 2018 (France). (Copyright ARA France)

parasites such as *Anguillicola crassus*, *Pseudodactylogyrus* sp. *Ichthyophtirius multifiliis* are targeted. EVEX virus detection tests are being undertaken, and in the case of glass-eel restocking in areas officially free from salmonid diseases such as IHN (Infectious Hematopoietic Necrosis) and VHS (Viral Haemorrhagic Septicaemia), a complementary virologic examination is carried out (Fig. 4).

## 2.4 Tagging of Glass Eels

The marking of otoliths (bony pieces) makes it possible to follow marked fish for several years (Mazel et al. 2017). It may be optional if the species is absent in the monitoring area (or in negligible quantity), or if differences in size or age class are sufficient to differentiate restocked individuals from natural ones.

The marking of 30% of glass eels makes it possible to limit the risks of mortality induced by dipping (Anonymous 2018). Nevertheless, when an eel population is already present on the site, it is better to tag all the individuals. Alizarin is used as the vital dye and the glass eels are mass-labelled in trays containing 40 L of alizarin solution at 150 mg $L^{-1}$ without thermic and osmotic shock (Alcobendas et al. 1991). In each tank, 3–4 kg of glass eels are introduced for 3 h dipping with alizarin (Fig. 5). During the entire duration of the dipping, the oxygen level must be

**Fig. 5** Tagging operation carried out by Fish-Pass biologists. (Copyright ARA France)

**Fig. 6** Fish hatchery facilities to stock glass-eels before further transportation. (Copyright ARA France)

maintained between 150 and 200% saturation.

### *2.5 Packaging and Transport*

Just after they have been caught, glass-eels are sold to accredited fishmongers. They are transferred in fish hatchery facilities and stocked in a pond (Fig. 6). In these facilities, the sorting of injured or dead animals can be made easily before the next transportation (Fig. 7).

### *2.6 Restocking Operation*

Before the fish release, special attention is paid to the temperature and salinity of the water during the holding phase in the fishmonger and after the transportation to the site of release in order to diminish as far as possible the difference in temperature between the transportation water and the water of the release site. Thus, a gradual adaptation of glass eels to the temperature of the stream in which they will be released is necessary to avoid any thermal shock.


**Fig. 7** Restocking operation in the Loire river in 2018. (Copyright ARA France)

## *2.7 Scientific Monitoring*

A scientific survey is conducted six months, one year and three years after the restocking to evaluate its effectiveness. The electrofishing is practised in and near the area of release.

First of all, electrofishing operations are carried out at the sites of release using the Punctual Abundance Sampling (PPA) method (Germis 2009), combined, if possible, with fine mesh filleting operations. The principle is to achieve at least 25 fishing stations located along and upstream the areas of eels released. In each of the stations, 20 punctual samplings of abundance are carried out and recorded (Fig. 8).

For example, the restocking in the Erdre river (tributary of the Loire river) in 2014.

This project was carried out by two associations of fishers: 'l'Association Départementale Agréée de Pêcheurs Amateurs aux Engins et aux Filets de Loire-Atlantique' and 'l'Association agréée départementale des pêcheurs professionnels maritimes et fluviaux en eau douce de Loire-Atlantique'.

It concerned the transfer of 825 kg of glass eels in the river Erdre at the 'Plaines de Mazerolles' in 2014. 30% of glass-eels released were marked with alizarin (Fig. 9).

The recapture of individuals during the different surveys provides information on several biological parameters: growth, internal parasitology and external pathology. Despite a number of uncertainties due to the fishing method, the emigration of released fish outside the controlled area, the rate of survival after 1 year is far from negligible (Table 1 from Mazel et al. 2017). Surveys also provide information on the level of recruitment in the study area, the behaviour of individuals in the early years, and the environment in which glass-eels were released.

**Fig. 8** Control electrofishing to evaluate the rate of recapture of glass-eels released. (Copyright ARA France)

**Fig. 9** Restocking operation in the Erdre river in 2014. (Copyright ARA France)

**Table 1** Recaptures of eel on the Erdre: six months, one year and three years after the restocking (Mazel et al. 2017)

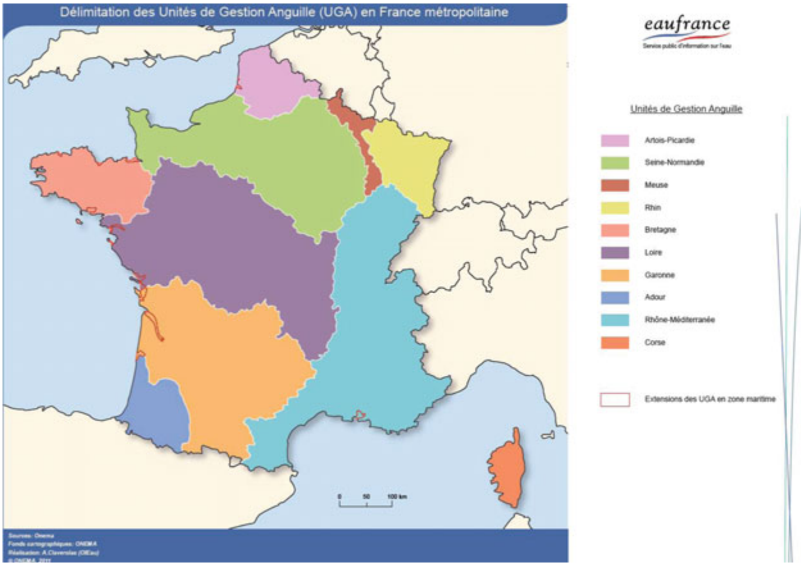
| Monitoring | After six months | After one year | After three years |
|---|---|---|---|
| Eel caught (group a) | 788 | 547 | 551 |
| Eel of the desired size class (group b) | 426 | 164 | 255 |
| % of eels marked in group b | 28.3 | 36.4 | 20 |

## 3 Initial Assessment of French Eel Restocking

Restocking projects are submitted to a national selection committee[3] which ensures compliance with the technical and scientific protocol by the project leader. In addition, the State finances 96% of restocking operations and ensures the smooth running of each of them through the territorial services (Maritime Affairs, French Biodiversity Agency).

For example, in 2018, the eight validated restocking projects enabled the release of 3166 kg of glass-eels (Fig. 10), representing 5.9% of the national production (Fig. 11).

As shown in Fig. 11, from 2010 to 2018, 6.5% of the glass-eel production in France was used, on average, for restocking experiments (minimum: 0.51; maximum 16.5) reaching the target defined by the national PGA: objective between 5 and 10%.




| Eel Management Unit (UGA) | Number released (in millions) | Weight (in kg ) |
|---|---|---|
| **Picardie et Seine-Normandie** | 0.2 | 68 |
| **Bretagne** | 1.4 | 432 |
| **Loire Côtiers Vendéens** | 4.5 | 1342 |
| **Garonne-Dordogne Charente** | 3.2 | 971 |
| **Adour et Côtiers Landais** | 1.2 | 353 |
| **Total 2018** | 10.6 | 3166 |

**Fig. 10** Quantities of glass eels released in France in 2018 for the national eel restocking program

[3]Ministry of Ecological and Solidarity Transition, Ministry of Agriculture and Food, the French Agency for Biodiversity (AFB), and the regional directorates of the Environment, Planning and Housing.

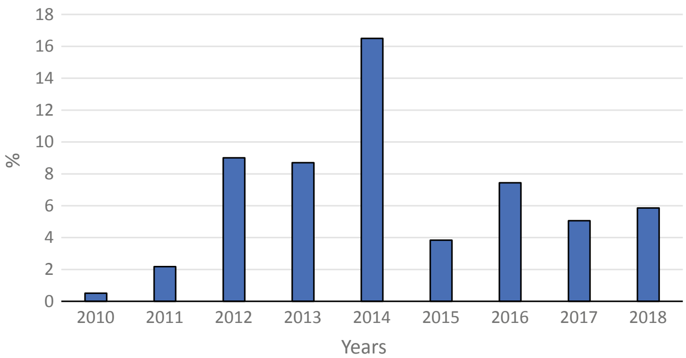



**Fig. 11** Evolution of the percentage of glass-eel production used for eel restocking program in France

Beyond this quantitative objective, the improvement of the quality of the fry combined with the experience gained by the operators gives hope for a good success of future operations.

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# Management of Aquaculture and Marine Environment in an Open-Type Inner Bay Through the Satoumi Approach: The Case of Shizugawa Bay

**Teruhisa Komatsu, Shuji Sasa, Shuhei Sawayama, Hiroki Murata, Shigeru Montani, Osamu Nishimura, Takashi Sakamaki, Chihiro Yoshimura, Manabu Fujii, and Tetsuo Yanagi**

**Abstract** A demarcated fishery right is set on a sea area for aquaculture designated by a governor of a prefecture in Japan. Around Japan, this right area broadly covers open-type inner bays, where oyster culture is one of the most active types of aquaculture. It is necessary to develop a coastal management approach for realizing sustainable aquaculture in a sound marine environment in the open-type inner bay through understanding suspended and benthic material circulation as well as aquaculture impact on the marine environment. We have therefore conducted the monitoring of the marine environment and aquaculture and made studies on material circulation and ecosystem modeling of Shizugawa Bay, a typical rias-type bay as an open-type inner bay since 2014. We have established a council for sharing data obtained from the studies and discussing on marine environment in the bay based on scientific data with stakeholders from Shizugawa Bay since 2015. After the Great East Japan Earthquake in 2011, Shizugawa Branch of Miyagi Prefecture Fishery Cooperative succeeded in reducing oyster culture rafts to 55 and 23% to those before the tsunami

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event in the sea areas of Shizugawa and Tokura areas, respectively, both located in the head area of Shizugawa Bay. The result of the reduction lead to an increase in the growth rate of oysters, consequently shortening the oysters' culture period. In situ experiments showed that feces and pseudofeces of young oysters contained less percentage of organic matter than in the case of the old ones, leading to less organic matter on the sea bottom. Nitrogen is a limiting nutrient in Shizugawa Bay. Dissolved iron was insufficient for boosting phytoplankton (diatom) in the surface layer of the center part of the bay in summer. These nutrients were mainly exported from the offshore waters compared to little inflow from the rivers due to their narrow watersheds like as many rias-type bays. The physical–biological coupling ecosystem model of Shizugawa Bay predicted marine environment and aquaculture production based on several scenarios co-produced by scientists and fishermen. Through the Council for the Future Marine Environment of Shizugawa Bay, the stakeholders, including the authors of the study, discussed how many aquaculture rafts and target species were optimal on the basis of the predicted results. The discussion was reflected in the renewal of the demarcated fishing right area in 2018. In Shizugawa Bay, the forestry activity, with a FSC international ecolabel, was linked to oyster culture with an ASC ecolabel through macrophyte beds registered as a Ramsar Site in 2018. These efforts and the reduction in the number of aquaculture rafts are activities called satoumi and satoyama, which enhance biodiversity and productivity through sustainable use of the coastal waters and mountains and will become a new universal coastal area management tool.

**Keywords** Shizugawa Bay · Open-type inner bay · Sustainable aquaculture · Oyster culture · Satoumi and satoyama · Council · ASC

## 1 Introduction

A demarcated fishery right is set on a sea area for aquaculture along the coast designated by a governor of a prefecture in Japan. This right area covers all open-type inner bays around Japan because oyster (*Crassostrea gigas*) and wakame (edible brown algae: *Undaria pinnatifida* (Harvey) Suringar) are actively cultured in such bays.

The future world population is projected to reach 9.8 billion in 2050 (United Nations 2017), which may lead to food shortages. The ability to obtain marine products without the need for land and water is extremely important for Japan, which has a small land area and a large population. It is now required to lay the foundation for achieving sustainable aquaculture on which fishermen can live their lives while maintaining a healthy marine environment. Therefore, it is necessary to develop a management method of the open-type inner bay for realizing sustainable aquaculture in a sound marine environment through understanding the suspended and benthic material circulation and influence of aquaculture on the marine environment.

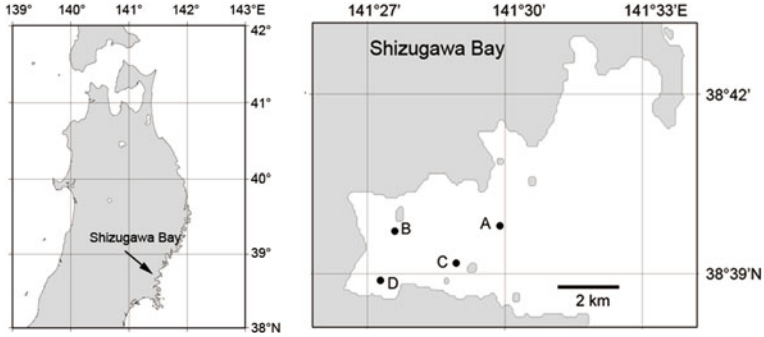


**Fig. 1** Maps showing location of Shizugawa Bay in northern Honshu Island (left panel) and enlarged Shizugawa Bay (right panel). Stations A, B, C and D shown as black circles (right panel) are referred in Fig. 4

Inspired by the way the coast has been used since ancient times in Japan, Yanagi defined "satoumi" where optimal human intervention to coastal waters increases biodiversity and productivity (Yanagi 2006). In order to examine whether it is possible to realize rich, clean, prosperous coastal waters (satoumi) based on this satoumi concept, the study entitled as "Development of coastal management method to realize the sustainable coastal sea" was conducted thanks to the Environment Research and Technology Development Fund S-13 of the Ministry of Environment of Japan from 2014 to 2018 fiscal year. This article reports the results obtained from "Topic 2: Development of coastal environmental management methods on the Sanriku Coast." That area is characterized by a succession of inner bays facing the Pacific Ocean and hit by the huge tsunami in March 2011. Topic 2 of S-13 focused on Shizugawa Bay situated on the Sanriku Coast (Fig. 1).

## 2 Aquaculture Changes in Shizugawa Bay Before and After the Huge Tsunami on March 11, 2011

In Shizugawa Bay, oysters, wakame, scallops (*Patinopecten yessoensis*), ascidians (*Halocynthia roretzi*), kelp (*Saccharina japonica* (Areschoug) C. Lane, Mayes, Druehl and G.W. Saunders), and coho salmon (*Oncorhynchus kisutch*) are cultivated. Among them, oysters and wakame are the top two productions. Before the earthquake disaster, oyster culture rafts were densely spread in the bay headwaters. It took about three years from submersion of oyster juveniles under the sea to harvest. The first author visited the Shizugawa Branch of Miyagi Prefecture Fishery Cooperative in September 2011 and discussed with the late Mr. Norio Sasaki, the president of the branch, on future aquaculture in Shizugawa Bay. Mr. Sasaki told him that the branch was examining a drastic reduction of aquaculture rafts to turn the terrible disaster in an opportunity as the late Prof. Emeritus Yasutsugu Yokohama of Tsukuba University, Former Director of Minami Sanriku Town Nature Center at that time, had pointed out that excessive deployment of oyster culture rafts deteriorates the marine environment and worsen oyster growth, and such culture is therefore not sustainable. As the first author previously published a paper that mapped oyster rafts in Yamada Bay, Iwate Prefecture by satellite remote sensing (Komatsu et al. 2002), he showed the paper to Mr. Sasaki in September 2011. Mr. Sasaki requested him to map aquaculture rafts in Shizugawa Bay because the branch did not know the location of aquaculture rafts.

Oyster aquaculture in Shizugawa Bay is a longline raft system consisting of two horizontal ropes of 100 m, into which a rope of 200 m was folded 200 m in half, to which 20 buoys having a diameter of 1.5 m are linearly attached at equal intervals and around 160 vertical ropes of 8 m long suspending oyster clumps at vertical intervals of around 0.4 m (about 20 in total per vertical rope) attached at horizontal intervals of 1.25 m to two horizontal ropes (refer Fig. 6). Aquaculture of wakame is also a longline raft system consisting of only three horizontal ropes of around 65 m, into which a rope of 200 m rope was folded into three ropes, in which ropes with juveniles of wakame are inserted at intervals of 30–40 cm and 20 buoys having a diameter of 25 cm attached to the horizontal rope at equal intervals. The coho salmon is cultured in an octagonal iron cage with a side of 6 m or rectangle iron cage with a side of 13 m with buoys from spring to summer while the iron cages with buoys remain without a net from autumn to winter.

We examined changes in aquaculture rafts before and after the tsunami in Shizugawa and Tokura districts belong to Shizugawa Brach of Miyagi Prefecture Fishery Cooperative (Fig. 2), which manage the demarcated fishery rights in the bay head of Shizugawa Bay using available satellite images (Komatsu et al. 2019b).

On February 3, 2009, before the tsunami hit the coast, oyster culture rafts of Shizugawa and Tokura district waters were 471 and 916, respectively. On August 6, 2015, after the tsunami, they were reduced to 55 and 23% to those of 2009 before the striking of the huge tsunami in 2011, respectively (Fig. 3).

How was such reduction of the number of oyster rafts possible in the inner part of Shizugawa Bay? The Fisheries Agency of Japan launched "Gambaru Fishery Revival Support Project (fishery revival support project to do its best)" that supported fishermen who worked together and shared boats and facilities among them. In Japan, aquaculture farmers are also fishermen and compose a fishery cooperative with non-aquaculture fishermen in a community, and sometimes conduct fishing depending on the season. Under this project, in Shizugawa Bay, oyster farmers deployed a few oyster seeds, which had remained after the tsunami, in autumn 2011. Although it took about three years to grow the oysters to the market size before the tsunami, i.e., when oyster culture rafts were deployed overcrowdedly, once the raft density was forcibly reduced, it took only about 7 months to grow them to the market size. The oyster farmers shared this experience under the Gambaru Fishery Revival Support Project. The cooperative works among oyster farmers and equal sharing of income from fishery activities during the project permitted the farmers to deepen discussions on the use of their demarcated fishery right areas in each district. Two district areas of the branch succeeded to significantly reduce the number of oyster rafts thanks to the discussions (Komatsu et al. 2019a).

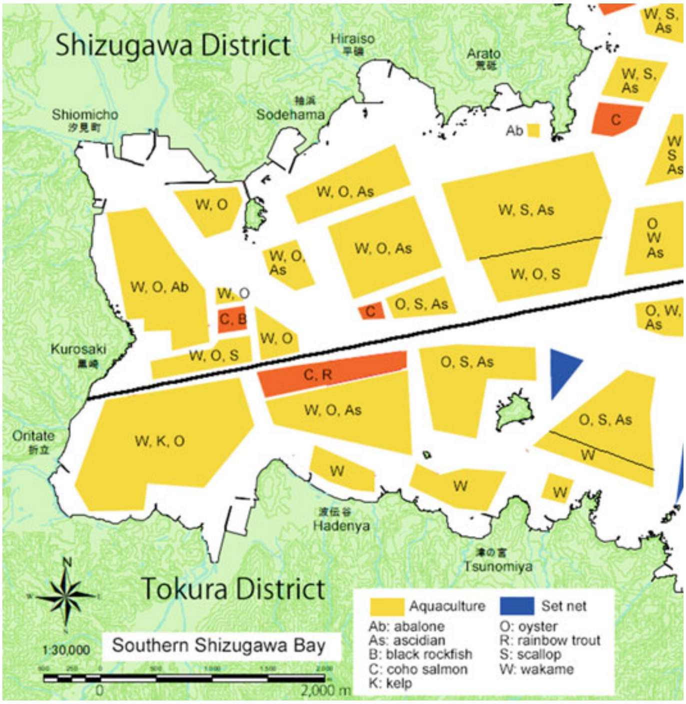


**Fig. 2** Map showing demarcated fishery right areas in Shizugawa and in Tokura district waters. Black line, and yellow and blue polygons indicate the boundary between two district waters, and demarcated fishery right areas of aquaculture and set net, respectively (Miyagi Prefecture 2018). Alphabets in the figure indicate target species that can be cultured in each area: abalone (Ab), ascidian (As), rainbow trout (R), black rockfish (B), coho salmon (C), kelp (K), oyster (O), scallop (S) and wakame (W)

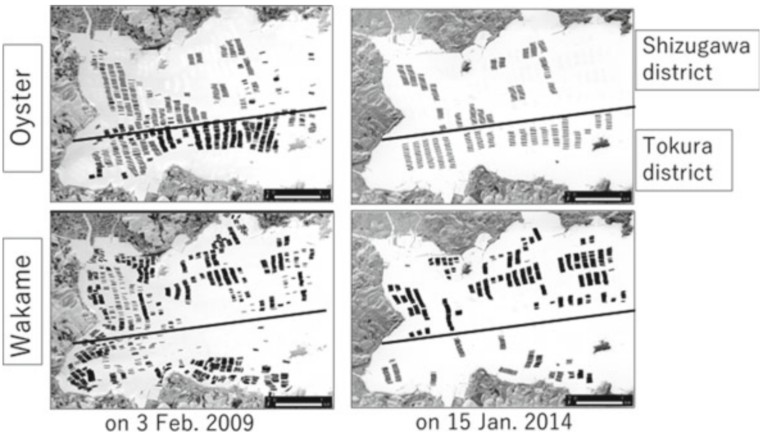


**Fig. 3** Distributions of oyster culture rafts (upper panels) and wakame culture rafts (lower panels) on February 3, 2009 (left panels) and January 15, 2014 (right panels). Bold solid lines indicate boundary between Shizugawa and Tokura district waters

## 3 Effects of Reducing the Number of Oyster Rafts on the Marine Environment

Sakamaki and Nishimura (2019) examined fresh weight of oysters cultured in net cages set at four places in Tokura and Shizugawa district waters of Shizugawa Bay (Fig. 1). The results showed that growth speed of oysters in Tokura district waters was greater than those in Shizugawa district waters (Fig. 4).

On the other hand, the density of particulate organic matters feeding the oysters was sufficiently distributed in the head areas of Shizugawa Bay. These observations suggest that the availability of oyster food depends on oyster density indicated as raft density, because oyster density impacts the water volume filtered by oysters and the water flow around oyster raft as resistance to flow. Hence, food availability in Tokura district waters with lower oyster raft distribution density is higher than that in Shizugawa district waters.

Oyster rafts require their regular maintenance to remove attached organisms on oysters and ropes. Attached organisms fall on the seabed and are decomposed by microorganisms by consuming oxygen that deteriorate the bottom environment. Oyster culture needs three years to produce market-size oysters with a high density of rafts. Thus, present regular maintenance operations to remove attached organisms on oysters and rafts might be one third of that before the tsunami. In addition, the rapid growth of oysters will reduce maintenance work and will provide more free time for farmers as well as improvement of the seabed environment. Recently, the number of young farmers is increasing with reduction of working hours and increase in wage.

Installing water tanks on the side of the fishing boat in the sea, Sakamaki and Nishimura (2019) measured organic carbon content in feces and pseudofeces) of oysters and the oxygen consumption rate for decomposing the organic carbon depending on ages of oysters (Fig. 5).

Pseudofeces are particles of grit which have been rejected by filter-feeding bivalve mollusks. The results showed that percentage of organiccarbon content in feces and pseudofeces and oxygen requirement for decomposing organic carbon increased with

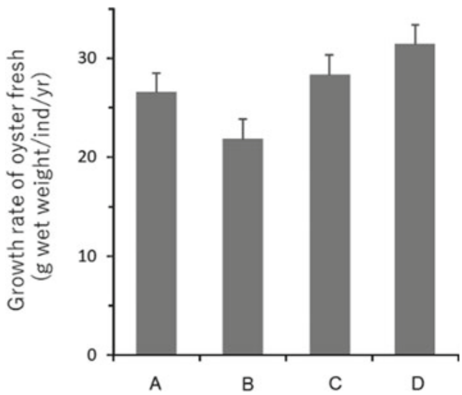


**Fig. 4** Growth rate of oyster cultured in net cages during one and half years (g wet weight per individual per year) at stations A and B in Shizugawa district waters and at stations C and D in Tokura district waters (see Fig. 1 for location of the stations)

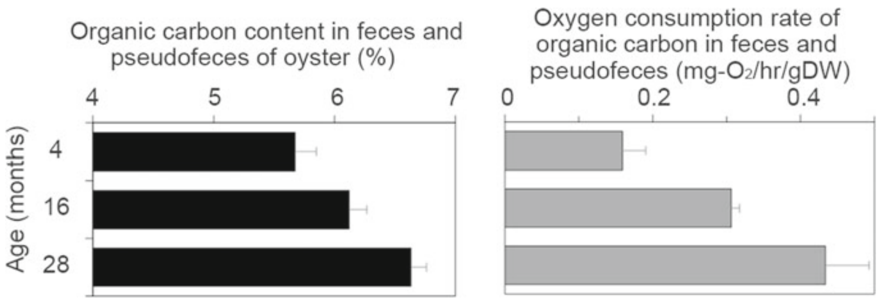


**Fig. 5** Organic carbon content in oyster feces and pseudofeces (left panel) and oxygen consumption rate for decomposing organic matter in oyster feces and pseudofeces (mg-$O^2$/hr/g-DW) (right panel) depending on ages of oysters

age of oysters. Young oysters efficiently absorb organic matters. Efficient absorption of organic matters by young oysters serves for the decrease in organic load from the oysters to the seabed through feces and pseudofeces. Scientific data demonstrate that shortening the culture period of oysters, by reducing oyster raft density, is good for the marine environment. We can say that this is a typical satoumi approach.

## 4 Nutrient and Dissolved Iron Circulations and Gardening Effect of Oyster Rafts as a Satoumi Activity

Montani et al. (2019) conducted a series of field surveys to clarify the whole picture of nutrient circulation in Shizugawa Bay. They monitored nutrient load and photosynthetic pigment concentration from the main three rivers flowing into Shizugawa Bay by sampling river water at their estuaries at intervals of one week from July 2014 to March 2015. They took water samples at stations located in a wide area of the bay over the four seasons in a year for measuring spatial distribution of nutrients and estimating standing stocks of nutrients in the bay. Seawater samples collected at a fixed point in the central part of the bay were brought to a laboratory on land for estimating primary production by the simulated in situ method of $^{13}C$. The oysters cultured in the bay were also brought back to the laboratory, and nutrient regeneration from their excrements was quantified over the four seasons. At the same time, the particle sedimentation flux was measured by deploying sediment traps during each season in order to estimate the impact of excrements from oysters to the aquaculture area.

The result showed that the nitrogen stock of oysters was comparable to the stock of the nitrogen pool in the innermost bay or surpassed it in autumn and had a great influence on the nitrogen circulation (Montani et al. 2019). In Shizugawa Bay, the nitrogen was a limiting nutrient factor. The nutrient supply from the river with narrow watershed was limited to the estuary, and from the open sea to the bay was dominant.

Montani et al. (2019) quantitatively surveyed nutrient flow between oysters and attached microalgae growing on oyster and ropes of oyster culture facilities by field sampling and laboratory experiments. When microalgae cover the substrates provided by oyster culture, some detached from them (Fig. 6). Oysters feed detached microalgae immediately by filtering seawater. Oysters excrete feces and urine which return to nutrients and are immediately absorbed by microalgae covering oysters and oyster culture facilities such as bouys and rope (Fig. 6). Montani et al. (2019) estimated that a regeneration rate of nutrient (DIN) by oyster per day is 7–8% of the nutrient pool in the cultured area of Shizugawa Bay. Oysters have a big impact on nutrient flow. Montani et al. (2019) named this relation between oyster culture and microalgae as "a self-gardening effect of oyster culture." Appropriate oyster culture is effective for gardening microalgae and makes material (nutrient) cycle longer and faster. Thus, we can say that appropriate oyster culture is a "satoumi" approach.

Dissolved iron in seawater, essential for the growth of marine plants, is supplied from the river to the sea, but it becomes iron oxide that algae cannot use. This iron oxide is heavier than seawater and sink on the seabed. Organic substances that form complexes with iron, such as humic acid and fulvic acid, prevent oxidization of dissolved iron. Based on the hypothesis that a broadleaf forest is an important source of such substances (Matsunaga 1993), the afforestation movement of fishermen called "The forest is the lover of the sea" is being carried out around Sanriku Coast. However, there were no quantitative studies on iron circulation that broadleaf forests affected. Fujii et al. (2019) examined dissolved iron and organic matter from the rivers for a year, as well as nutrients, every week, and dissolved iron and corrosive substances in the bay at four seasons. The supply of dissolved iron from the river to the bay was limited to the estuarine area due to low river inflow from their narrow

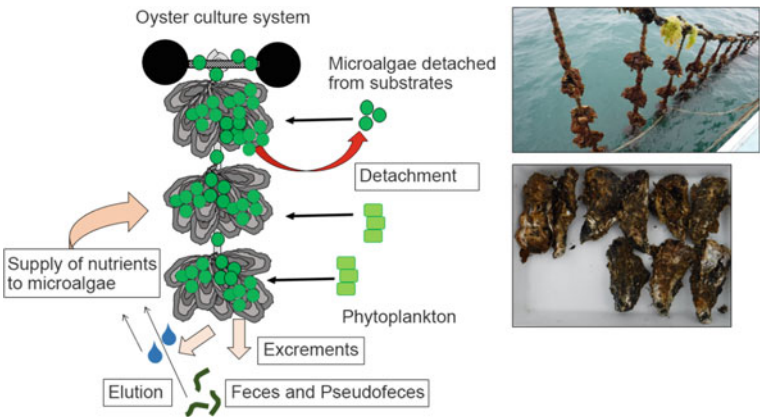


**Fig. 6** Schematic view of oysters feeding on phytoplankton and detached microalgae attaching on oyster shells and aquaculture facilities, excreting urine and feces and pseudofeces that are source of nutrient for microalgae (green circle) attaching on oyster shells and aquaculture facilities (left panel), and pictures of aquaculture facilities (upper right panel) and oyster shells (lower right panel) covered with attached microalgae

watersheds. The supply of dissolved iron is mainly from the open sea to the bay. In summer, it was found that the concentration of dissolved iron was lower than the half-saturation constant which suppresses the growth of diatom, which is the predominant phytoplankton in the bay, in the surface layer in the central area of the bay. There was no difference observed in the supply of corrosive substances between coniferous forests and broadleaf forests (Fujii et al. 2019). It is thought that broadleaf trees are better at controlling runoff and the loss of topsoil than abandoned coniferous forests without thinning or pruning. Good effects of the broadleaf forest on the coastal marine environment, rather than dissolved iron, should be assessed and used as a basis for afforestation activities of broadleaf trees (Komatsu et al. 2019a, b).

## 5 The Council for Future Marine Environment in Shizugawa Bay

Shizugawa Branch of Miyagi Prefecture Fishery Cooperative and us established the "Council for Future Marine Environment in Shizugawa Bay" with participation of officers of Minami Sanriku Town, Miyagi Prefecture and Ministry of Environment of Japan, WWF, Non-Profitable Organization and fishermen of Shizugawa Branch of Miyagi Prefecture Fishery Cooperative. It was held on April 30, 2015 (Fig. 7), May 16, 2016, January 16, 2017, October 11, 2017, July 31, 2018, and March 12, 2019.

Through that Council, the authors presented the research results conducted in Shizugawa Bay and discussed with the participants (Komatsu et al. 2019a). Aquaculture scenarios were co-designed for predicting marine environments and aquaculture productions with a physical–biological coupling ecosystem model using material circulation data obtained by the project. Scenarios included cultured species and the raft number. The predicted results were presented at the Council. Moreover, the office of Minami Sanriku Town presented progress in registration of macrophyte beds in Shizugawa Bay as a Ramsar site and situations of sea urchin barrens and its countermeasure since 2014. The WWF officer presented why an ecolabel of ASC (mentioned

**Fig. 7** Picture on the first Council for Future Marine Environment at Hiraiso Citizen Hall of Minami Sanriku Town on April 30, 2015. Participants were Shizugawa Branch of Miyagi Prefecture Fishery Cooperative, fishermen, researchers, officers of Miyagi Prefecture, Minami Sanriku Town and WWF, a journalist and us

later) for culture products is important for sustainable aquaculture. The Council discussed the fading color of wakame fronds because of low nitrogen concentration and global warming impacts on fish catch in Sanriku coastal waters.

## 6 Prediction Through Ecosystem Modeling and Discussion with the Council

Miyagi Prefecture is the number one producer of ascidians by aquaculture in Japan. Korea imported 70% of the Miyagi Prefecture production before the Great East Japan Earthquake in 2011. Korea has banned the import of all fishery products including ascidian from September 2013 due to suspection of their radioactive contamination caused by Fukushima Daiichi Nuclear Power Plant accident. Miyagi Prefecture Fishery Cooperative had to decrease ascidian culture production to adjust it to demand in 2018. Production of cultured scallops remains low because of the death of a large number of juvenile shells purchased from Hokkaido Prefecture. In the innermost area of Shizugawa bay, wakame fronds present fading colors due to less nitrogen concentration and have no commercial value except receptacle organs. In such situation, the Council decided to examine whether the cultures of scallops and ascidians conducted in the central bay could be converted to wakame culture or whether the number of wakame culture reared in the innermost area of the bay could be reduced to an appropriate number of rafts. Since discussion at the Council required scientific evidence, four scenarios on changes in aquaculture practices were co-developed by Shizugawa Branch of Miyagi Prefecture Fishery Cooperative and the authors of this article for predicting aquaculture productions including income from the productions and impacts on the marine environment through the Shizugawa Bay ecosystem modeling.

The four scenarios are as follows:

- Case 1: current condition (business as usual)
- Case 2: Reduction of wakame rafts to 75% of current number in the innermost area of the bay. Reduction of scallop and ascidian rafts to 75% of current number and conversion of reduced number of scallop and ascidian rafts to wakame rafts.
- Case 3: Reduction of wakame rafts to 50% of current number of rafts in the innermost area of the bay. Reduction of scallop and ascidian rafts to 50% of current number and conversion of reduced number of scallop and ascidian rafts to wakame rafts.
- Case 4: Reduction of wakame rafts to 25% of current number of rafts in the innermost area of the bay. Reduction of scallop and ascidian rafts to 25% of current number and conversion of reduced number of scallop and ascidian rafts to wakame rafts.

The results from the bay ecosystem modeling showed that the harvest of cultured wakame per raft was increased in proportion to the decrease in wakame culture

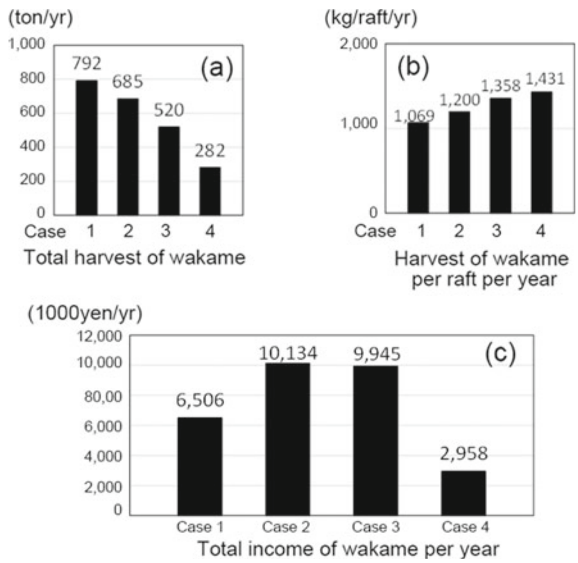


**Fig. 8** Total harvest of wakame (**a**: upper left panel), the harvest of wakame per raft (**b**: upper right panel) and the total income of wakame per raft cultured in the innermost area in a year (**c**) calculated by the Shizugawa Bay Ecosystem model based on four cases (Yamamoto et al. 2018)

while the total harvests in quantity (Fig. 8) and in cash were decreased in the innermost area (Yamamoto et al. 2018).

The total harvesting of cultured oysters in quantity and in cash was nearly not changed in any of the scenarios. Net incomes of one wakame raft depending on the four scenarios were estimated from the total production of one raft in cash and the total cost of wakame culture per raft. The income per raft under Case 2 scenario was the best among the four ones since the cost reduction due to the reduction of wakame rafts was balanced with the increase in harvest of wakame per raft due to an increase in nutrient availability (Yamamoto et al. 2018).

In the center part of the bay, the harvest of wakame under scenario Case 4 was similar to those under the other scenarios although it was slightly better. Case 2, 3, and 4 scenarios showed that the oxygen content of the bottom layer was improved from that under Case 1 scenario (Yamamoto et al. 2018).

Wakame needs nutrient (nitrogen) especially from late winter to spring, during its growth season, while phytoplankton and attached microalgae as food for oyster need nutrient from autumn to early winter, when oysters actively feed after spawning. Therefore, the increase in wakame culture rafts does not influence greatly the oysters' growth. Since oysters, ascidians and scallops are filter-feeders, converting the aquaculture of ascidians and scallops to wakame reduces competition between them. Clumps of scallops and ascidians suspended from the horizontal longlines offer a great resistance to flow and impede sea water exchange. Therefore, water exchange in the area of wakame culture converted from scallop and ascidian cultures is greater than in the area of the original scallop and ascidian cultures because wakame culture takes place only in the surface layer and offer less resistance to water flow than scallop and ascidian clumps. Then, nutrient inflow from the open sea is increased due to the decrease in the impediment. Thus, converting culture of scallops and ascidians to wakame is more sustainable for the marine environment of the bay and oyster culture (Komatsu et al. 2019a, b).

The results from the four different scenarios were presented and discussed with the Council members. Shizugawa Branch of Miyagi Prefecture Fishery Cooperative used the discussion as a reference for updating target culture species of demarcated fishery right areas in Shizugawa Bay. In that way, the Council can use the visualized scientific data to advance efforts toward a more sustainable marine environment and make fishery production compatible. By pursuing the Council's initiative, a rich, clean, and prosperous Shizugawa Bay might be possible. Such positive experience may be extended to other open inner bays, where the greatest anthropogenic impact of suspended and benthic material circulation is coming from aquaculture.

## 7 The Link Between Mountain and Sea: Ecolabels and Registration of Ramsar Site

The Aquaculture Stewardship Council (ASC) is a global organization that certifies aquaculture with little environmental impact in consideration of the local community. Aquaculture products in accordance with the standard of ASC can be shipped with an ASC ecolabel and be traced (Maekawa 2016). By succeeding in reducing the number of oyster rafts after the 2011 tsunami with data provided by Topic 2 of S-13, the first ASC certification to bivalve culture in Japan was given to oyster culture in Tokura district waters in May 2016 (Komatsu et al. 2018). Sound aquaculture, certificated with an ecolabel, leads to a rich, clean, and prosperous environment through satoumi (Matsuda 2007). However, Tokura district alone cannot preserve the marine environment of Shizugawa Bay. Since land use and the way of aquaculture in whole Shizugawa Bay are related to the marine environment of Shizugawa Bay, it is necessary to cooperate on a larger scale to keep the ecolabel for oysters cultured in Tokura district waters. In order to win many stakeholders' understanding, it will become more important to monitor the coastal ecosystem, make predictions with ecosystem models based on co-designed scenarios with stakeholders, and visualize the anthropogenic effects. It will be necessary to form a consensus among stakeholders through discussion within the Council.

Until recently, cutting of fuel woods, cutting undergrowth, thinning and pruning of trees have been conducted in the mountain near the village for obtaining fuel and natural fertilizer. This traditional wisdom of using forests sustainably is called Satoyama. Satoyama practice makes the trunk of the tree thicker, keeping the roots deep to make the forest alive and let the light penetrating the forest enough for undercover development, increasing biodiversity eventually. The Minami Sanriku Town Forest Association received FSC certification from the Forest Stewardship Council (FSC), which has its office in Bonn, Germany, in October 2015 (Maruoka and Yasumatsu 2016). The FSC mission is to promote environmentally sound, socially beneficial and economically prosperous management of the world's forests. Its vision is that FSC can meet our current needs for forest products without compromising the health of the world's forests for future generations. To achieve its mission and vision, FSC has developed a set of 10 principles and 57 criteria that apply to FSC-certified forests around the world. One of the criteria is as follows: Forest management shall conserve biological diversity and its associated values, water resources, soils, and unique and fragile ecosystems and landscapes, and, by so doing, maintain the ecological functions and the integrity of the forest. The water resources and soil of forest also influence coastal waters through river discharge. Ecologically sound forests can regulate discharges of water and runoff of surface soil through the river to the sea after heavy precipitation. In this way, FSC-certificated forests are equivalent to forests maintained by Satoyama practice. In Shizugawa Bay, FSC-certified forests are necessary to ASC-certified oysters.

The Convention on Wetlands, called the Ramsar Convention, is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. One of Ramsar site definitions is mangroves, coral reefs, seagrass beds, tidal flats, and estuaries, up to 6 m depth at low tide (Cybèle 2010). Minami Sanriku Town started to register seaweed beds in Shizugawa Bay because it is very rare that cold water species, *S. japonica*, and warm water species, *Eisenia bicyclis* (Kjellman) Setchell of Order Laminariales are distributed in the same bay. Shizugawa Bay is the northern limit of *E. bicyclis* distribution and the southern limit of *S. japonica* distribution. Shizugawa Bay is a wintering ground for brant, *Branta bernicla*, that is designated as an endangered species and natural monument of Japan. Conditions of its habitat in winter consist of a calm inner bay, stable and abundant distributions of seagrass and seaweeds distributed among rocky reefs as resting places. Shizugawa Bay meets these conditions and was registered at the Ramsar Convention Secretariat at Gland, Switzerland on October 18, 2018 before the 13th Ramsar Conference on Contracts held in Dubai from October 21, 2018 to October 29, 2018. This completes the link with suspended and benthic material circulation from the forest to Shizugawa Bay. Such a link enhances the symbiosis with nature and people that is one of the goals of Minami Sanriku Town after the huge 2011 tsunami (Minami Sanriku Town 2012).

## 8 Conclusion

In oyster aquaculture, it was shown that reduction of overcrowded oyster culture rafts to an appropriate density leads to the harvesting of commercial-size oysters in one year with a better sea bottom environment by efficiently using food resources for oysters and reducing the load of organic matter on the seabed through oysters' feces and pseudofeces. Results from physical–biological coupling ecosystem model indicate that the oyster culture increases the speed of nutrient circulation through the self-gardening effect of oyster rafts when the oyster aquaculture raft density is within a range where primary productivity in the bay is not reduced. In this way, satoumi practice enhances the speed of biological production including cultured oysters and promotes a sustainable aquaculture and sound marine environment.

The international ecolabeling of forests and oysters and registration of macrophyte beds as Ramsar site contribute to the improvement of suspended material circulation, leading to a sound marine environment with high biodiversity and productivity. In other words, satoyama and satoumi practices, corresponding to human relationship with nature for ensuring sustainable use of living resources in a sound environment while increasing biodiversity and productivity (Yanagi 2006), are efficient approaches for the management of coastal environment.

This coastal management approach has been developed in the case of Shizugawa Bay and can be easily expanded and applied to other rias-type bays where aquaculture is actively conducted. Hopefully, this kind of approach could be widely disseminated in various places of the world in the future, leading to a sound marine environment and sustainable aquaculture.

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# Innovation and Adaptation of Recent Oyster Culture Techniques in Japan

**Yasuyuki Koike and Tetsuo Seki**

**Abstract** After the tsunami disaster in 2011, oyster production in Japan declined due to the shortage of seed oysters and the reduction in culturing facilities. However, the current trend by Japanese consumers is to look for European style raw oysters served on a half shell as well as traditional cooked oysters. This trend has triggered a demand for high-quality oysters with local characteristics of flavor, size and taste. While the quantity of shucked oysters for mass retailers is decreasing, the proportion of whole oysters with shells that are shipped is increasing in relation to the demand for high-quality raw oysters. Recent efforts in Japan to establish local oyster brands based on diverse characteristics have been undertaken at local oyster production area through intense collaboration between oyster growers, fisheries cooperatives and local governments. Here, we introduce the latest innovative oyster culture techniques and report on the efforts targeting various trends in consumer demand. Innovation points in oyster culture in Japan. (i) Single-seed oysters: to grow oysters individually and the appearance of the shells; (ii) intertidal zone culture (Miyagi Prefecture): to grow oysters in their natural habitat, to make hard shells, to have tolerance to exposure to air and improve the quality of taste; (iii) virgin oysters (Miyagi Prefecture): to grow oysters before their maturation (in a year); (iv) culture in salt pans (Hiroshima Prefecture): to obtain a quality of taste with a special flavor like the oysters of Marennes, in France; (v) abyssal sea water treatment and culture: to control pathogens before shipping; (vi) marketing management: to adjust to recent consumer demands.

**Keywords** Oyster farming · Tsunami · Restoration · Single-seed oyster · Virgin oyster · Intertidal zone

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# 1 Changes in Oyster Production Around the Tohoku Region Before and After the Tsunami Disaster

Before the tsunami in 2011, the top oyster-producing prefecture was Hiroshima, followed by Miyagi, Okayama and Iwate. After the disaster, Miyagi and Iwate did not recover for several years, and Okayama's production was higher than that in Miyagi. Finally, in 2016, Miyagi's annual production recovered to about half of its previous production (Fig. 1; Table 1).

As oysters are one of the most important resources in fishery products for Miyagi Prefecture, the stakeholders have made extensive efforts in reconstruction since the tsunami disaster. As one path to recovery, the Miyagi Prefectural Government created a ten-year revival plan, setting three objectives for each fixed period: Recovery (the first three years), Rebirth (the next four years) and Progress (the last three years).

Not only the prefecture but also national and prefectural organizations and assessment companies have worked together to acquire reconstruction budgets to stabilize and reduce costs and to enhance efficiency in shellfish farming. The period for the budgets was five years, from 2013 to 2017. The organizations that participated in these projects are the National Fisheries Research Agency, the Miyagi Prefecture Fisheries Technology Institute, Kaiyo Engineering Co. Ltd., Sanyo Techno Marine

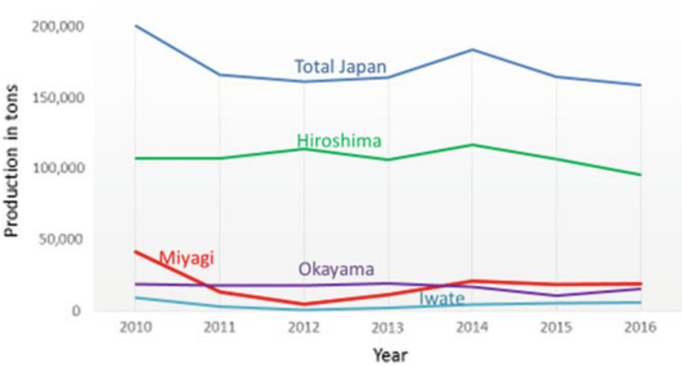


**Fig. 1** Recent oyster production in Japan. Statistics from the portal site of official statistics of Japan, e-Stat (2010–2016)

**Table 1** Recent oyster production in Japan (tons)

| Year | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|
| Total Japan | 200,298 | 165,910 | 161,116 | 164,139 | 183,685 | 164,380 | 158,925 |
| Hiroshima | 107,320 | 107,383 | 114,104 | 106,111 | 116,672 | 106,851 | 95,634 |
| Miyagi | 41,653 | 13,221 | 5024 | 11,581 | 20,865 | 18,691 | 19,061 |
| Okayama | 19,017 | 17,724 | 17,926 | 19,366 | 16,825 | 10,657 | 15,461 |
| Iwate | 9578 | 3288 | 565 | 2074 | 4774 | 5755 | 6024 |

Co. Ltd. and the National Institute of Advanced Industrial Science and Technology (AFFREC 2017). The projects' objectives are as follows:

(i) Establishing natural seedling technology
(ii) Cultivating single-seed oysters and virgin oysters
(iii) Creating culture techniques in the intertidal zone
(iv) Increasing consumer ratings
(v) Doubling producer profits through improved marketing.

Details of these objectives and practices are as follows;

(i-A) As a natural seedling technology, technical guidance was given to help fishermen confirm the oyster larvae. This technology helps to determine when the collector must be put in the sea by recognizing the oyster larvae among captured plankton and calculate the density at each growth stage and the collection point (Fig. 2a, b).

(i-B) A model for trace estimation of oyster larvae in the field at Matsushima Bay was established from the integrated data of the current strength and direction in the field. The result makes it possible to estimate the period and point of setting the collector in the fishing grounds, thereby increasing efficiency.

(ii) At Shizugawa Bay, single-seed oysters, called Amakoro kaki, are grown from natural spat, cultured under conditions of low density and a plankton-rich sea surface. Under these conditions, the growth rate is very high, and they can be marketed within one year, before their maturation. Just after the tsunami, the cultures' installations and longlines were almost washed away, so a cooperative of oyster growers in Shizugawa Bay decided to limit the number of these installations suitably to the surface of the bay area (Komatsu et al. 2018).

(iii) At Matsushima Bay, the intertidal zone culture for single-seed oysters is carried out in baskets installed at the mid-tidal level. The characteristics of these


**Fig. 2** Wild spat collection. **a** Promotion and lecture of spat detection for the oyster growers: species, identification, development, density, etc. [from: Agriculture, Forestry and Fisheries Research Council (2017): The results pamphlet]. **b** A young oyster grower of Matsushima-Coop., detecting the oyster larvae. (© Y. Koike). After this lecture, the number of oyster growers who offered their own microscopes has increased


**Fig. 3** Intertidal zone culture from single seeds, Atamakko kaki, in Matsushima Bay (© Y. Koike). **a**, **b** Cages for the single-seed oyster hanged in the mid-intertidal level using the traditional shelves of bamboo. **c**, **d** Tetsuo Seki checking his experimental culture site

oysters include a small size, hard shell, strong survivability in air and firm muscle texture [Atamakko kaki]. The culture method must be reasonable for Japanese oysters to fix and grow in the intertidal zone under natural conditions (Fig. 3).

To culture the single-seed oysters in France, plastic plates called 'Coupelle' which have been developed in recent years instead of old roof tiles are used in many oyster grounds now. Thin plastic plates are convenient to handle and do not hurt the spats even when using the releasing machine with a rotating brush. In traditional culture system in Japan, open scallop shells have been used for the collectors for a long time (Fig. 4). To culture the single-seed and the higher-grade oyster with well-shaped shells, the cooperative of Matsushima Bay has imported these Coupelles and releasing machine from France. Fishermen and some cooperatives in Miyagi have also learned and adapted the technique of intertidal zone culture (Quéro and Quéro 2016).

(iv) As consumers' evaluation of the products in cases (2) and (3) was very high, they were commercialized under the brand names of 'Amakoro kaki' for case 2, 'Atamakko kaki' for case 3.


**Fig. 4** Spat collectors. **a**, **b** Plastic plates called 'Coupelle' in France (Arcachon). **c**, **d** Open scallop shells in Japan (Matsushima Bay). (© Y. Koike)

In consumers' evaluation of Amakoro kaki, two of the four target elements, 'texture' and 'flavor' were slightly inferior to the oysters of other regions; 'aroma' prevailed slightly, but it gained a high reputation in the overall evaluation by 'appearance.' This evaluation was an interesting result in that it showed the importance of appearance when serving raw oysters with shells.

An analysis of four amino acids in oysters as evaluated by the consumers was investigated. The results showed that a higher content of the four amino acids—glycine, alanine, threonine and serine—was found to increase the sweetness. This result was useful as an index for oyster product brands from various places.

Traditionally, oyster distribution in Japan has involved 'shucking,' and most oysters have been served as cooked hot. However, in recent years, the European style of oyster consumption has grown in popularity, that is, raw oysters served on a half shell. In big cities, the number of dedicated oyster bars and restaurants has increased, and many raw oysters are served using the European style. The marketing style is changing slowly to distribute whole oysters with shells instead of shucked oysters. After the tsunami disaster, the number of workers as oyster shuckers declined because they are members of oyster grower's family and it was difficult to find time of working as before the


**Fig. 5** Marketing revolution: estimation of oyster growers' annual income. **a**, **b** Preparing shucked oysters at a cooperative. **c** Shucked oyster for heat cooking in a market. **d** From growers and coops. **e** Direct ordered from Internet. **f** Restaurant and oyster bars (© Y. Koike)

disaster. In this situation, the oysters grown from single seeds are in greater demand than before. In other words, the demand for farmed oysters has been added to the demand for traditional shucked oysters, by marketing live oysters with shells. This has gradually changing to a diversified distribution style.

(v) A new method to distribute whole living oysters with shells is now being investigated in the market. This will enable the products to be distributed directly from the cooperatives or growers to the consumers without the middle margin. The production rate is anticipated to be about two times higher, and this is expected to double the annual income (Fig. 5).

## 2 Innovation in Culture Technology in All Regions of Japan

Innovations in culture technology have been attempted in order to improve the quality of oysters in several regions in Japan. As a result, culture techniques are now carried out that reflect the geographical characteristics and the marine environment of various places, and high-quality oysters are produced. The number of branded oysters in Japan has risen to about 300. In the future, it will be necessary to consider regional and national standards which unify the quality evaluation of the brand.

## 2.1 Some Examples of Branded Oysters

### 2.1.1 Green Oysters of Farm Suzuki[1] in Hiroshima Prefecture in the Seto Inland Sea

At Farm Suzuki, situated Ohsaki-Kamishima in Hiroshima Prefecture, the green oysters are produced under the conditions and historical techniques as those in Marennes-Oléron, in France, using the traditional former salt fields in this region.

The owner of this farm has learned and adapted the same techniques which have been handed down in Marennes-Oléron in France (Ouest and Lavl 1999. http://www.huitresmarennesoleron.com). In the old salt fields, a special green phytoplankton occurs under some conditions when seawater is kept for several months. Single-seed oysters grown here will change the color of their gills to green, and they have a special taste and aroma. The owner of this farm provides this oyster brand in the restaurant located in the same facility, and it is widely promoted by the Internet for distribution.

### 2.1.2 Development of a Culture Technique by Using the Deep Seawater of General Oyster Group and Human Webb Co., Ltd.[2]

This group developed a purifying technique by using the deep-sea water in Toyama Prefecture and ultraviolet-radiated seawater at the cleaning facility. Oysters produced in various regions in Japan are gathered at this facility and purified before marketing.

The group is developing a full culture system for oysters on Kumejima Island in Okinawa, using the deep-sea water and feeding them with cultured phytoplankton in the tank. This system enables the production of safe, virus-free oysters (Seki 2012). As the demand for raw oysters with shells increases, it can be said that this is an effective technological innovation not only for domestic demand but also as an export resource.

## 2.2 Considering the Change in Dietary Habits Regarding Oysters in Japan

In Japan, oyster farming has been a productive endeavor for many years. About half century ago, oysters were mostly heated and cooked because it took time to transport them from the region of production to the consumption area. Most oysters were shucked in preparation for cooking before they were traded. They can be simmered, potted, grilled, fried, etc. Fried oysters are, in particular, very popular in Japan, and

[1] https://www.farmsuzuki.jp/.

[2] https://www.oysterbar.co.jp/.


**Fig. 6** Recent gastronomic variations in Japan, marketing for both raw and heat cooking. **a** Cooking by steam at Kaki-Goya (Oyster cabin). **b** Frozen shucked oysters. **c** Fried oysters prepared for family use. **d** Single oysters with shells for raw dish. **e** Shucked oysters for eating raw or cooked. **f** Raw oysters on half shell served at oyster bar (© Y. Koike)

in some restaurants, fried oysters are served year-round because they can be frozen and stored. In many supermarkets, fried oysters are prepared for family use.

For the Japanese people, oysters are considered as an ordinary, plain dish. Even now, most oysters are shucked before delivery, which is generally the distribution system that best fits the consumer's needs (Fig. 6).

Over the last decade in Japan, it has become more apparent that the oysters are being increasingly treated as a high-class food from the usual dishes, and the distribution of whole living oysters with shells has gradually increased. However, many oyster growers still produce shucked oysters in the usual way, according to our traditional dietary habits.

In France, almost all oyster productions are sold fresh and eaten raw straight from the shell. Oysters are considered a special dish for parties at the end of the year such as Christmas and New Year's Day. Therefore, most oyster consumption in France occurs in December and January (Buestel et al. 2009).

As such, the eating habits and method of preparation cannot be easily compared between the two countries. To change or increase the quality of the products, consumers' tastes must be well reflected. The technical exchange on the oyster culture between Japan and France started at the end of the 1960's, when French oyster farming suffered much damage from disease. To solve this problem, oyster spats were sent from Miyagi Prefecture to France for transplanting in the farming area (Buestel et al. 2009; Mariojouls and Prou 2015). After the big tsunami disaster in Japan in 2011, a French cooperative of oyster farmers sent gear such as ropes and buoys to the

Sanriku regions. This was called the Okaeshi project, and relations have continued between the cooperatives of the two countries (Koike 2015).

At the French–Japanese Oceanography Symposium in Bordeaux, many Japanese researchers and the chief of oyster farmers of Kesennuma cooperative gave assistance, and before the conference, they visited two famous oyster farms, Arcachon and Marennes. At these oyster farming grounds, they exchanged technical knowledge and discussed the special production of these regions to compare with that of Japan. Among the French and Japanese cooperatives, they also planned an exchange of visits for young oyster farmers between the two countries to share techniques and know-how. These techniques and knowledge are not directly adaptable, but they must be modified to be suitable for the region's natural and economic conditions.

## 3 Conclusion

The restoration after the disaster in Tohoku is still ongoing, even after six years; however, new techniques and methods are being adapted and realized.

After the tsunami, the number of oyster growers decreased about 75%, but annual production in Miyagi Prefecture has now increased to almost half of its previous production.

The research project is considered to be a success. Much technical progress is recognized everywhere, especially for the density of facilities on the sea surface.

To change or increase the quality of the products, consumers' tastes and economic background must be well reflected.

As one of the results of the Bordeaux symposium, technical exchanges between young oyster farmers of Japan and France have been discussed, and technology development in both countries is anticipated.

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# Innovative Role of Restoration Support for Tsunami-Affected Oyster Farming in the Karakuwa District, Miyagi Japan, Contribution to the Rationalization of Fishing Ground Management

**Masanori Hatakeyama and Tetsuo Seki**

**Abstract** The Great East Japan Earthquake and caused the tsunami on March 11th, 2011 that destroyed much of the fisheries infrastructure along the North Pacific coast of Japan. After this disaster, most of the oyster growers of Karakuwa district have been sitting in a shocked condition in the evacuation facility. However, the role of restoration support by iLINK Inc. who conveyed the earnest desire of consumers for Karakuwa oysters and the aid from home and abroad awakened the grower's mind back to the ocean. To restart oyster farming, it was necessary to overcome difficulties arisen before the tsunami disaster. Through the continued discussion, members of Karakuwa Branch, Miyagi Fisheries Cooperative Association decided new agreement to solve problems such as overcrowded raft setting, irregular growth of oyster caused by interference of the current flow and old customs blocking efficient utilization of fishing ground. Based on these agreements an improved and rational oyster farming system has started with a goal of rationalizing production for the future. The interactions with the restoration supporters have enabled the fishermen to look at their work from a new prospective. Now the oyster growers have realized the significance of oyster farming which is watched with keen interest by the consumers. Interchanges between restoration supporters for tsunami-affected oyster farming inspired the minds of growers' and contributed to the innovative and rational oyster farming.

**Keywords** Restoration support · Tsunami · Oyster farming · Karakuwa Japan

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# 1 Tsunami Disaster and Oyster Farming in Karakuwa, Kesennuma Japan

Fisheries grounds for oyster farming in the Karakuwa Branch, Miyagi Fisheries Cooperative Association (MFCA) are locating along both sides of the Karakuwa Peninsula at the northern end of Miyagi Prefecture (Fig. 1). Oyster farming in this area was started in the 1930s and has since developed (MPG 1994). The Great East Japan Earthquake and caused the tsunami on March 11th, 2011 destroyed North Pacific coast of Japan. It left 10,455 dead, 1297 missing and a total of over 9 trillion yen ($79.73 billion) damage in Miyagi Prefecture. In the MFCA, a total of 392 members died, 5341 housing were damaged, and 35 billion yen ($310.01 million) of total damage occurred (Seki 2018). In the Karakuwa district, among a total of 960 fishing vessels, 640 were washed away. The geographic feature of rias coastline enhanced the effect of the tsunami wave which ran up to 40.5 m (Miyako, Iwate Prefecture) and a maximum inundation height was 28.8 m (Iwaizumi, Iwate Prefecture). In Karakuwa, the tsunami runs up to a height of 12 m and inundation height was 8 m. By this tsunami, every oyster farming raft, shucking house with depuration facility was lost.

Before the tsunami disaster, Karakuwa Branch, MFCA had approximately 1200 (include 800 associate members) fishery members who engaged in aquaculture and boat fishing. In 2018, members have been reduced to 850 (include 664 associate members). Oyster growers in the Karakuwa Branch were 30 members before the disaster and now reduced to 15 members. Besides the self-retirement of growers due to old age, inefficient growers whose production had not reached to a standard level were also requested to retire. Annual fisheries turnover of oyster, the seaweed *Undaria*

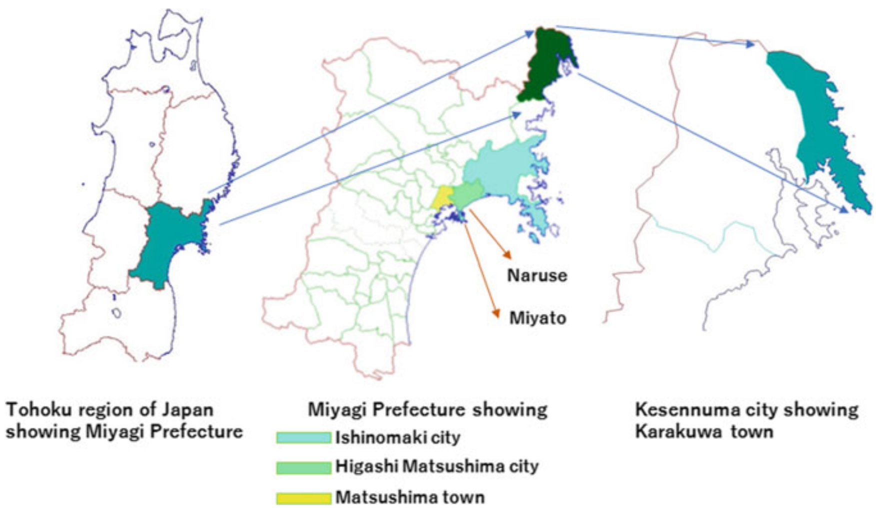


**Fig. 1** Location of Karakuwa district in Kesennuma City, Miyagi Prefecture, Japan

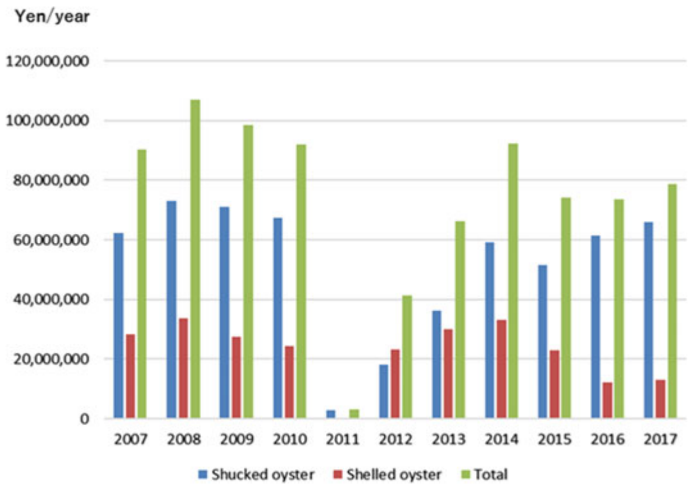


**Fig. 2** Record of annual oyster yield in the Karakuwa Branch, Miyagi Fisheries Cooperative Association (yen/year)

(wakame), scallop and boat fishing at the Karakuwa Branch has been maintained at about 700 million yen ($6.2 million) level before the disaster. By the tsunami, it was reduced to only 100 million yen ($885,185) in 2011. After 2015, aquaculture production has recovered to closer to the former level (Figs. 2 and 3). Oyster production of shucked was 42.7 tons and shelled was 700,000 individuals in 2010 and no production in 2011. In 2017, a distinct recovery was achieved 79 million-yen ($699,734) of annual turnover with 42.3 tons of shucked oysters and 664,000 shelled oysters (Fig. 3).

## 2 Restarting the Process of Oyster Farming After the Tsunami

Although many fishing vessels were lost, the private boat of myself (Mr. M. Hatakeyama) was fortunately found safe. One of the author's (Mr. M. Hatakeyama) motivation to be an aquaculture grower came back while checking the damaged fishing ground from the boat where fishing gear debris had been scattered. To motivate the affected aquaculture workers, it was considered that usual boat running opportunity as before may recall inclination to work. Most of the habitants in the Karakuwa district know that a strong earthquake causes tsunami and the saying "protect yourself first and your boat next against tsunami" has been handed down. So, 10 fishermen took their boats into the offshore area before the tsunami hit and came back the next day. Even though several boats became available, most growers have been sitting in their devastated condition in the evacuation facility until the end of March. During

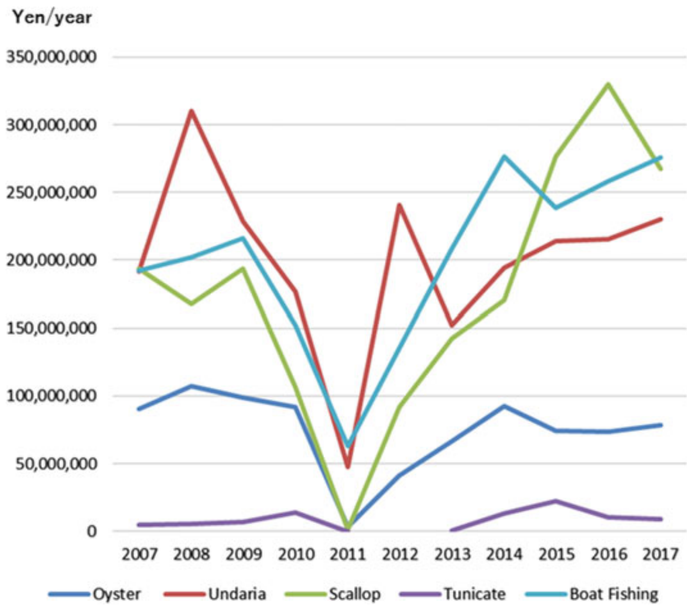


**Fig. 3** Record of annual aquaculture and boat fishing yield in the Karakuwa Branch, Miyagi Fisheries Cooperative Association (yen/year)

this time, the president of iLINK Inc. (an oyster dealer company by internet shop), Mr. Hiroaki Saito, visited Karakuwa to convey an earnest desire of consumers for Karakuwa oyster from all Japan hoping for a prompt restart of oyster farming. He proposed restoration support to establish an ownership system for oyster production (prepaid system to purchase produced oyster prior to its farming include production supporting donation to be the farmer's fund) with approved members. By this request, the motivation to return to work on the sea was strongly inspired. Soon after, plans for debris collection in the sea were approached to MFCA Karakuwa Branch members two weeks after the tsunami. In one week of debris collection work, some 30 fishing boats had been recovered. These activities revitalized the solid will of the members to work on aquaculture again. As the consensus to restart aquaculture farming become realistic among Karakuwa Branch members, the reconstruction project team was formed in the Karakuwa Branch with the leading role of Mr. Yasuhiro Obama and one of the authors (Mr. M. Hatakeyama). To discuss the course of future aquaculture in the Karakuwa Branch, a meeting of all the members was held. Most of the oyster growers hoped to restart farming around the beginning of April in 2011. Then, the office work continuation was announced to the Branch office staffs and an immediate action to procure farming materials as well as seed oyster and scallop was directed. At this time, one of the authors (Mr. M. Hatakeyama) took over as the Chairman of the Management Committee of Karakuwa branch by the offer of Mr.

**Fig. 4** The suspending oyster seed collectors so-called "ren" at the shelf of the intertidal zone (each of the "ren" folds down in the middle to hook)

Hiroshi Tachibana, the former Chairman, who encouraged further restoring management of the Branch will require enough experience in aquaculture rather than the former Chairman's boat fishing specialty.

As the majority of oyster seeds in Japan have been collected mainly in two coastal areas of Matsushima and Ishinomaki in Miyagi Prefecture, damage by the tsunami caused a severe shortage of seed for countrywide oyster farms. Though the difficulty of seed oyster procure was predicted, we had the contacts from both of oyster seed collectors in Miyato and Naruse coastal area in Miyagi Prefecture. Since Karakuwa oyster growers had purchased seed oysters from these collectors for a long time, they offered us to use survived seeds for restarting oyster farming. Although our order of seed oysters prior to the tsunami was 1000 rens (1 ren of oyster seeds consists of 72 half-shells of scallop tied with steel wire through the center hole of the clutch. Figure 4), their kind offer was to provide 3000 rens. By this, our oyster seed has been ensured to restart farming. Additionally, Mr. Saito of iLINK Inc. informed us an advantageous condition of Karakuwa Branch to procure farming materials to deliver from the only one functioning factory contracted since Karakuwa was the only operating organization at that time.

## 3 Supports to Restore Farming Oyster Yearning for Karakuwa Oyster

Soon after the restart of oyster farming, the television news media visited Karakuwa and our endeavors to restart were broadcasted. Although our action to restart oyster farming one month after the tsunami received surrounding criticism because of busy circumstances to clear debris elsewhere, our news was noticed by the Section Manager of Fisheries Division of Hiroshima Prefecture, the major oyster producing prefecture in Japan. This section manager Mr. Yutaka Miyabayashi visited our district to make an on-the-spot inspection of our immediate action of oyster farming restoration in the tsunami-stricken site. He had to come to Karakuwa since we were the only group who had been engaging in oyster farm restoration. He enquired about what sort of support would be a most effective help for us. We showed him the vacant farming sea surface due to the loss of the entire oyster rafts and explained the necessity to procure rafts. After this inspection, the Hiroshima prefectural assembly approved a revised budget for disaster recovery of oyster farming in Miyagi Prefecture. Forty days later, the authority of Miyagi Prefecture and MFCA sounded us out about the applicability of material bamboo for rafts, float and binding wire accommodated by Hiroshima prefectural authority. Immediately we requested the necessary materials to build a total of 200 sets of oyster rafts including 100 sets for neighboring Oshima Branch, MFCA. These materials were delivered till July that year. In July, the governor of Hiroshima Prefecture Mr. Hidehiko Yuzawa visited Karakuwa and inspected the arrived materials together with Mr. Rikitaro Abe, Chief Director and Mr. Ryuhei Funato, Managing Director of MFCA, and Mr. Kazuyoshi Hatakeyama, Chairman of Miyagi Prefectural Assembly. Surprisingly Hiroshima prefectural authority looked for 13 volunteer oyster growers in Hiroshima and seconded them to Karakuwa for three days of raft building work assistance. A total of 45 members consisted of oyster growers at Oshima Branch, Karakuwa Branch and Hiroshima plus other volunteers started raft building in early August (Fig. 5).

Members of the Oshima Branch were asked to join before their meeting, and the Oshima members commented deep appreciation for such a party of cooperation and they might quit oyster farming if the Hiroshima members had not provided such support. At the end of work, everybody has been reluctant to leave with a tear.

Soon after the Hiroshima support, there was another restoration support offer from France through the contacts from iLINK Inc. Namely, NPO Planet Finance

**Fig. 5** 45 oyster raft construction workers with supporters (oyster growers from Hiroshima, Karakuwa and Oshima branch members and volunteers)

who coordinated the "France Okaeshi (return gift)" project, airlifted materials for oyster culture from France with the received subsidy of France Foundation and a donation from Brittany Chamber of Commerce. By this project, we received a total of 7 tons of materials for oyster raft construction such as floats for rafts and ropes for long line-systems. Additionally, plenty of supporting workers as volunteers arrived since Karakuwa Reconstruction Supporting Committee had established by the work of Sontoku Ninomiya Houtoku Shrine in Odawara, Kanagawa Prefecture. Many travel agents who approved this Committee such as Japan Travel Bureau Foundation, Meitetsu World Travel Inc. helped to recruit further volunteer helpers. By these kind of support, reconstruction operations at the Karakuwa district progressed promptly.

The Japanese government established the Reconstruction Agency in February 2012 and published the Basic Guidelines for Reconstruction to the Great East Japan Earthquake. Based on these guidelines, Miyagi prefectural authority applied for a subsidy for the reconstruction of the fishing port and aquaculture facilities. Money for many of the subsided fishing wharves by the earthquake including the Karakuwa fishing port had been raised by this subsidy budget for the northern Pacific coast. Aquaculture related facilities in the Karakuwa Branch such as marine equipment, buildings for shucking, depuration and warehouses have been reconstructed using the fund from the national government (378,338,197 yen, $3,323,477) and prefectural authority (94,606,901 yen, $831,065). The Nippon Foundation offered a public subsidy for community revitalization and damaged facility improvement after the disaster. Among the applications to this offer, MFCA application for the project of "shelled oyster branding strategy" was adopted. The Karakuwa Branch has been playing the leading role of shelled oyster popularization and sales promotion as a member of this project.

## 4 Innovative Agreements for Rational of Fishing Ground Utilization Aiming at High-Quality Karakuwa Oyster

To improve problems considered to be resolved before a tsunami disaster, a thorough discussion was necessary by repeated meetings before the restart of oyster farming. Since the tsunami washed entire aquaculture facilities away, a rational and productive placement of farming rafts became possible avoiding the overcrowded setting and irregular growth of oysters caused by current interference. Although it was not possible to improve long-held local customs that have been blocking the control of raft setting before the tsunami, the necessity for an efficient fishing ground utilization was gradually understood. As all the members lost properties impartially and ocean had become empty, an insistence of vested rights lost convincing power.

Reconstruction of aquaculture in the east and west side of the Karakuwa peninsula was specifically planed separately. Restoration targets of the aquaculture facilities on the east side of the Karakuwa peninsula, facing offshore and rough waves, were set for the culture of the seaweed *Undaria* (wakame), scallop and tunicate. Contrary, on the sheltered west side of the peninsula, facility restoration was targeted for oyster and scallop. Although these improvements have been achieved by the cooperated work of all the members in the Karakuwa branch of MFCA, the farming division of the fishing ground was allocated from Karakuwa branch MFCA adjusted to the individual competence of household economy and physical labor. Since each grower is a manager of a sole proprietorship, their managing capability as well as operating power is not applicable to the cooperating and uniform work through daily care to harvest. Usually, in each prefecture, the governors have authority over aquaculture and grant fishing rights for oyster farming, in consultation with the Fisheries Coordinating Committees, every five years. The head of each Fisheries Cooperative branch can recommend candidates to be granted a right to farm oysters if they have been engaged in fisheries work for more than 90 days a year and have experience in fisheries. Rights are granted following a review process. So, the granted grower has rights evenly to culture oysters in the branch managed fishing grounds. However, in the Karakuwa Branch, renting a number of rafts were decided to share differently depending on each grower's ability. We also agreed to the following objectives aiming at producing higher quality oysters into some 20 years in the future.

- All members should establish the Karakuwa brand products by the new fishing ground.
- Utilization of the demarcated fishing ground should be maximized rationally.
- Every sale of the products should be undertaken through MFCA.
- Hanging culture rope length, number of hanging ropes on one raft, spacing between hanging ropes should be standardized.
- Confiscation of the fishing ground allocation will be considered if one's third year production result was insufficient due to an intentional idle work.

To ensure suitable conditions for rationalized fishing ground utilization and excellent growth of oysters and scallops, a further restriction was stipulated. Namely, 70% of the wooden raft system, which had been fully occupied at Karakuwa fishing ground before tsunami, has been altered to a long line-system due to its advantage. As the narrow structure of the long line-system (width: 1 m) provides enough space for harvesting boat without stepping on to the raft. Additionally, the long line-system holds only two stem ropes to suspend the oyster ropes in both sides of float arrangement, it allows more seawater to flow than wooden raft system. Also, this system is highly resistant to rough waves. The rest of 30% of wooden rafts were kept holding seed collector rens before each piece of scallop clutch with seed oyster was separated and tied to suspend culture rope. Since one of the 100 m long line system require 1.48 times more area than wooden raft (former wooden raft: 4.5 m $\times$ 9 m, long line system 1 m $\times$ 100 m) (Fig. 6), total number of raft system were reduced to 1400 from the previous 2000 in the Karakuwa Branch fishing ground. This resulted in the avoidance of overcrowded conditions. Also, hanging oyster ropes to suspend in long line-system was set to be less than 9 m, interval of each hanging rope to be more than 50 cm. Wooden (bamboo) raft system dimension was altered from the former size of 9 m $\times$ 4.5 m to 6.5 m $\times$ 13 m to enhance the seawater flow for the middle portion of rafts. Number of hanging ropes from one raft also was limited to be less than 240

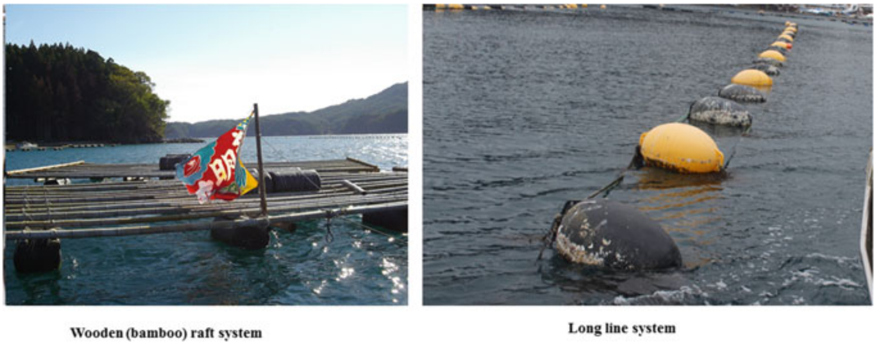


**Fig. 6** Features of a wooden raft system and a long line system of oyster culture

(10 lines × 24 rows). Presently approximately 160 oyster ropes were suspended in most of the rafts. Thus, carefully attained agreement and closely united membership of the Karakuwa Branch oyster growers resulted in the same level of annual turnover as before with a higher unit price and scarce loss (Fig. 2).

## 5 Developing Interchanges Among Oyster Growers of Home and Abroad

After the French Okaeshi project, one of the authors (Mr. M. Hatakeyama) had an opportunity of visiting Bretagne, France in October 2012 to exchange fisherman's experience between both countries together with 4 nominated fishermen from Iwate and Miyagi prefectures. This was arranged by the leadership of Bretagne University and French companies to aid tsunami-affected fisheries in the Sanriku region (Northern Pacific coastal region). From Miyagi Prefecture Mr. Masanori Hatakeyama was nominated by MFCA since an introduction of the restoration status of the oyster farming area was considered a matter of interest in France. Around this time several French groups had agreed to aid affected oyster farming areas. The Société franco-japonaise d'Océanographie of Japan (SFJO-J) and France (SFJO-F) members had discussed with researchers and fisheries cooperatives members of the Sanriku region and decided to donate microscopes and plankton nets to the organizations in Miyagi and Iwate prefectures for their examination of oyster larvae (Koike 2015). Prof. Catherine Mariojouls, the President of the Association of the Development of Aquaculture, visited Sanriku region and related organizations and regional fisheries cooperatives at the end of the year 2011 to encourage them (Koike 2015). Following Dr. Hubert-Jean Ceccaldi, the president of SFJO-F and Dr. Georges Stora of Centre d'Océanologie visited there in February 2012, accompanied by Dr. Yasuyuki Koike (Member of Maritime and Fisheries Promotion Society in Tokyo University of Marine Science and Technology, Counselor of SFJO-J). In September 2012, a French delegation of 14 members including eight oyster farmers visited the damaged areas and a joint seminar was held at the Tohoku National Fisheries Institute in Shiogama (Koike 2015). During this seminar, one of the authors (Dr. T. Seki) introduced the status of oyster farming in the Miyagi region, and oyster growers of both countries exchanged their experiences. Based on the proposal of Mr. Olivier Laban (President of Aquitaine and Arcachon Regional Committee of Shellfish Culture), who was the president of First Oyster World Congress at Arcachon from 28 November to 2 December 2012, Dr. Tetsuo Seki attended the Congress session at Arcachon to present topics of oyster diseases and their prevention in Japan (Seki 2012). Prior to the 16th Japanese–French Oceanography Symposium in Shiogama Japan from 19 to 20 November 2015, French delegation of 14 members of SFJO-F visited Karakuwa on 17 November 2015 to observe our oyster farming on the course of restoration observing excursion along with Sanriku coastal areas (Koike 2016). Then SFJO offered us to attend the 17th Japanese-French Oceanography Symposium and one of the authors Mr. Masanori Hatakeyama attended the symposium at Bordeaux University and the excursion to Arcachon. Thus, SFJO members of both countries have been interchanged earnestly between French and Sanriku oyster growers. As disturbances of oyster diseases and toxic algae contamination commonly occur around the world, oyster growers are hoping to share their experiences to overcome difficulties. Therefore, the further necessity of interchange among oyster growers of home and abroad was discussed at the 11th All Japan Oyster Summit (Oyster Growers' representatives' meeting) in Okayama 13–14 July 2018.

## 6 Conclusion

Presently, most of the fisheries (aquaculture and boat fishing) in Karakuwa Branch MFCA has been restored to the previous production level by intensive reconstruction support. However, the huge subsidy budget from the national government, prefectural government and municipality left continuous payment of own expenses. Even though each item was a small amount, procurement of all items, that had been prepared in tens of years, at one time was the cause of the present difficulty.

As a lone-wolf characteristic fisherman has been subjected to the restoration work in the cooperated condition, the joint management type of business become acceptable and "Kaki-goya Karakuwa Banya (Grilled oyster serving log cabin Karakuwa)" was established by cooperated management. Most of the fisherman in Karakuwa had felt that fisheries was a job with due to its hard work with low income. Also, such consciousness with hardship like early dark morning work in cold winter prevented family successors. However, we could realize through interchanges with many volunteer supporters that fisheries work is considered by many people as a valuable and important job attracting many people's interest. The manner of visited volunteers who vividly practicing hands-on fishery experiment and cheerful smiles at their leaving greatly encouraged us to have confidence in fisheries. In the Karakuwa Branch, the young generation of growers' families are returning to succeed fisheries and successor-less growers became fewer than other districts. Earnest support of restoration from home and abroad provided us broad interchanging opportunity. This socialization widens our consciousness and drove us to form an innovative agreement for rationalized fishing ground utilization. The support from France and Société franco-japonaise d'Océanographie started succeeding international interchange movement in the Japanese oyster growers. Fully restored oyster farming has come back and new efforts to produce higher quality oysters are also going to be established seeing some 20 years into the future.

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# A Comparative Study of the Work Environments of Fishermen in France and Japan Using Statistics and Images

**Hideyuki Takahashi and Yvon Le Roy**

**Abstract** Due partly to their working conditions, the decrease in numbers and increase in the average age of fishers are significant issues in Japan and could affect France similarly in the future. A comparison of the status of fishermen in both countries will contribute to finding solutions to these problems, promote the recovery of the industry's workforce, and encourage mutual understanding between these countries. This study compares statistical data of the trends in the average age and population of fishermen. Specific images of fishing boats in both countries are also compared to illustrate the working conditions of fishermen. We found that Japanese fishing boats seem to be in greater need of improved conditions than French boats. It may be necessary for the Japanese fishing industry to learn from France's industry.

**Keywords** Fishing industry · Labor force · Aging of fishermen · Work environment · Coastal fisheries · Otter-trawler · Gill-netter

## 1 Introduction

There were approximately 500,000 Japanese fishermen active in the industry in the 1980s. However, that number has been steadily decreasing and is currently at less than 200,000. The average age of Japanese fishermen has also increased, with more than 35% of fishermen aged 65 years or older (Fisheries Agency of Japan 2017). To improve the labor situation in the fishing industry—which is comprised mainly of aged workers—work environments on fishing boats must be improved to better the circumstances of what is dangerous and physically demanding work. Additionally, a safer and more efficient work environment may contribute to the employment of a younger workforce. Takahashi and Hisamune investigated the actual working conditions of coastal fisheries and aquacultures to discover ways to improve them (Takahashi 2009, 2013, 2015a, b; Takahashi and Hisamune 2010; Takahashi

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et al. 2012, 2017). Similar kinds of studies concerning fishermen work, however, are rarely seen in countries other than Japan, except for some studies in the USA (e.g., Lipscomb et al. 2004; Mirka et al. 2004; Kucera et al. 2008, 2009; Kucera and Lipscomb 2010). Comparing different working environments in the industry could contribute to finding ways to improve them. For instance, we may find a solution to improve fishermen's work environment by inspecting the work environments of other fishermen. This process can either be applied to a country or be employed to compare countries. This study addresses the subject of "A comparative study between France and Japan of fishermen's work environments" under the sub-committee of ocean development between France and Japan authorized by Japan's Ministry of Education, Culture, Sports, Science, and Technology (MEXT). The study aims to investigate possible improvements to fishermen's work environments as well as to promote a mutual understanding of the fishing cultures of both countries through the comparison of statistics and journals and work situations. However, no study is found which evaluates French fishermen's work quantitatively. Accordingly, this study summarizes the fishing industry labor force based on statistical information and qualitatively compares the work environments of coastal fishing boats in Japan and France by on-the-spot investigations for the first step of the comparative study.

## 2 Materials and Methods

### *2.1 Materials*

#### 2.1.1 Statistical Data

Statistical data of both France and Japan were gathered from the Data Book of the World 2016 (Ninomiya-Shoten Publishers Ltd. 2016). For France, the fishery workforce and fishermen's age compositions were collected from the report "La section Professionnelle Paritaire Pêche et Cultures Marines" (La section Professionnelle Paritaire Pêche et Cultures Marines, 2015), and for Japan, the statistical data were collected from the survey of the trends of fisheries occupations (Ministry of Agriculture, Forestry and Fisheries of Japan 2007–2017).

#### 2.1.2 Images of Coastal Fishing Boats

On-the-spot investigations were carried out on coastal otter-trawlers and gill-netters, two of the prevalent coastal fishing boats in France and Japan. Japanese coastal otter-trawlers were inspected in the Chiba, Aichi, and Mie prefectures, and gill-netters were inspected in Hokkaido and Fukui prefectures. Inspections in Japan were conducted between 2007 and 2016. French fishing boats were inspected in 2016 at Boulogne-sur-Mer, one of the largest fishing ports on the Atlantic coast of France.

## 2.2 Methods

### 2.2.1 Comparison of Statistical Data

Referring to the above sources, the national population, the average age of national population, the fishermen's population, the proportion of fishermen to national population, the number of aged fishermen, and the total catch of the two countries were compared during 2015. The trend of the fishermen population and their age composition were also compared from 2006 to 2016 (excluding the period 2013 to 2016 for France, and the years 2008 and 2013 for Japan). To compare the intensity of decreasing of fishers population in each country, the ratio of fisher population in 2012 against that in 2006 was also calculated for each age class and total population from statistical information.

### 2.2.2 Comparison of the Images of Coastal Fishing Boats

Three photographs of coastal otter-trawlers and gill-netters from both Japan and France, considered to be typical fishing boats based on the authors' experiences of investigations for many years, were chosen for the comparison. The shapes of ship hulls, equipment (especially for fishing operations), and deck arrangements were investigated and compared to address their work environments.

# 3 Results

## 3.1 Comparison of Statistics

A comparison of the statistics is shown in Table 1.

**Table 1** Overview of statistics of France and Japan in 2015

| | France | Japan | Japan/France* |
|---|---|---|---|
| National population ($\times 10^3$ persons) | 67,250 | 126,160 | 1.88 |
| Elderly population (%) | 17.6 | 25.9 | 1.47 |
| Fishermen population ($\times 10^3$ persons) | 21 | 167 | 7.95 |
| Proportion of fishermen per national population (%) | 0.03 | 0.13 | 4.33 |
| Elderly fishermen (%)** | 14.0 | 36.3 | – |
| Fish catch ($\times 10^3$ tons) | 490 | 3,660 | 7.47 |

*ratio Japan/France
**proportions of 55 years and older for France, and 65 years and older for Japan

The ratio of Japanese fishers to Japan's national population is approximately four times higher than the French one. The total amount of fish caught in Japan is approximately seven times higher than in France. The percentage of elderly is 25.9% in Japan, compared to 17.6% in France. However, the percentage of 65 years or older fishers in Japan is higher than the percentage of elderly in the overall national-aged population. In France, the percentage of elderly fishers who are 55 years or older is lower than that of the national elderly population.

The trends of the number of fishermen split according to their age categories are shown in Fig. 1. The data are collected from 2006 to 2012 for France and from 2006 to 2016 for Japan (except for 2008 and 2013). The age and sex classifications were derived from the crude data.

French fishermen were classified in five age groups with no distinction of sex, and Japanese fishermen into a single female group and five male age groups. The total numbers of fishermen in both countries have been decreasing since 2006. The decrease of fishermen in the age group 40–59 years in Japan, as well as the age group 35–44 years in France, was significant.

The ratios of fishermen population in 2012 against that of 2006 for both countries were shown in Fig. 2.

The decrease of the total number of fishers was slightly higher in Japan than the French one. The number of younger fishers (44 years old or less) decreased, whereas the number of older fishers (55 years or more) increased in France. Age classes of 40–59 years old and more than 65 years are decreased as well as female in Japan.

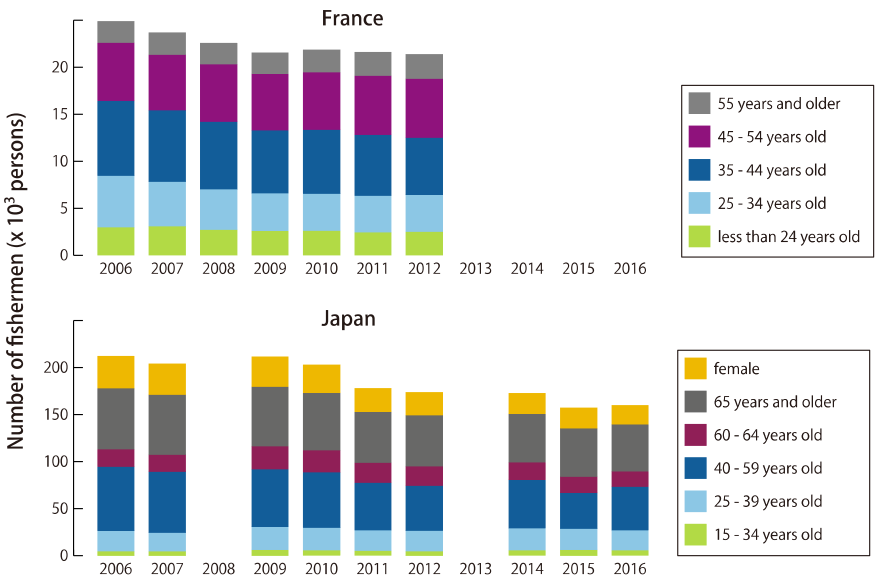


**Fig. 1** Trends of fisher's populations split according their age categories in France and Japan (The data of several prefectures are not included for 2011 and 2012 for Japan.)

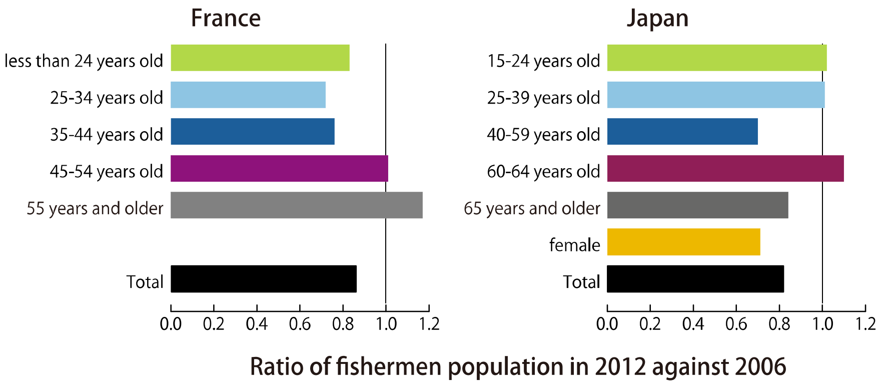


**Fig. 2** Ratios of fisher populations in 2012 against 2006 in France and Japan

## *3.2 Comparison of Fishing Boats*

### 3.2.1 Coastal Otter-Trawlers

Figure 3 shows both Japanese and French coastal otter-trawlers. Japanese otter-trawlers have narrower hull shapes and relatively short ship widths in relation to ship length compared to French trawlers.

The bridges of the Japanese otter-trawlers are located in the center of the hulls, whereas those of French otter-trawlers are located in the bow. On the Japanese trawlers, the decks are divided into two parts (bow and stern) due to the bridge arrangements, while those of French otter-trawlers are not. In general, a large net winch is located on the stern deck on Japanese otter-trawlers, while the winches of French otter-trawlers are fixed on a high flame on the stern deck, where the crew can work under the winches.

### 3.2.2 Gill-Netters

Japanese and French gill-netters are shown in Fig. 4.

We observed that the hull shapes and the bridge arrangements are similar to those of the coastal otter-trawlers for both countries, which have narrow hull shapes and centered bridges in Japan and wide hull shapes with short lengths and bow bridges in France. On a typical Japanese gill-netter, a gill-net is placed on and cast from the stern deck and hauled back in by a hydraulic or electric net hauler on the bow deck. Additionally, the work decks in the bow are sometimes covered with awnings. However, small gill-netters usually have no awnings and their bridges are too small for the crew to avoid inclement weather, which means that they are almost always exposed to the weather. In typical French gill-netters, the work decks are completely covered with roofs and walls, except for the stern side from which the gill-nets are cast and hauled in.


**Fig. 3** Images of Japanese (left) and French (right) coastal otter-trawlers. Locations of fishing boats are **a** Aichi, **b** Chiba, **c** Mie, **d–f** Boulogne-sur-mer

## 4 Discussion

Based on the comparison of data collected, the fishing industry in Japan seems more developed than in France. The decrease in the number of fishers in Japan is a serious problem. These results imply that maintaining as well as securing employment for fishing industry workers are significant issues in Japan. The mean age of fishermen is probably increasing also in France, since the decline in the number of young fishermen is noticeable. Regarding the fishing boats compared in this study, it is difficult to determine whether the work environment on Japanese fishing boats is better than that of French fishing boats. It seems that the purpose of the narrow hull shapes of Japanese fishing boats is to increase the speed of movement between their fishing grounds, which improves their catch and selling price. For example, the stick-net fishing boat for Pacific saury tends to move at full speed at the returning


**Fig. 4** Images of Japanese (left) and French (right) gill-netters. Locations of fishing boats are **a**, **b** Hokkaido, **c** Fukui, **d**–**f** Boulogne-sur-mer

navigations due to the order of fish landing being decided by the order of returning to port (Hasegawa 2014). The bridge in the center of the ship's deck divides the deck into two work areas on the typical small Japanese fishing boat. The big net winch occupies a large area on the stern of a typical Japanese coastal otter-trawler. These factors all contribute to a narrow and divided workplace on Japanese fishing boats. In contrast, French fishing boats have wide and undivided workplaces due to their wide and short hull shapes and the position of the bridges on the bows. Moreover, the work decks in the stern of French gill-netters are covered with roofs and walls, protecting the crew from inclement weather or falling overboard. The French fishing boats studied here generally seemed to possess superior features regarding occupational safety and health. We do, however, have to add that it is not clear whether the superior work environments of French fishing boats were intentionally built that way or not. The specifications of the boats were possibly decided based on the conditions of their operations, sea conditions, legal regulations, habits, and many other factors. Nevertheless, it seems that the Japanese fishing industry could benefit from studying the work environments on French fishing boats. For future studies, it could be beneficial to investigate why this work environment is developed in the French fishing industry but not in the Japanese industry in spite of the economy's dependence on the industry. The history of the development of fishing boats in both countries should also to be investigated to understand the process of how the current work environments were established. This knowledge will be also useful to France in the future since the number of young French fishermen is also declining. It is also very important of course that investigating how the features mentioned above actually function on each fishing boat.

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# Regional Schemes for the Development of Marine Aquaculture (SRDAM) and Access to New Farming Sites on the French Mediterranean Coast

**Catherine Mariojouls and Sophie Girard**

**Abstract** In France, the absence of further development of marine fish farming over the last 20 years has been attributed to regulatory constraints, and to the difficult access to new farming sites, due to high competition between different uses in the coastal zone, and to the shortcomings of governance in these areas. The regional schemes for the development of marine aquaculture (SRDAM) were introduced by the French Law on modernization of agriculture and fisheries (LMAP, July 27, 2010). The goals of SRDAMs are to make an inventory of existing aquaculture sites and to identify potential sites suitable for aquaculture, and to conciliate the development of marine aquaculture with other coastal activities. They are expected to allow access to new fish farming sites. Our study focuses on the three SRDAMs on French Mediterranean coast, in order to investigate to which extent the SRDAMs offer opportunities for a new development of marine fish farming, in line with the quantified objectives of the French national strategic plan for the development of sustainable aquaculture. Based on desk work and on enquiries with professional representatives, administration, and experts, our study aims to analyze the building process and the results of SRDAMs and discusses the constraints to an extension of marine fish farming.

**Keywords** Marine fish farming · Marine spatial planning

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## 1 Introduction

Despite a long coastal zone (5850 km on metropolitan territory, 18,300 km in total with overseas territories, Estimation SHOM,[1] 1999), France has a limited development of marine fish farming, representing only 4920 tons in 2016 (source CIPA[2]). The absence of further development of marine fish farming over the last 20 years has been attributed to the difficult access to new farming sites, due to high competition between different uses in the coastal zone and shortcomings of governance in these areas, to regulatory constraints and to a lack of social acceptability.

At EU level, "improving access to space and water" is one of the four priorities defined in the Strategic Guidelines for the Sustainable Development of EU Aquaculture and focused by the Member States' plans when developing Multiannual National Strategic Plans (EU Commission, 2016) for the promotion of sustainable aquaculture and related operational programs for the EMFF[3] (2014–2020). The quantified objectives of the French NSPA[4] are particularly ambitious for marine fish farming and target a production ranging from 10,000 to 20,000 tons (lower and higher hypothesis). In France, the regional schemes for the development of marine aquaculture (SRDAM[5]) were introduced by the French Law on modernization of agriculture and fisheries (LMAP,[6] July 27, 2010). The goals of SRDAM are to make an inventory of existing aquaculture sites and to identify potential sites suitable for aquaculture, and to conciliate the development of marine aquaculture with other coastal activities or uses. As a tool for spatial planning, they are expected to improve the access to new fish farming sites.

In 2016, the marine fish farming sector in France produced 4920 tons, among which 1928 tons of sea bass (*Dicentrarchus labrax*), 1671 tons of sea bream (*Sparus aurata*), and 236 tons of meager (*Argyrosomus regius*) (source CIPA). About half of the marine farmed fish are produced on the Mediterranean coast, in 20 farms in 2009 (source DIRM). The Mediterranean fish farms mainly focus on growing sea bass, sea bream and meager in cages in coastal areas. According to Mare I Stagni, the syndicate of Corsican aquaculturists, in 2017, Corsica alone produced 1700 tons in eight farms.

The SRDAMs for the three Mediterranean administrative regions: Provence–Alpes–Cote d'Azur (PACA), Languedoc-Roussillon (LR), and Corsica, were approved in 2015. We investigated whether the SRDAMs could provide a room for

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[1]SHOM: Service Hydrographique et Océanographique de la Marine.

[2]CIPA: Comité Interprofessionnel des produits de l'aquaculture http://www.poisson-aquaculture.fr/le-cipa/.

[3]EMFF: European Maritime and Fisheries Fund.

[4]MEDDED (updated December 2015). Plan Stratégique National: Développement des aquacultures durables 2020—France. https://ec.europa.eu/fisheries/cfp/aquaculture/multiannual-national-plans.

[5]SRDAM (Schéma régionaux de développement de l'aquaculture marine): Regional scheme for the development of marine aquaculture.

[6]LMAP (Loi de modernisation de l'agriculture et de la pêche): Law for modernization of aquaculture and fisheries.

improvement of the development of marine fish farming in Mediterranean coastal zones. The objectives of our study are (i) to understand the building and the contents of the SRDAMS; (ii) to look at the changes occurred after the publication of SRDAMs in 2015, and (iii) to analyze the other constraints to a further growth of marine fish farming. While SRDAMs apply to all aquaculture, our study focuses only marine fish farming.

## 2 Methods

The present study included desk work and interviews. We analyzed the available documents about SRDAMs and other planning documents, and scientific literature. From June to November 2017, we carried out 13 interviews (1–2 h each) following a semi-directive guide, with several types of actors: five representatives of national administration (two at national scale, one at inter-regional scale—DIRM[7] Méditerranée—and two in the Corsica region—DDTM[8] South Corsica, DREAL); one representative of region Corsica administration; four key actors and representatives in the fish farming sector (two CEO[9] of the two main marine fish farming companies in France), one for the professional body SFAM (syndicate for marine fish farmers and one for the syndicate of Corsican aquaculturists); three researchers (two in IFREMER, one in University of Corte).

The semi-directive guide was organized in four groups of questions, concerning: the elaboration of the SRDAMs and the role played for it; the changes introduced by the SRDAMs in the development of the marine fish farming sector; the constraints, other than access to farming sites, limiting the growth of this sector; and the possible contribution of SRDAMs to marine spatial planning.

## 3 Description of the SRDAMs

### *3.1 General Features*

The SRDAMs are guidance and management documents for marine aquaculture that have been introduced by the French Law on modernization of agriculture and fisheries (LMAP), July 27, 2010, and then integrated into the French Rural and Fishing Code. According to Article D 923-2, the SRDAMs apply to the public maritime domain and to the waters under French jurisdiction, and also to the territory of coastal municipalities. The SRDAMS should inventory exhaustively the existing aquaculture sites and

[7]DIRM: Direction Interrégionale de la Mer.

[8]DDTM: Direction Départementale des Territoires et de la Mer.

[9]CEO: Chief Executive Officer.

the sites conducive to the development of marine sustainable aquaculture, including the access routes and also the terrestrial surfaces required for their exploitation. The identification of suitable[10] sites is based notably on the assessment of different characteristics (see below) and takes into account the environmental impacts and socio-economic benefits that the activity is likely to create, on the basis of estimated production.

So, the SRDAMs include a double inventory: (i) an inventory of existing aquaculture sites, for all types of aquaculture (shellfish, fish, algae, etc.); (ii) an inventory of suitable sites for the creation of new aquaculture farms, in order to ensure a development of marine aquaculture, in harmony with other coastal activities. The identification of suitable sites should be based on a minimum consensus between the concerned stakeholders.

The territorial scope is specified by the decree no 2011-888 of July 26, 2011: The perimeter concerned by these schemes is the maritime public domain and the territory of coastal municipalities. This decree was completed by an administrative circular which describes the implementation and development methods for the SRDAMs.

Once adopted by order of the regional prefect, the SRDAM provides a general spatial plan that must be taken into account during the administrative examination of each application for aquaculture concessions located on the public maritime domain. However, the set of procedures (environmental impact assessment and Natura 2000 impact assessment in particular) foreseen in the framework of authorization for fish farming, remains necessary.

The SRDAMs are also intended to be considered when preparing the DSF[11] (*Document Stratégique de Façade*), which are strategic documents for implementing the integrated maritime policy, including the maritime spatial planning (MSP). But, as underlined in the Mediterranean SRDAMs reports, the SRDAMs are evolving and flexible documents which are expected to be revised every five years. At revision, some options different from the previous elaboration may be taken, concerning the targeted sites (including or not the landing sites on shore), the *criteria* and thresholds considered for site selection, and the farming techniques.

## *3.2 The Process for Drawing up the Mediterranean SRDAMs*

The Inter-regional Directorate for the Sea (DIRM) for Mediterranean coast was in charge, under the authority of each Regional Prefect, of the elaboration of the three regional aquaculture plans concerning the Mediterranean coast. This was carried out in close collaboration with the departmental directorates of territories and sea (DDTMs) and benefited from the scientific and technical support of the Ifremer Méditerranée and of the CEREMA.[12]

[10] We use the English word “suitable” to translate the French “propice.”

[11] DSF: Document Stratégique de Façade, i.e., Strategic document for a marine region.

[12] Center for Studies and Expertise on Risks, Environment, Mobility and development.

The method adopted for the three Mediterranean regions was based on six successive steps:

1. First concertation phase, including three steps: (i) collection of information and data from the State services and from aquaculture professionals; (ii) elaboration of projects of two directory (existing sites, suitable sites); (iii) regional working meetings between State services, professionals (aquaculture) or their representatives, regional territorial collectivity;
2. Written consultation about the first draft of SRDAM: of the public services and of the public institutes; of the professional bodies concerned by SRDAM (aquaculture, capture fisheries); and of the territorial collectivities at regional and departmental scales;
3. Concertation meeting (or several meetings) with stakeholders (elected representatives of territorial collectivities, representatives of public bodies, representatives of concerned professionals, qualified persons—from associations or NGO—chosen for their capacities as for the protection of environment or sea and coastal uses); and consultation of the Maritime Façade Council;
4. Elaboration of the environmental evaluation of SRDAM, and submission to the Environmental Authority for advice;
5. Consultation of the public (SRDAM available on Web site during one month);
6. Adoption of the SRDAM by the regional prefect.

Two directories were elaborated in the SRDAMs:

a. The directory of existing aquaculture sites was carried out with data collected from DDTMs and from professionals.
b. The directory of sites suitable for the development of marine aquaculture. It was the subject of a planning process starting from the inventory of sites proposed by the professionals, crossed with several categories of geolocalized data, such as:

    - physical or environmental data required to assess the feasibility of fish or shellfish farming activities:

        – at sea: depth, wind, swell, water quality, distance to coast, distance to the landing point,
        – onshore: distance to coastline, present land uses, underground water resources, maximum altitude, zone with technological risks.

    - data referring to other uses and potential conflict uses: navigation (all types, including in particular fishing), air traffic, mooring zones.
    - data related to the protection of the natural environment: existing protected zones (MPA, etc.), zones with vulnerable benthic biocenosis (*Posidonia* meadows, coralligenous, etc.).

All these data contributed to the selection of suitable sites for aquaculture, or helped eliminate or reduce the perimeter of certain suitable sites. The selection and mapping of suitable sites also benefited from scientific expertise and previous works on the subject, in particular the Ifremer document about the potential sites for aquaculture (1999) and a GIS[13] tool applied to the development of Corsican marine fish farming in floating cages (SI REMCO,[14] Ifremer, Maurin et al., 2007).

In addition to mapping, the SRDAMs have also a strategic dimension. The Mediterranean SRDAMs aim at doubling the present production, which is coherent with the low hypothesis of the French Multiannual National Strategic Plan issued in 2015. In this first edition, they have been designed in continuity with the structure of the present fish farming sector: The considered techniques are marine net pen cages nearshore (no offshore marine fish farming) and fish farms on shore, and the SRDAM for the region PACA explicitly focuses on small- to medium-scale farms.

### *3.3 Corsica: A Particular Case*

Regarding the planning of aquaculture in the coastal zone, the situation in Corsica is different from that of inland regions like Languedoc-Roussillon and PACA. Actually, the region of Corsica began early, in the 2000s, to work on the potential sites for aquaculture, and so had already an important database and methodological basis for mapping the suitable sites for aquaculture. Another important point is that the preparation of SRDAM was simultaneous and congruous with the preparation of the PADDUC,[15] a document defined in Article 12 of the law of January 22, 2002, concerning Corsica. The latter has the value of a territorial land planning directive. Accordingly, the PADDUC shall prevail against any other land planning documents, which means that it provides a stronger legal framework than a SRDAM for the maps related to aquaculture zones.

Within the PADDUC, the part dedicated to coastal zones corresponds to a SMVM.[16] The final report for the SMVM, resulting from in-depth studies and consultations, includes several detailed maps for issues, threats, potentialities, and vocations. It is interesting to note that the vocation map quotes the possible activities (or the only possible activity in the case of "exclusive vocation"), with several levels of priority (three levels for maritime space, two levels for coastal land). So, for aquaculture, the SMVM vocation map provides a detailed framework for public decision making.

The PADDUC presents marine fish farming as a key and promising activity for the economy of Corsica, today being the second exporting activity after citrus, with 95% of Corsican farmed fish either exported or sold in mainland France. The production of aquaculture is expected to increase threefold compared to the current production in 5 years (i.e. reaching 5000 tons), and there is a clear political will to support

[13]GIS: Groupement d'intérêt scientifique.

[14]SI REMCO: Système d'Information pour l'exploitation durable des REssources Marines COrses.

[15]PADDUC (Plan d'aménagement et de développement durable de la Corse), i.e., the Plan for land management and sustainable development in Corsica—approved in 2015.

[16]SMVM: Schéma de Mise en Valeur de la Mer, i.e., "Scheme for valorization of the sea".

**Table 1** Number of sites considered for marine fish farming in the three Mediterranean regions (*Source* SRDAMs of the three regions)

| Regional scheme | Number of existing sites | Number of identified suitable sites |
|---|---|---|
| SRDAM Languedoc-Roussillon (New Region Occitanie) | 5 | 17 |
| SRDAM PACA (Provence, Alpes, Côte d'Azur) | 15 | 10 |
| SRDAM Corse | 8 (+1 for research) | 14 |

this growth. It must be recalled that Corsica presents very good natural conditions for fish farming development (high water quality, long coastline) and is regarded as the French Mediterranean region with the most important potential for marine fish farming growth. Particularly in Corsica, rich in remarkable natural habitats, the environmental issues have been taken into account in the studies and the consultations, leading to the mappings prepared in PADDUC, and in the SRDAM. Finally, we can underline that the PADDUC and the SRDAM published in 2015 constitute a very favorable framework for a development of aquaculture in Corsica.

## *3.4 The Scope of the SRDAMs*

The Mediterranean SRDAMs in their strategic aspects aim to double the current production. To achieve this objective, the number of selected suitable sites is not very high (Table 1). It can be underlined that the state of mind of the fish farmers consulted during the process was not to ask for a great number of potential sites, but a number allowing a reasonable growth of their activity.

# 4 Results: Analysis of Interviews

## *4.1 Analysis of the Building Process*

### 4.1.1 An Important Input from the "DIRM Méditerranée"

The DIRM Méditerranée achieved a very important work to build the three SRDAMs. From 2011 to 2015, the work done is equivalent to two years of a full-time equivalent.

The aims in elaborating SRDAMs in Mediterranean regions include not only the final mapping of suitable sites, but also the writing of a strategic document for a sustainable aquaculture development, taking into account all other uses and issues. The elaboration of SRDAMs was based on a clear willing to consult the users of the coastal zone, or their representatives, through a progressively broadening approach. A first concertation phase took place with a “first circle” of stakeholders (aquaculture professionals, Ifremer, concerned public administration DDTMs, OEC) for the elaboration of a first draft, submitted then through written consultation to a “second circle” (other public administrations, mayors of local municipalities, public bodies). This was followed by concertation meetings on a wide basis (territorial collectivities, public bodies, concerned professionals, qualified persons from associations or NGO) and by a public consultation on Internet.

Beforehand, many bilateral meetings had been organized, which contributed to low down the tensions before the official meetings and made possible to find a consensus. In Corsica, a similar work was done locally for preparing the PADDUC and so benefited to the drawing up of the SRDAM, and reciprocally.

#### 4.1.2 A Great Involvement from the Marine Fish Farming Sector

The marine fish farmers, through their national syndicate SFAM and local fish farmers as representatives, were involved in the SRDAM process, providing information and data, and being consulted on the choice of *criteria*. Importantly, in each region the directory of suitable sites was based first on proposals from professionals, before crossing with other issues. Unanimously, interviewed professionals declared that they were very involved in the preparation of SRDAMs and were satisfied with the results that took into account their wishes and advices. Nevertheless, they also underlined that the time necessary for participating to the building of SRDAM was very important for professional representatives and difficult to find for companies.

#### 4.1.3 A Process Longer Than Expected

Although the circular from DPMA (2011) mentioned that the SRDAMs should be drawn up in few months, it finally took about 4 years to finish the Mediterranean SRDAMs. Not only it was the first attempt to map aquaculture sites exhaustively (except Ifremer’s study in 1999, but at lower precision), but a lot of unforeseen difficulties, notably methodological, appeared.

### *4.2 Methodological Lessons Brought by the SRDAMs Building*

The SRDAMs represented the first opportunity to gather and process a great amount of data required to characterize the different uses and the environment. The work done by Ifremer in Corsica as SI REMCO (Maurin et al., 2007) provided a first methodological framework for databases and GIS and was completed by adding other *criteria*. But despite this methodological basis, the experience of building SRDAMs brought out the difficulties inherent to a spatial planning in the coastal area, notably some shortcomings in available data and the need for further homogeneity of data sources. For this first edition of the three Mediterranean SRDAMs, it was decided to restrict the *criteria* to a common list for which the approach could be homogeneous.

Moreover, while initially the SRDAMs were expected to allow a mapping for aquaculture with an average precision, after the submission of the first draft to the "second circle," especially mayors, it became obvious that a finer precision was needed. Actually, for the various uses already existing in the coastal zone, an average precision was not enough to plan their own activity or to solve conflicts with other users. This experience confirmed that key questions for MSP, at least in coastal areas, will be the scale for data and the accuracy of mapping.

The SRDAMs thus appear as a first step for setting up a methodology for spatial planning in the coastal zone.

### 4.3 Some Missing Points in SRDAMs

The professionals mentioned clearly two weaknesses in the concept of SRDAMs.

One is the weak legal value of SRDAMs, as they cannot prevail against other planning documents. Even in Corsica, where the PADDUC provides a stronger framework concerning that aspect, no new projects have emerged since 2015. We shall discuss later the key issue of conditions for a successful allocation of space for aquaculture.

The other point is the absence of land-based sites for aquaculture companies in Mediterranean SRDAMs. The land-based sites are key components of aquaculture operations and need to be considered also in planning documents because land coastal zone is also a place of high conflicts between users. An example of the difficulty to work without dedicated zone for land-based facility can be found today in Corsica in the bay of Ajaccio: After decades, a large farm has not yet obtained the right to build land-based facilities and is obliged to work in abnormal conditions.

### 4.4 Development of Marine Fish Farming After SRDAMs Publication?

Two years after that the three Mediterranean SRDAMs were published, there have been no new projects of fish farming. Despite the relatively short period of time, it thus seems that the access to new sites is not the main obstacle to development, and our interviews show that other issues are at stake.

Most interviewees mentioned spontaneously the administrative burden concerning the application files for fish farming authorization as the main constraint for development. It represents a lot of files to fill in, is very time-consuming, and is a source of uncertainty for professionals. It is also a cause of abandon for some projects prepared by small companies.

Financial or economic factors were also questioned. The interviewed professionals indicated that there are investors interested in aquaculture projects, but the difficulty to create new farms in France already made some of them invest in other countries with more favorable conditions regarding access to farming sites, as for administrative procedure and availability. Banks and public support for marine fish farming do exist; sometimes slow, the financing support could be improved. The market is not either regarded as a limiting factor for the development of marine fish farming. The professionals mentioned that the French market would accept more French products sold at prices higher than imported sea bass and sea bream, as long as the total French production "does not reach very high level." The corresponding production level (threshold) could not be estimated by interviews and would therefore require further investigation. Some segmentation through origin label is also wished by some marine fish farmers.

More widely, the issue at stake remains the lack of social acceptability that strikes aquaculture. While the French fish farmers hoped initially that SRDAMs would improve the social acceptability of aquaculture, the absence of further development two years after the SRDAMs publication is a cause of a great disappointment among the fish farmers. Interestingly, the launching of SRDAMs was perceived by the fish farmers as a very positive sign. Politically, it was interpreted as recognition and a mark of attention for their sector. A great expectation was placed in the SRDAMs, as a tool for enhancing the access to new sites and a way to improve the social acceptability of aquaculture. This positive interpretation played a role in the important involvement of fish farmers in the elaboration of SRDAMs. The initial expectation of fish farmers relied to some extent on a misunderstanding about the goal of the SRDAM, but the consequence is now some skepticism towards the future spatial planning tools.

## *4.5 The Future Marine Spatial Planning*

For all interviewees, it was clear that SRDAMs are one step on the way to elaborate a maritime spatial planning. The SRDAMs will be included in the Maritime Spatial Planning due for 2021, presently prepared by DIRMs in the framework of DSF, the French framework for integrated maritime policy and maritime spatial planning.

For marine aquaculture, the French Government launched in 2016 the MEAP[17] (best sites for aquaculture) as a step following SRDAMs. It was the subject of a working group gathering professionals, administration, and research. The aim would be to develop an interactive mapping tool for choosing the best sites for aquaculture.

A feasibility study was carried out by consultants in 2017. It has not been put in application since then.

[17]MEAP: Meilleurs Emplacements Aquacoles Possibles = best sites for aquaculture.

# 5 Discussion

The publication of Mediterranean SRDAMs has not yet been put into effect in terms of creation of new marine fish farms, and this can be considered as a failure at this stage. On the other hand, the SRDAMs can be regarded as the first experience in France to set up a marine spatial planning, and despite focusing only one activity, it constitutes an interesting opportunity to analyze a process for maritime spatial planning.

## *5.1 Stakeholders Participation*

The literature about maritime spatial planning insists on the importance of stakeholder participation. But the involvement of stakeholders in the maritime spatial planning process can occur at different levels, as shown by Pomeroy and Douvere (2008) who distinguish six levels in the participation. Using their representation of the range for stakeholders' participation, we attempted to characterize the participation of stakeholders as concerns the Mediterranean SRDAMs (Fig. 1). Despite the large work done by the Mediterranean DIRM in the concertation and consultation phases, and in the numerous bilateral contacts, the participation of stakeholders did not concern all stakeholders on the full process. Only the fish farmers were involved up to the highest level "negotiation" leading to final decisions, and the fishermen were just involved up to "dialogue." The other coastal zone users were not consulted

| Possible types of stakeholders participation in an MSP process | | Participation in SRDAMs process | | | |
|---|---|---|---|---|---|
| | | Fish farmers | Fishermen | Other users | Public |
| Negotiation | Reach a decision | X | | | |
| Concertation | Determine objectives, actions | X | | | |
| Dialogue | Develop proximity | X | X | | |
| Consultation | Reciprocal flows | X | X | X | (X) |
| Information | Descending univocal flows | X | X | | X |
| Communication | | | | | X |

**Fig. 1** Attempt to characterize the stakeholders' participation in Mediterranean SRDAMS, using the "possible types of stakeholders participation in an MSP process" proposed by Pomeroy and Douvere (2008)

directly but mainly through the representation of their concerned public administration, and through the elected representatives at different scales (French region and French Department). During meetings, the public were neither consulted directly but through the mayors of local municipalities and some qualified people from associations. Public opinion could be expressed only by Internet during a one-month consultation.

The choice of this pattern for stakeholders' involvement corresponds to what was planned by the Administrative Circular (DPMA 2011) and can be well understood in the case of the SRDAMs, considering their means and goals. But a wider participation of stakeholders will be necessary for the MSP included for France in the elaboration of the DSF (in progress). As shown by the literature on marine spatial planning, a significant involvement of stakeholders is a key component of the process and a key factor of success for its implementation. About aquaculture zoning, FAO and World Bank (2015, 2017) underline that to solve social conflicts as the lack of public confidence in the sustainability of aquaculture or the competition with other users for space and water, the involvement of relevant stakeholders at all levels of the process allows an improved accountability and transparency. Pomeroy and Douvere (2008) explain that in MSP process, the "empowerment of stakeholders" is essential, and they present the interest of the "social preparation" of stakeholders during the initial phase. They mention a number of participatory tools and methods including focus group's discussions, problem trees, and preference ranking. Veidemane and Nikodemus (2015) insist on the need to adopt a broad view in consultation, including land stakeholders in addition to marine stakeholders, when dealing with marine spatial planning that includes activities with some potential visual impacts.

Indeed, what is at stake is the construction of a shared culture about the different marine activities and their respective issues, in addition to common issues for the concerned zone. Marine fish farming is the last comer, still a "new activity" hardly known by other users and coastal communities or even negatively perceived due to negative communication in the media about intensive and impacting aquaculture cases. The challenge in that context is to provide through wide participative approaches the opportunity to become visible and to make social acceptability progress at local scale.

### 5.2 *Social Acceptability*

While the difficult access to space in the coastal zone has been identified for long as the main factor hampering the development of marine fish farming in France, it is interesting to note that the launching of SRDAMs was interpreted by the professional fish farming sector as a way to improve social acceptability.

In recent decades, the decrease in social acceptability that strikes the agriculture sector, especially for husbandry, brings some interesting lessons. Delanoue et al. (2015) reviewed the studies done about the opinions and expectations from society stakeholders toward animal husbandry in France and analyzed them using the tools of sociology of controversies. Interestingly, they show that the debates about animal husbandry are controversies, as defined by Schmoll (2008, in Delanoue et al. 2017), that combine scientific uncertainties, a public opinion with an affect component and antagonism between different groups of stakeholders. In the complex set of debates, they found four main groups of subjects: environmental impact, animal welfare, health (animal and human), and, together, animal farming systems and meat consumption. Although there are differences between the situation of land animal husbandry and that of aquaculture, there are also similarities and the aquaculture sector would indeed benefit from a similar approach. The debates about aquaculture should be recognized as a controversy, showing the need for organizing real debates allowing exchanges between aquaculture stakeholders and other stakeholders. Moreover, the identification of the main subjects focused by the controversy about aquaculture would help to communicate properly and could contribute to make aquaculture emerge from its current marginal position. And above all, the debate should not be restricted to coastal users or representatives only but should also involve consumer representatives and be more integrated with food policies.

Social acceptability is today the main question for the development of marine fish farming and would require research work to make light on a major constraint for development. Rey-Valette and Mathe (2017) consider that social acceptability for aquaculture concerns both the territorial acceptability and the acceptability of the techniques and production modes in aquaculture. We would rather propose, especially for marine fish farming, a three-dimensional approach where the problem of social acceptability can be described as a system with three interlinked components: a spatial acceptability, an environmental acceptability, and the acceptability for farming techniques.

### *5.3 Status of Zones for Aquaculture: Suitability, Vocation and Priority, Allocation*

The SRDAMs provide a framework aiming to map the "suitable sites for aquaculture," by crossing professional and scientific advices, objective *criteria* and presence of other activities. That framework is a help for further creation of farms, but it gives no right for aquaculture to claim for these zones, due to the weak legal value of SRDAMs. Other statutes for zoning are possible, giving more strength: vocation and priority, and allocation.

Vocation and priority are the bases of the mapping of marine space and coastal land in the PADDUC (Corsica). This system restricts the competition between activities and gives direction for management.

The FAO General Fisheries Commission for the Mediterranean achieved a long work before reaching the concept of allocated zones for aquaculture (AZA) in marine coastal areas, defined in the Resolution GFCM/36/2012/1. Article 2 states that "*AZAs shall comprise specific areas dedicated to aquaculture activities*…". As analyzed by

Sanchez-Jerez et al. (2016), the AZA are zones in which "*aquaculture has secured use and priority over other activities, and where potential adverse environmental impacts and negative interactions with other users are minimised or avoided.*" A main key to avoid conflicts with other users is a participatory approach in the spatial planning leading to the creation of AZA. The authors describe the cases of numerous countries where AZA have been set up (Malta, Croatia, Greece, New Zealand, Australia, Chile, Canada, Morocco, and Italy and Spain at regional scale), and beyond, also underline the necessary enforcement of regulations for sustainable aquaculture by the relevant authorities. In conclusion to their extensive review, they assess the need of a spatial planning through AZA for developing aquaculture in a context of competition for space in coastal areas. Jeffery et al. (2014) in their recommendations issued from the study about sustainable aquaculture development addressing in particular environmental protection (SUSAQ), also recommended the setting up of AZA.

In France, while there is today a strong political will to develop aquaculture, the question of dedicating some coastal zones to fish farming, beyond defining suitable sites, should be considered by the public authorities.

## *5.4 Other Room for Improvement and Outlooks*

The inclusion of environmental issues in aquaculture zoning is a key question. SRDAMs took into account the protection of natural environment in the mapping of existing and suitable sites, and the final versions were subject to an environmental assessment, agreed by the Environmental Authority, before final approvals by the regional prefects. Nevertheless, the tension between production growth and protection of the environment remains important, as already mentioned. It appeared notably through the opposition from some local associations or NGOs, and even through the weak support of some administration departments.

According to some public and private stakeholders we met, addressing the environmental issues since the beginning of the process would improve the situation. Ifremer is today testing in Mayotte the use of the model DEPOMOD for modeling the deposition and biological effects of waste solids from marine cage farms (Cromey et al. 2002), coupled with the use of a biotic index on benthic communities, in order to predict the environmental impact of marine fish farming. The model DEPOMOD is already included in the regulation of some countries (Canada and Scotland, source Ifremer 2017). More generally, the compliance of aquaculture zoning and management with the carrying capacity approach, which is at the basis of the Ecosystem Approach for Aquaculture (EAA) (FAO and World Bank 2017), must be considered.

Also, the question of time deserves attention. One aspect well identified in numerous EU countries in 2009 (Hedley and Hutington 2009) relates to the administrative burden, but it is still largely quoted in our study. It is planned to be addressed in the

French PSNPDA[18] 2014–2020. Another aspect is the gap between the short-term needs of the French marine fish farming sector for a facilitation of development, and the long-term work required by public policies. The SRDAMs, despite a dedicated policy early initiated, required several years and did not fulfill the sector needs. The MSP, as a holistic approach should allow a maturation of relationships among users of the coastal zone and may improve the place of aquaculture, but is a long process.

## 6 Conclusion

The SRDAMs published in 2015 have not yet allowed further development of marine fish farming in the Mediterranean coast, but our analysis shows that other obstacles to the development of production should be considered and removed. Moreover, the SRDAMs are a national instrument that was created early compared to some European directives like MSP and MSFD and there is a need to (re)consider and analyze their place among these policies.

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# Japanese-Type MPAs and Self-organized MPAs by Local Communities in Japan

**Teruhisa Komatsu and Nozomi Aoki**

**Abstract** Marine protected areas (MPAs) are a practical tool to conserve biodiversity and also fishery resources. They are essential for the sustainable development of coastal waters. In Japan, fishing villages have had a long history of conserving marine resources in coastal waters like a marine protected area corresponding to an MPA category of "Protected Area with sustainable use of natural resources," one of the six MPA categories defined by IUCN. This article introduces three successful MPAs in Japan from the boreal to subtropical zones through temperate zone: Shiretoko, Taketomi, and Tsushima. Fishermen and fishery cooperatives play an important role to conserve marine resources in these MPAs. Their function is essential for maintaining MPAs. Since a fishery cooperative manages its own common fishery right area by itself, it is needed to merge common fishery right areas of several fishery cooperatives to protect marine bioresources and biodiversity. At this point, local governments play a key role to coordinate fishery cooperatives and other users of coastal waters such as leisure industries to discuss problems for realizing MPAs. Of course, related ministries of central government must support them with a liaison of local governments. In Japan, successful MPAs have been established through bottom-up efforts from fishermen and fishery cooperatives via local governments. This type of MPA management of which people deeply depends on coastal bioresources might be different from that of occidental countries.

**Keywords** Japanese-type marine protected areas · Bottom-up management · Fishery cooperative · Local government · Common fishery right · Fishery management

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## 1 Introduction

Biological diversity is indispensable for the human society through making ecosystems functioning well and maintaining ecosystem services such as providing foods, medicines, and scientific inspirations for engineering. Thus, it is now well recognized that biological diversity is essential for realizing sustainable development goals. The 10th Conference of the Parties (COP) to the Convention on Biological Diversity (CBD) in Nagoya, Japan, adopted the Strategic Plan for Biodiversity 2011–2020 including Aichi Biodiversity Targets. According to CBD (https://www.cbd.int/sp/targets/), Aichi Biodiversity Targets consisting of 20 targets are grouped into five objectives related to the adopted strategies as follows:

Strategic Goal A: Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society;
Strategic Goal B: Reduce the direct pressures on biodiversity and promote sustainable use;
Strategic Goal C: Improve the status of biodiversity by safeguarding ecosystems, species, and genetic diversity;
Strategic Goal D: Enhance the benefits to all from biodiversity and ecosystem services;
Strategic Goal E: Enhance implementation through participatory planning, knowledge management, and capacity building.

Target 11 related to Strategic Goal C is as follows:

> By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.

This target asks to the parties to set marine protected areas (MPAs) in each state. Therefore, Japan also needs to set them by 2020.

IUCN defined marine protected areas depending on management objectives (Table 1). The concept of marine protected area in Japan is probably different from that in occidental countries because dependence of people in Japan as an isle state with a high population density surrounded with the sea is culturally, historically and traditionally more important. Since Japanese people have obtained protein from the sea while occidental people from on land, Japan defines marine protected areas (MPAs) that are an effective means of preserving the biodiversity of the sea based on the historical context in use of coastal waters in Japan.

**Table 1** Categories of marine protected areas defined by Day et al. (2012)

| Category of marine protected areas | | Areas managed mainly for |
|---|---|---|
| Ia | Strict nature reserve | Strict protection |
| Ib | Wilderness area | Strict protection |
| II | National park | Ecosystem conservation and protection |
| III | Natural monument or feature | Conservation of natural features |
| IV | Habitat/species management area | Conservation through active management |
| V | Protected landscape/seascape | Landscape/seascape conservation and recreation |
| VI | Protected area with sustainable use of natural resources | Sustainable use of natural resources |

## 2 History of Management of Coastal Fishing Grounds in Japan

Local fishermen have used fisheries grounds along the coast. In the history, opening day of wakame (*Undaria pinnatifida*) was recorded in the eighth century as a ritual ceremony of Shinto shrine in Kyushu (Urushihara 2019). Urushihara (2019) stated that a system of the opening day of rocky shore is to ensure a common use of coastal bioresources among village people because everybody can participate in fisheries mainly on foot. This system shows that a village manages fishing grounds in front of the village. Therefore, village people have used such fisheries grounds with a sustainable manner. For example, opening days of abalone fisheries or seaweed collection for village people were decided by the village. All village people were permitted to conduct such fisheries only for opening days (e.g. Urushihara 2019). It was a self-management system by each village. The Fisheries Law decided in Meiji Era in 1901 succeeded the traditional rule of self-management system in Edo Period (Izumura 2005). Although the Fisheries Law was amended in 1949 from the viewpoint of democratization of fishing villages after the World War II, a concept of the management rule of coastal waters was not changed. In 2018, the Fisheries Law was revised to meet present situation (Ministry of Agriculture, Forestry and Fisheries of Japan 2018). In this law revision, a system that fishermen's cooperatives and others designated by the prefectural government promote conservation activities on fisheries resources is introduced (Ministry of Agriculture, Forestry and Fisheries of Japan 2011). However, it does not change conservation activities along the coast in front of the villages much as before. Thus, the Ministry of the Environment of Japan which is the authority of Japanese government on MPAs states that it is important to use a system of MPAs that meets the management purpose based on the cooperation of stakeholders after grasping the sea area with a high degree of importance for conservation (Ministry of the Environment of Japan 2011). In setting MPAs along the coast in Japan, it is important to harmonize traditional use of coastal waters with conservation.

## 3 Marine Protected Areas in Japan

Japanese Archipelago is longitudinal from Etorofu Island at 45° 33′ 26″ N in the boreal zone to Okino-Torishima Island at 24° 16′ 59″ N in the subtropical zone (Fig. 1) (Japan Coast Guard 2018). Japan has an exclusive economic zone (EEZ) of about 4,050,000 km$^2$ (Japan Coast Guard 2018). According to the survey on marine organisms that live in the waters within the jurisdiction of Japan's EEZ, there are approximately 34,000 species, 15% of 230,000 species in the world, that have been identified (Fujikura et al. 2010) because of this diverse environment. Of these, about 1900 are endemic species in Japan (Fujikura et al. 2010). There are a wide variety of species including 122 out of about 300 seabirds in the world (Harrison 1985; Ornithological Society of Japan 2000), and about 3700 (25%) of the total of approximately 15,000 marine fishes (Taki et al. 2005; Ueno and Sakamoto 2005) inhabit and grow. 50 of the 127 species of marine mammals inhabit the world (40 species of whales and dolphins, eight species of seals and sea lions, sea otters and dugongs) are found in the waters near Japan (Jefferson et al. 2015; Ohdachi et al. 2009).

The Japanese government has recognized MPAs in 2011 and the Ministry of the Environment of Japan (MOE) listed ten categories of MPAs depending on the laws in 2013 (Table 2). The five categories and one category belong to MPAs defined by environmental laws such as the Natural Park Law under the Ministry of the Environment (MOE) and by the Cultural Property Protection Law under the Agency of Culture, Ministry of Education, Culture, Sports, Science and Technology (MEXT), respectively. Some categories are mainly managed by a related ministry and the others by a local government of which territory includes MPAs. The other four categories belong to MPAs defined by the laws concerning fisheries and protection of fisheries

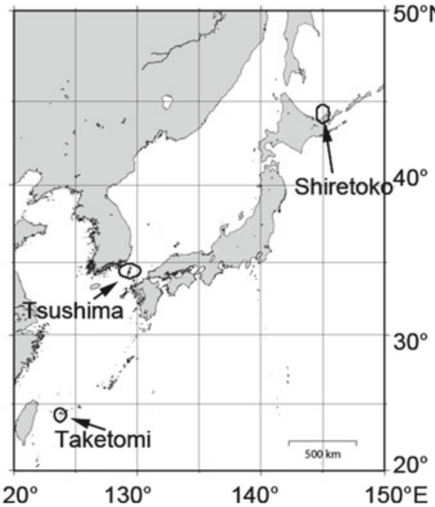


**Fig. 1** Map showing three MPAs of Shiretoko, Tsushima, and. Taketomi

resources under the Fisheries Agency of Japan (JFA), the Ministry of Agriculture, Forestry, and Fisheries.

In this way, MPAs consist of three different groups according to the laws. However, MPAs designated by three groups or categories of MPAs are overlapped on other MPAs because the last group of MPAs is managed by local fishermen and extends broadly on other MPAs along the Japanese coast.

In 2018, the total area of MPAs in Japan is about 369,000 $km^2$ to attain about 8.3% of EEZ, of which the Ministry of the Environment and Fisheries Agency of Japan manage about 21,000 $km^2$ (about 0.5%) and 364,000 $km^2$ (about 8.1%), respectively (Table 2) (Ministry of the Environment of Japan 2018). The area overlapped by managements of the two governmental organizations is about 0.3%, which consists of mainly natural parks and MPAs related to fisheries. MPAs in offshore waters will be set for achieving the 10% of EEZ by 2020 (Ministry of the Environment of Japan 2018).

MPAs which the two ministries (MOE and JFA) manage are ecologically or biologically significant areas (EBSAs). The definition of an EBSA from the CBD decision text is: "geographically or oceanographically discrete areas that provide important services to one or more species/populations of an ecosystem or to the ecosystem as a whole, compared to other surrounding areas or areas of similar ecological characteristics, or otherwise meet the EBSA criteria" (CBD Secretariat 2012). EBSA criteria consist of (1) uniqueness or rarity: area contains either (i) unique ("the only one of its kind"), rare (occurs only in few locations) or endemic species, populations or communities; and/or (ii) unique, rare or distinct, habitats or ecosystems; and/or (iii) unique or unusual geomorphological or oceanographic features, (2) special importance for life history stages of species: areas required for a population to survive and thrive, (3) importance for threatened, endangered, or declining species and/or habitats: area containing habitat for the survival and recovery of endangered, threatened, declining species, or area with significant assemblages of such species, (4) vulnerability, fragility, sensitivity, or slow recovery: areas that contain a relatively high proportion of sensitive habitats, biotopes, or species that are functionally fragile (highly susceptible to degradation or depletion by human activity or by natural events) or with slow recovery, (5) biological productivity: area containing species, populations, or communities with comparatively higher natural biological productivity, (6) biological diversity: area contains comparatively higher diversity of ecosystems, habitats, communities, or species, or has higher genetic diversity, and (7) naturalness: area with a comparatively higher degree of naturalness as a result of the lack of or low level of human-induced disturbance or degradation.

It is, however, impossible to set a no-take zone in coastal waters even in national park areas due to traditional artisanal fisheries along the coast. To highlight the difference of MPAs between France or occidental countries and Japan, it is very interesting to introduce common fishery right areas overlapping with national parks. Such three sites along the longitude are demonstrated as typic examples of Japanese-type MPAs. We introduce three cases of MPAs in Japan from the boreal to the subtropical zones through the temperate zone. These areas of MPAs are classified into EBSA by the Ministry of the Environment of Japan (Ministry of the Environment of Japan 2018).

**Table 2** Categories of marine protected areas in Japan defined by laws, management bodies, percentage of surface area per exclusive economic zone of Japan and number of sites based on Tsurita and Matsuda (2013) and the Ministry of the Environment of Japan (MOE) (2018). JFA and CA correspond to the Fisheries Agency of Japan and the Agency of of Culture of Japan, respectively

| Category | Name of MPA | | Related law | Related ministry | Management body | | | Percentage of surface area per EEZ's (%) | Number of sites |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | National government | Local government | Others | | |
| 1 | Natural park | National park | Natural Park Law (1957) | MOE | 1 | – | – | 0.4% 19,000 km$^2$ | 82 |
| | | National designated park | Natural Park Law (1957) | MOE | 2 | 1 | – | | |
| | | Prefectural natural park | Prefectural act | MOE | 2 | 1 | | | |
| 2 | Natural seashore protection area | | Special Law for Environmental Protection of Seto Inland Sea (1971) | MOE | 2 | 1 | – | | – |
| 3 | Natural environment conservation area (special undersea area) | | Conservation Law of Natural Environment (1972) | MOE | 1 | 2 | – | 0.1% 2000 km$^2$ | 1 |
| 4 | Animal reserve | National designation | Law for Preservation and Appropriate Hunting of Animals | MOE | 1 | 2 | – | | 23 |
| | | Prefectural designation | | MOE | 2 | 1 | – | | |
| 5 | Habitat area | | Preservation Law for Threatened Species of Wild Animals and Plants | MOE | 1 | 2 | – | | – |
| 6 | Natural monument | | Cultural Property Protection Law (1950) | CA | 1 | 2 | – | | – |
| 7 | Protected sea area | | Fisheries Resources Conservation Law (1951) | JFA | 1 | 2 | – | 8.1% 364,000 km$^2$ | 52 |

(continued)

**Table 2** (continued)

| Category | Name of MPA | | Related law | Related ministry | Management body | | | Percentage of surface area per EEZ's (%) | Number of sites |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | National government | Local government | Others | | |
| 8 | Sea area designated for exploitation of coastal fisheries resources | | Promoting Law for Exploitation of Marine Fisheries Resources (1971) | JFA | 2 | 1 | – | | 616 |
| 9 | Common fishing right area | | Fisheries Law (2018) | JFA | 2 | 2 | 1 | | 387 |
| 10 | Area designated by fisheries groups | Area where catch is regulated | Fisheries Resources Conservation Law (1951)<br>Fisheries Cooperative Law (1948) | JFA | 2 | 2 | 1 | | |
| | | Area where fisheries cooperative autonomously regulates catch | Fisheries Law (2018) | JFA | 2 | 2 | 1 | | |

# 4 Examples of Japanese-Type MPAs

## 4.1 Three Representative MPAs and Shiretoko

We selected three representative MPAs (Fig. 1) as follows:

a. Shiretoko Peninsular: MPA consisting of common fishery right areas in Shiretoko National Park and World Natural Heritage of UNESCO.
b. Taketomi Island: MPA consisting of a common fishery right area under the community marine policy in a subtropical zone in Sekisei Lagoon belonging to Iriomote-Ishigaki National Park.
c. Tsushima Islands: MPA consisting of common fishery right areas managed by fishermen's cooperative and a local community in a temperate zone in Iki-Tsushima Quasi-National Park bounded with Korea.

Coastal fisheries areas commonly shared by local fishermen and managed under traditional self-managements by themselves for sustainable use of coastal marine resources. Japanese-type MPAs on which management plans are set for sustainable use of marine bioresources.

Shiretoko consisting of the mountains, forests and common fishery right areas was registered as a World Natural Heritage site in 2005 (Makino et al. 2019) (Fig. 2). The reasons why Shiretoko was registered as a world heritage site are the southern limit covered with drifting ice in the northern hemisphere, the remarkable interaction between marine and terrestrial ecosystems such as a relation between homing salmon and a brown bear as a predator of the salmon, and the rich biodiversity including

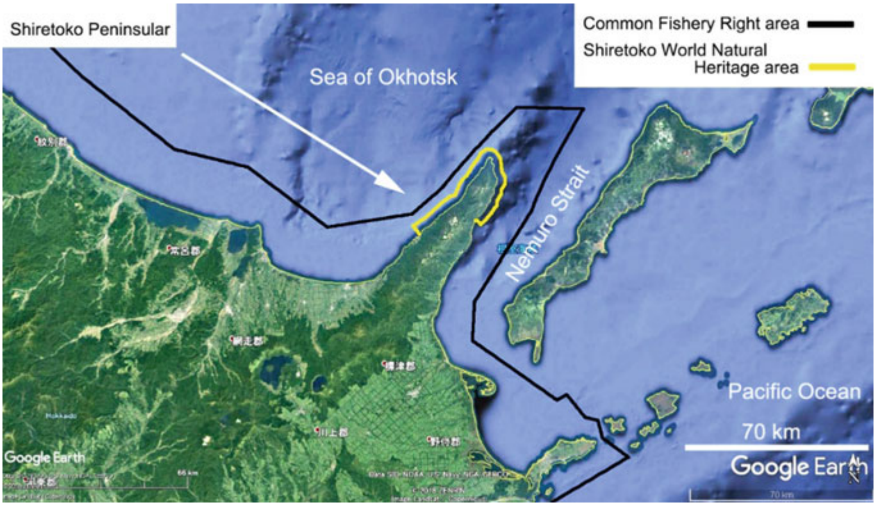


**Fig. 2** Map showing Shiretoko MPA consisting of common fishery right areas (black solid line) and Shiretoko World Natural Heritage (yellow solid line) in waters around the Shiretoko Peninsular

endangered species of both ecosystems. Fisheries have been given roles to conserve ecosystem functions and structures under a cooperative management of fisheries in 2005, which has been highly appreciated by UNESCO (Makino et al. 2009). The management method is regarded overseas as "Shiretoko approach." The sea of Shiretoko is a very important area as EBSA in northern Japan. The Criteria of International Union for Conservation of Nature (IUCN) for Selection of the World Heritage List sites must be of outstanding universal value and meet at least one out of ten selection criteria. Shiretoko corresponds to the criteria of IUCN (ix) to be outstanding examples representing significant ongoing ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals, and (x) to contain the most important and significant natural habitats for in situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation (Dudley 2008).

For the coexistence of marine ecosystem conservation and coastal fisheries, examination and implementation of various monitoring and adaptive management measures are continuing in Japan. The definition of marine protected areas includes coexistence of sustainable fisheries and conservation of marine ecosystems based on voluntary management (Dudley 2008). Fishermen around Shiretoko have already set the voluntary management of fisheries consisting of the fishing season, fishing areas for salmonids and pollock fishery, and fishing methods (Sakurai 2006). In Shiretoko area, local economy depends on fisheries and tourism. The conservation of biodiversity in marine and terrestrial ecosystems is important for sustainable fisheries and tourism. For example, it is recognized that homing salmon transports nutrients as its body from the sea to river, brown bears as its predator transform part of salmon in the river to nutrients on land and the river provides nutrients from riverbank forests to the sea (Sakurai 2017). Therefore, river structures have been improved to promote natural spawning salmon individuals to swim up the river and spawn on the riverbed. Local gillnet fishermen have implemented seasonal no-take zones for its spawning since 1995 (Makino 2013). The no-take zones are re-examined every year on the basis of the previous year's performance and scientific advice from the local research station. In addition to the setting of the no-fishing season and no-take zones, self-management-type fisheries such as reduction of fishing vessels are being implemented for walleye pollock of the Nemuro Strait, which decreased sharply after the 1990s (Sakurai 2017). Coastal fishermen, fishery cooperatives, local governments, citizens' groups including tourisms, prefectural government, the Ministry of the Environment of Japan and scientists organized Community Liaison Council for Shiretoko World Natural Heritage Site in 2003 and reformed it to the Scientific Committee in Shiretoko World Heritage Site in 2007 with the agreement of the local stakeholders in the management of national park. The activities above-mentioned are officially incorporated into the marine management plan of the heritage area as a part of the ecosystem-based management measures (Makino et al. 2009). Thus, the MPAs began with local initiatives, but are formally recognized under the World Natural Heritage framework of the UNESCO (Makino 2013). In this way, "Shiretoko approach" is the bottom-up approach based on the appropriate advice by the Scientific

Committee in Shiretoko World Heritage Site. The Shiretoko approach implements long-term monitoring based on adaptive management, with the impacts of climate change also in mind, and encourages scientific advice and voluntary efforts by stakeholders (Matsuda 2009). A management system that shares management decision-making authority and responsibility among stakeholders is called joint management. Coastal fisheries in Japan are highly appreciated worldwide as a case where this joint management has worked for many years. Shiretoko World Heritage Site had an opportunity to explain it to the world.

There are 37 monitoring items in all consisting of physical environments, flora and fauna on land and in the sea (Ministry of the Environment of Japan 2012a). The duration of one period of the plan is 10 years, with the first period beginning in April 2012 and ending in March 2022. The plan classified marine organisms into indicator species groups: keystone species, predators of higher trophic levels, endangered species and other characteristic species constituting the food web in the waters surrounding Shiretoko. Deliberations on the continuation and/or revision of the plan are to be held every five years or so. It is the most important for the Shiretoko approach to conduct adaptive management in Shiretoko marine ecosystem based on the monitored indicators through sharing scientific information among stakeholders and agreement on the conservation on Shiretoko marine ecosystem to decide a policy for its conservation. Moreover, Alaska pollack (*Theragra chalcogramma*) needs adaptive resource management across the border between Japan and Russia.

## 4.2 *Taketomi Town*

Taketomi Town is a municipality that belongs to Yaeyama Islands (Okinawa Prefecture 2018) located at the most southwest end of Okinawa Prefecture and includes 16 uninhabited islands of about 40 km north–south, 42 km east–west, about 1700 km$^2$ of vast ocean with a total land area of about 334 km$^2$ (Tsuuji 2018). Because it belongs to a subtropical oceanic climate, Taketomi Town surrounded by the Pacific Ocean (Fig. 1) forms a rich ecosystem represented by coral reefs, mangrove forests and seagrass beds (Yokochi 2004). Iriomote wild cat (*Prionailurus bengalensis iriomotensis*) is an endemic species only in Iriomote Island (Okinawa Prefecture 2015a). Yellow-marginated box turtle (*Cuora flavomarginata evelynae*) is also an endemic species in Iriomote and Ishigaki Islands (Okinawa Prefecture 2015a). Yaeyama Islands where many precious wildlife lives are all designated Iriomote-Ishigaki National Park in 2007 through integrating a part of Ishigaki Island after the designation of Iriomote National Park in 1972. The land and the sea areas of Iriomote-Ishigaki National Park were 205.7 and 521.0 km$^2$ including 20 sea area parks with 110.7 km$^2$, respectively (Ministry of the Environment of Japan 2012b).

Taketomi Town decided its own Marine Basic Plan in 2010 after the National Marine Basic Plan of the central government was established in 2008 at the first time based on the Marine Basic Law enacted in 2007 (Taketomi Town 2011). One of principles of Marine Basic Plan of Taketomi Town is to protect "nature and culture that are precious property of our country by appropriate and integral management of marine environments with islands."

The first Marine Basic Plan of Taketomi Town listed 23 measures for the future of Taketomi Town and its contribution to Japan as the oceanic state (Taketomi Town 2011). One of them is to establish MPAs of Taketomi Town with Taketomi Town, Yaeyama Fishery Cooperative, operators of diving, canoeing and recreational fishing, citizens of Taketomi Town, Okinawa Prefectural Government, Sea-area Fisheries Adjustment Commissions of Okinawa Prefecture and Naha Natural Environment Office of the Ministry of the Environment of Japan. In the sea area of Taketomi Town, four places in the Sekisei Lagoon are designated as underwater natural parks of Iriomote-Ishigaki National Park (Fig. 3). Sakiyama Bay on Iriomote Island is designated as only one underwater marine environment protected area in Japan. Compared with the whole Taketomi Town sea area, Taketomi Town considered the protected areas are limited and narrow (Taketomi Town 2011). Most of the large coral reefs, seagrass beds and mangrove forests, which are important natural habitats, are not designated. Aside from applying restrictions that limit the capture of animals and plants in the sea, it is important to designate MPAs to restrict developments and exploitations that leads to the destruction and extreme use of important nature. For setting MPAs, Taketomi Town decided to conduct the following two subjects. (1) Consider a system of marine protected areas covering wider waters, and propose and request to expand MPAs to the Ministry of the Environment of Japan, which administers national parks, the Ministry of Land, Infrastructure, Transport and Tourism, the

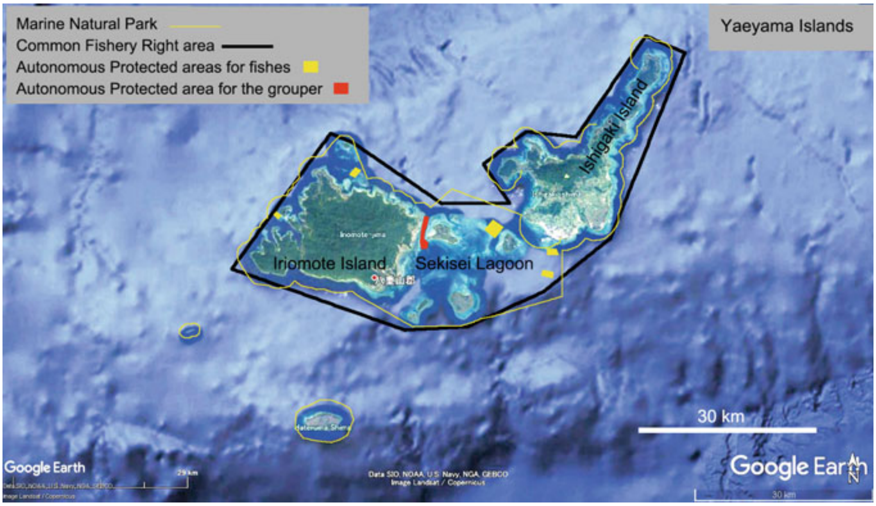


**Fig. 3** Map showing Taketomi MPAs consisting of a common fishery right area (fat black solid line) and Iriomote-Ishigaki National Park (thin yellow solid line) in waters around Yaeyama Islands. Areas painted with yellow and red colors correspond to autonomous protected area for fishes and that for the grouper, respectively

Ministry of Agriculture, Forestry and Fisheries of Japan and the Japan Coast Guard, which have jurisdiction over waters, and Okinawa Prefecture, which has jurisdiction over beaches and ports. (2) Not prohibit entry to marine protected areas or strictly restrict the collection of animals and plants but admit certain utilization to maintain the lives of the residents and improve their lives. (3) Establish a system suitable for Taketomi Town to restrict developments or uses of MPAs that might cause the destruction of natural environments. From 2011 to 2018, Taketomi Town attempted expansion of marine park areas, formulation and proposal of protected area plans linked to Okinawa Comprehensive Management Plan and examination of regulations, implementation of marine protection activities, and expansion of natural environment conservation area (Taketomi Town 2018). In 2016, these efforts resulted in the expansion of land and sea areas of the national park to 406.53 $km^2$ and 814.97 $km^2$, respectively (Fig. 3).

The sea area has the largest coral reef area in Japan called Sekisei Lagoon with approximately 296 $km^2$ (Fig. 3). In October 2017, the 2nd Committee for the Community Marine Policy of Taketomi Town was held to discuss a plan for more effective measures to conserve marine environments and to use fishery resources in a sustainable way (Taketomi Town 2018).

Fishery regulations to protect fish species in a common fishery right area are decided by a fishery cooperative such as closure and opening of fishing grounds, and decision of prohibited grounds. The Yaeyama Fishery Cooperative that manages the common fishery right area from Ishigaki Island to Iriomote Island (Fig. 3) (Okinawa Prefecture 2013) began resource management activities from 1998 to 2002 and has established four protected areas, where Pacific yellowtail emperor (*Lethrinus atkinsoni*) spawn in its common fishery right area from April to May (Shikakuma 2008). The Yaeyama Fishery Cooperative paid for the maintenance of buoys that marked the boundaries of the no-fishing zone. Thanks to the restriction, catch per unit effort (CPUE) increased (Shikakuma 2008). After the interruption of the first fish resource management activity, fish catch abruptly and greatly decreased. Then, the Yaeyama Fishery Cooperative set five marine protected areas (Fig. 3) with the total surface area five times greater than in the first management period and restrict fishing small fish under a decided fork length such as 20 cm for Scaridae, *Lethrinus,* and white-streaked grouper (*Epinephelus ongus*), 25 cm for other groupers in 2008 (Shikakuma 2008). The cooperative checks sizes of fish at the fish markets for selling fish to brokers (Shikakuma 2008). Because white-streaked grouper gathers in a specific spawning ground during the spawning season, the Lighting Diving Research Group of the Yaeyama Fishery Cooperative has established a protected area in Yonara Channel (Fig. 3) (Okinawa Prefecture 2015b). Many coastal fish species also use the protected area of the white-streaked grouper as a spawning area. The fishermen deploy buoys to indicate protected areas, conduct patrols and seek cooperation with tourist operators such as diving and leisure fishing (Anon. 2017). In 2017, the Yaeyama Fishery Cooperative set one reserve in Yonara Channel, where white-streaked grouper spawns, from 5 April to 25 April and from 4 May to 24 May and five reserve areas near Yaeyama from 1 April to 30 June (Anon. 2017, 2019). The cooperative called tourists not to fish neither dive at protected areas during these

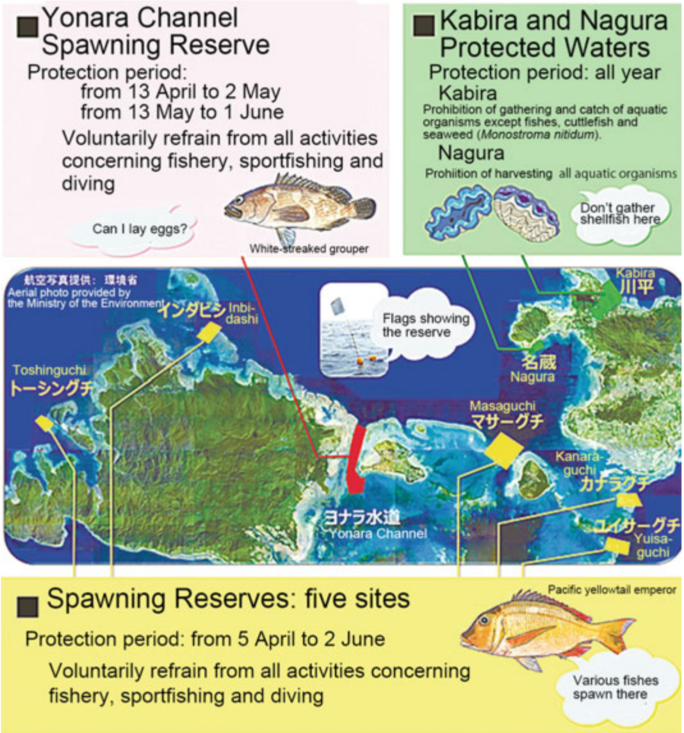


**Fig. 4** Poster for warning neither diving nor leisure nor professional fishing in five yellow areas (Toshinguchi, Indabishi, Masaguchi, Kanaraguchi and Yuisaguchi) from 5 April 2019 to 2 June 2019, in one red area (Yonara Channel) from 13 April 2019 to 2 May 2019 and from 13 May 2019 to 1 June 2019 and in two green areas (Kabira and Nagura bays) for all year

periods through informing it by a poster in cooperation with tourist operators (Fig. 4) (Anon. 2019). Even in Iriomote-Ishigaki Marine Natural Park Area, fishermen play important roles to conserve marine biodiversity by setting protected areas excluding fishing and diving (Fig. 4) and patrolling the areas. Penalty is payment equivalent to five times of catch of a month.

Taketomi Town, Ishigaki City, Yaeyama Fishery Cooperative, Yaeyama Diving Association, etc., based on external budgets such as the Agency of the Environment of Japan (the present Ministry of the Environment of Japan), eradicated a total of 1.9 million of the crown of thorns, *Acanthaster planci*, eating coral reefs in Sekisei Lagoon and its adjacent waters from 1972 to 1985 (Shimoike 2004). In 2004, some fishermen who concerned the threat of the crown of thorns to coral reefs voluntarily got rid of them. Fishermen in the Yaeyama Fishery Cooperative have participated in activities to conserve coral reefs because they know that fishes disappear when coral reefs disappeared. The Ministry of the Environment of Japan has organized activities to eradicate the crown of thorns with local governments, Yaeyama Fishery Cooperative, Yaeyama Diving Association, etc., since 2003 (Yaeyama Council for

Counter-measure against Crown of thorns 2008). Taketomi Town and Yaeyama Fishery Cooperative have played an important role to manage marine protected areas in Taketomi Town sea area with Yaeyama Diving Association and the Ministry of the Environment of Japan.

### *4.3 Tsushima*

Waters around Tsushima Islands are located on the boundary zone between East China Sea and the Sea of Japan (Fig. 1). The maximum velocity of the northeastward current is located in the central parts of the eastern and western channels of Tsushima Strait, and the maximum velocity in the western channel is stronger than that in the eastern channel (Takikawa et al. 2005). The volume transport of the Tsushima Warm Current through the straits has strong seasonal variation with the minimum in January and two maxima from spring to autumn (double peaks). In winter, the Tsushima Warm Current has a single source, the Kuroshio Branch Current in the west of Kyushu, which transports a mixture of Kuroshio Water and Changjiang River Diluted Water northward (Ichikawa and Beardsley 2002). In summer, the surface Tsushima Warm Current has multiple sources, i.e., the Taiwan Warm Current, the Kuroshio Branch Current to the north of Taiwan, and the Kuroshio Branch Current west of Kyushu.

The coast of Kami-Tsushima (North Island) and Shimo-Tsushima (South Island) of Tsushima consists of relatively larger open-type bays and rias-type bays (Fig. 5) (Yatsu 2014). The former and the latter bays form habitats for coral reefs and for large brown algae such as *Sargassum* species and *Eisenia bicyclis,* respectively. Thus, the coast provides high habitat diversity for marine organisms and fishery resources.

The Government of Tsushima City has focused on management of marine area by setting a marine protected area since 2009, when a marine protected area was not well known, and organized the Promotion Council of Tsushima City for Setting Marine Protected Area in 2010 consisting of members of fishery cooperatives of Tsushima (Anon. 2015). At the council, participants have discussed relations between fisheries and marine protected areas face to face with fishermen because protecting the ecosystem and environment of the sea would lead to the sustainable fisheries and human society receiving the benefits of the sea through sustainable use of the sea. In 2012, Tsushima City established the Scientific Committee of Tsushima City for Marine Protected Areas consisting of researchers of universities and national research institutes, members of NGO, and so on. In 2014, the committee published the report to share objective information on marine environments, ecosystem and biodiversity among stakeholders, and discuss on MPAs from a point of view of science (Nakata 2014). The council has been continuing discussions on how Tsushima continues to receive the blessings of the sea based on the report (Anon. 2015).

At the meetings on marine protected area, representatives of the fishery cooperatives have gathered to discuss on conserving fish resources throughout Tsushima. In the Tsushima area, protected areas on important fishery target species have already

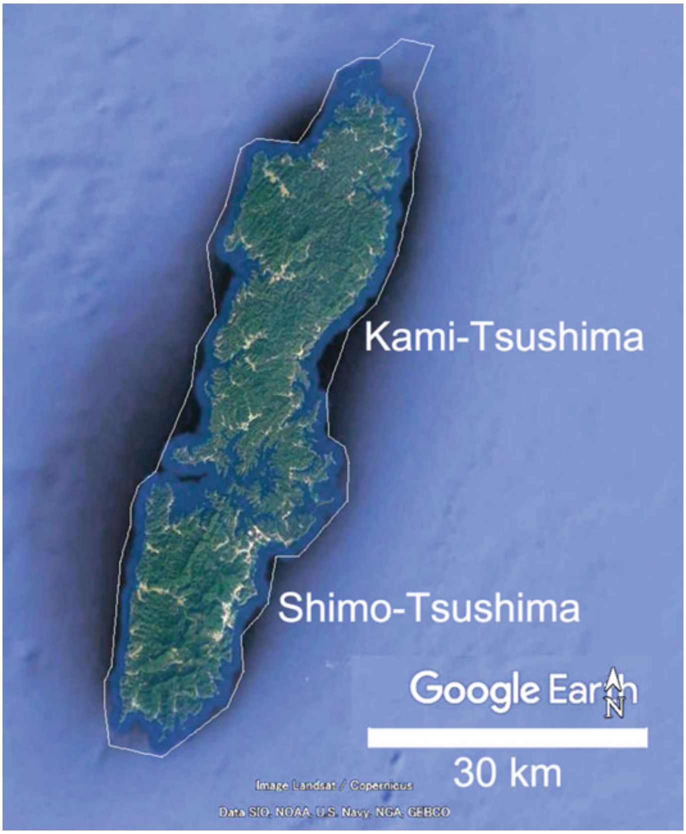


**Fig. 5** Map showing Tsushima consisting of Kami-Tsushima (North Island) and Shimo-Tsushima (South Island) and its common fishery right area along the coast encircled with thin line

been set up by the fishermen. For example, they have been set for the horsehead tilefish (*Branchiostegus japonicus*) and blackthroat seaperch (*Doederleinia berycoides*) (Fig. 6).

The Kami-Tsushima Fishery Cooperative, other fishery cooperatives (a total of 12 fishery cooperatives along the coasts of Tsushima Islands) and local governments organized the Council for Establishing Horsehead Tilefish Resource Management Plan of Nagasaki Prefecture in March 2010. The council has established the "Horsehead Tilefish Resource Management Plan of Nagasaki Prefecture" and set a marine protected area for the horsehead tilefish (Fig. 6) (Nagasaki Prefecture 2016). A variety of fish species are concentrated in the square area northeast of Tsushima Island with the horsehead tilefish. (Nagasaki Prefecture 2016). The plan set no-fishing days and operation time from the sunrise to 16:00, and restricted fishing gears to protect resources (Fisheries Agency of Japan 2010). This area is a fishing ground for various fish species in each season. The fishery management for the horsehead tilefish living

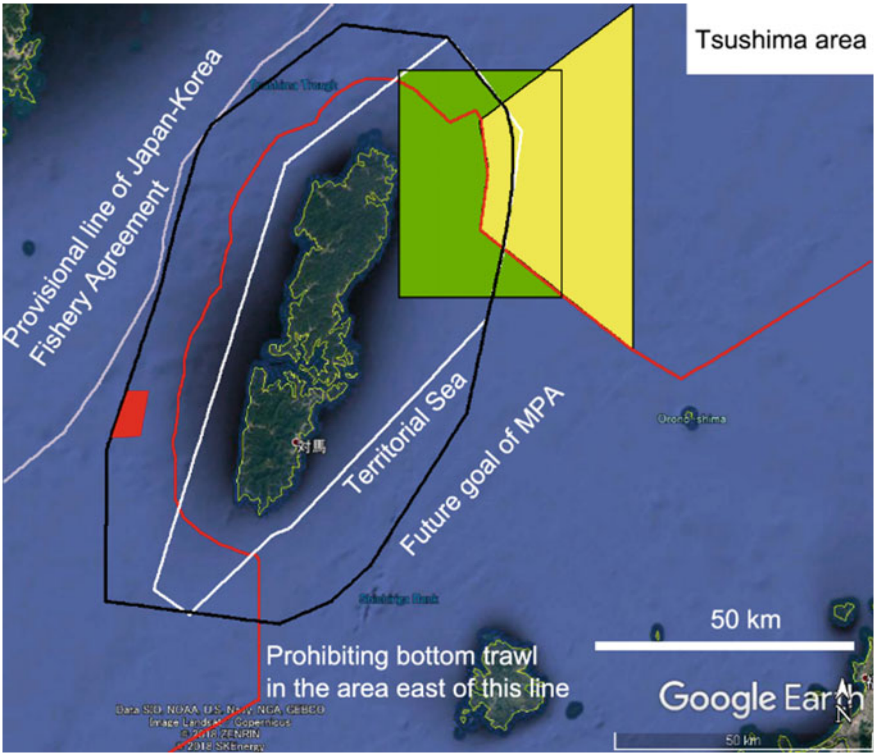


**Fig. 6** Map showing the provisional line of Japan–Korea Fishery Agreement (gray line), the area of Territorial Sea around Tsushima (white line), the area of Future Goal of Tsushima MPA within the 12 nautical miles off the coast of Tsushima (black line), the area of prohibiting bottom trawl (red line), the marine protected area for the horsehead tilefish (green rectangular area), the area of prohibiting bottom trawl with closures from 1 April to 30 September and from 19 hr to 5 hr of 1 October to 31 March (yellow area) overlapping a part of area with the marine protected area for the horsehead tilefish and the marine protected area for blackthroat seaperch (red area) west of Tsushima (Nagasaki Prefecture 2016)

in burrows in the seabed promotes conservation of other fish species on the same seabed in this sea area (Anon. 2015). Therefore, indirect resource management can be applied to bottom fishes and pelagic fishes in the water column such as yellowtail (*Seriola quinqueradiata*), Japanese common squid (*Todarodes pacificus*), spear squid (*Heterololigo bleekeri*), Pacific bluefin tuna (*Thunnus orientalis*), largehead hairtail (*Trichiurus japonicus*), marbled rockfish (*Sebastiscus marmoratus*) feeding on shellfish, and red sea bream (*Pagrus major*). Fishery cooperatives of Tsushima have set a marine protected area for blackthroat seaperch located west of Tsushima (Fig. 6) where the bottom trawl is prohibited (Fig. 7). Since this area is also a habitat for flatfish, the protected area is effective for ground fish conservation.

In 2018, the Promotion Council of Tsushima City for Setting Marine Protected Area established a plan named "Island Sea Management Plan for Marine Protected

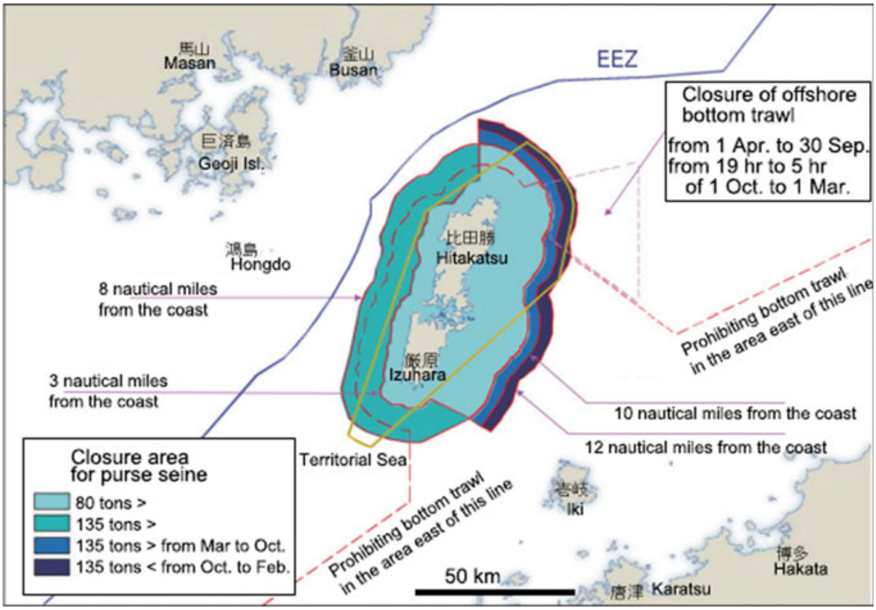


**Fig. 7** Map showing closure areas for purse seine and offshore bottom trawl (Seino 2014)

Areas of Tsushima" to promote "MPAs of Tsushima Version" to enforce management of marine ecosystem in the common fishery right area from 2018 to 2027 (Tsushima City 2018). They decided two principals: MPA is not an area that prohibits fishing activities for environmental protection, but an area that is appropriately managed to utilize fishery resources sustainably. MPA is not an area where the purse seine and bottom trawl are prohibited, but an area where parties concerned discuss and co-manage resources for their sustainable exploitation. This plan starts the management of marine bioresources in common fishery right area (Fig. 5). Its final goal is to extend MPAs to the area of the territorial sea within 12 nautical miles from the coastline of Tsushima (Fig. 6). The plan from 2018 to 2027 consists of two execution subplans: to manage marine resources in rocky coasts with 12 fishery cooperatives along the coast of Tsushima and to recover seaweed beds, which have been lost, with local people, local governments and scientists. In this way, the MPAs of Tsushima Version are advancing.

The territorial sea around Tsushima facing Korean Peninsular is limited to three nautical miles from the coastline (Fig. 7) because the West Channel of Tsushima Strait has been designated as an international strait used for international navigation. It is also necessary to cooperate with neighbouring foreign countries such as Korea and China to prevent foreign fishing vessels from conducting illegal fisheries and endangering fishery resources and biodiversity in MPAs located in the borders (Figs. 6 and 7). Thus, it is necessary to extend MPAs of Tsushima to the line of Exclusive Economic Zone between Japan and Korea that is Specified Sea Area.

## 5 Future of Japanese-Type MPAs

Three successful examples of MPAs in Japan indicate that fishery cooperatives are the most important actor among all the stakeholders. Marine bioresources along the coast in front of a village have been shared by its village people since the medieval. The Fishery Law of Meiji Era in 1910 explicitly indicated a common fishery right of a village in front of the sea. The fishery cooperative was formulated in Fishery Cooperative Law in 1948. The fishery cooperative has not only fishing rights but also a responsibility to manage coastal resources. Cooperatives have set marine protected areas and kept them by a bottom-up management. On the other hand, it is very important to connect fishing right areas belonging to each fishery cooperative for creating an effective comprehensive MPA. Three cases suggest that local governments at levels of prefecture and communities, especially community can promote to integrate related common fishing right areas into one MPA and formulate the MPA legally.

Japanese-type MPAs are not no-take zones but areas managed by stakeholders for sustainable use of marine bioresources. In areas under traditional self-management by local fishermen, they maintain bioresources with flexible ways that regulations cannot define. These areas are classified into “VI Managed Resource Protected Area” categorized by IUCN for a sustainable use of resources. The most important thing is a bottom-up management of MPAs in Japan with the active participation of fishermen and community. Japanese fishermen have traditionally used common fishery right areas considered as a property of all people living in their villages in front of the common fishery right areas.

A recent problem in Japan is a decrease in number of fishermen. It is necessary to maintain or increase the number of fishermen and promote concerns of Japanese people to the sea. For recruiting young generation to the fishery, production system and daily life in fishing village must be updated to the modern society. For example, direct connection between fishery cooperatives to consumers via internet or face-to-face relation and enough holidays for fishermen. Recently, the number of young city people head to the beach is decreasing. They will lose interests in the sea and fisheries. In such context, not only natural science but also social and human sciences are requested to support to set and maintain MPAs in Japan by stimulating city people to be interested in the sea and culture of the sea including fish cuisines. Of course, the central government must support researches on sciences and finance local governments and fishermen to set and maintain MPAs. Therefore, we need to look for collaborations along with the Future Earth because Future Earth is a new research initiative for global sustainability with transdisciplinary approaches taken by engagement of stakeholders throughout the research processes, namely by co-design, co-production and co-delivery (Kasuga 2014). When the conditions above-mentioned are possible, co-design, co-production, and co-delivery of MPAs along the coast will be established successfully and realized sustainable coastal management via MPAs.

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# From Coast to Coast, the Winding Road of a Nested Governance and Management Approach: Reconciling Biodiversity Conservation and Sustainable Development

**Yves Henocque**

**Abstract** The urgency of addressing coastal issues is now considerably greater than it was a decade ago. Moreover, the Oceans Day at COP21 (Paris, 4 December 2015) recognized 'the central role of the oceans in regulating climate, and the fact that the ocean will not be able to perform these functions in the future if global warming continues unabated'. Responsible management of any marine area should integrate integrated coastal zone management (ICZM), or more generally speaking integrated coastal management (ICM) and the ecosystem approach as well as applying the same principles from the coast to the offshore waters. By working together in a strategic way, ICM and biodiversity conservation practitioners can mutually support efforts to promote conservation of coastal resources and their habitats and the well-being of the people who depend upon them. This article advocates the possibility and urgency of clearly addressing in a coordinated way any coastal and marine managed area, including marine protected areas (MPAs), within the context of an overall integrated coastal and ocean management (ICOM) policy, with articulated plans developed at local, sub-national, national, and regional level to fulfil the grand objective of the Convention of Biodiversity, Aichi Target 11.

**Keywords** ICZM · ICM · Ecosystem approach · MPAs · ICOM

## 1 Introduction—Managing Humans

The urgency of addressing coastal issues is now considerably greater than it was a decade ago. Moreover, the Oceans Day at COP21 (Paris, 4 December 2015) recognized 'the central role of the oceans in regulating climate, and the fact that the ocean will not be able to perform these functions in the future if global warming continues unabated'. The fact is that in spite of the many international environmental treaties,

[1] https://en.unesco.org/ocean-decade/.

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declarations, and other promises of action, the quality of coastal environments continues to deteriorate in most of the world.[1] Many of the major pressures on coastal areas in the early 1990s have continued to intensify. Coastal fisheries in most of the world have continued to decline rapidly while the demand for coastal resources (including new activities like wind farming) and the subsequent pollution loads have increased in most areas due to many direct (land-use, uses and technological development, climate change…) and indirect (coastal populations, socio-economical development, science and technology…) drivers of change.

On the positive side, it is clear that globally, though in a very fragmented way, there is now a far greater appreciation of the environmental, economic, social, cultural and recreational importance of coastal and sea areas, and of the value of integrated approaches like integrated coastal management (ICM) coupled with the ecosystem approach. In spite of all, the misunderstanding and difficulties in implementing it, there is a worldwide consensus that an 'integrated coasts and seas ecosystem-based management' kind of approach is significantly better than more traditional sectoral approaches to managing human activities within coastal areas, the exclusive economic zone (EEZ) and beyond.[2]

One implication is that coastal management laws and regulations must be designed to manage humans to ensure that their impacts on coastal areas and beyond must respect certain natural limits or 'thresholds'. Indeed, the focus of coastal and ocean management should definitely be on managing people and their impacts on the environment and vice versa, rather than pretending managing the environment itself.

In response to the pressures facing coastal and marine ecosystems, two major types of approaches have emerged since the 1992 Rio Summit: integrated coastal management (ICM) from Agenda 21 Chap. 17, nowadays extended offshore through the Maritime Spatial Planning (MSP) approach, and marine biodiversity conservation supported by the Convention on Biological Diversity. Both fields of intervention share the same ultimate goal (healthy and sustained socio-ecosystem) and utilize similar tools though they may have differing priorities.

All in all, while we are supposed to deal with a totally interconnected system from coastal to offshore areas, the different applying policies and forms of governance are poorly or not at all articulated, weakening the efficiency of the numerous initiatives that are taking place in each compartment (Fig. 1).

[2]http://www.geftwap.org/water-systems/large-marine-ecosystems.

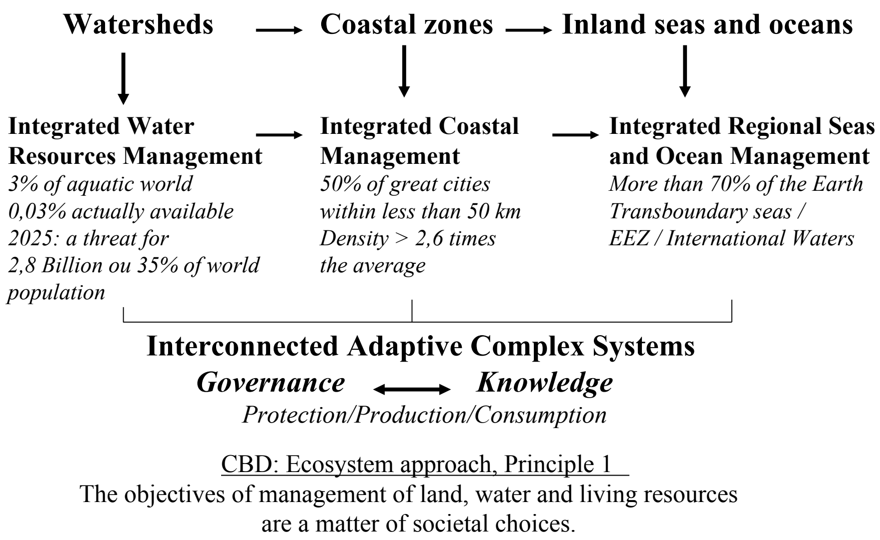


**Fig. 1** Continuum from watershed to deep waters

# 2 Managing Beyond the Divide Between Conservation and Development

## *2.1 A Common Source*

As not so well-known to the public, there are actually seven major programme areas included in the 1992 Earth Summit's Agenda 21, Chap. 17:

(A) integrated management and sustainable development of coastal and marine areas, including exclusive economic zones;
(B) marine environmental protection;
(C) sustainable use and conservation of living marine resources of the high seas;
(D) sustainable use and conservation of living marine resources under national jurisdiction;
(E) addressing critical uncertainties for the management of the marine environment and climate change;
(F) strengthening international, including regional, cooperation, and coordination;
(G) and sustainable development of small islands.

Therefore, the very comprehensive Agenda 21 challenge is about envisioning the entire spectrum, encompassing both the land and water sides, emphasizing as well the need for proper management of fishery resources in ocean areas under national control and the importance of the connection between land and sea, i.e. covering the inland areas which affect the oceans mainly via rivers and non-point sources of pollution, coastal lands (wetlands, marshes, etc.) where human activity

**Table 1** Features of ICM as set forth in Chap. 17 of Agenda 21 of United Nations Conference on Environment and Development (UNCED). According to building capacity for the adaptive governance of coastal ecosystems. A priority for the twenty-first century (Olsen et al. 2009)

| Practicing the ecosystem approach | Implementation as changed behaviour | Societal and environmental goals |
|---|---|---|
| • Coastal states commit themselves to integrated management and sustainable development of coastal areas and the marine environment under their jurisdiction 17.5)<br>• Coordinating mechanisms (such as a high-level policy planning body) are established at the local and national levels (17.6)<br>• The necessary funding is secured. The estimated average total annual cost (1993–2000) of implementing the activities of this programme is about $6 billion including $50 million from the international community on grant or concessional terms (17.12)<br>• Organize education and training in integrated coastal and marine management (17.15) | • Implement an integrated policy and decision-making process including all involved sectors to promote compatibility and a balance of uses (17.6)<br>• Cooperate in the development of necessary systematic observation, research and informational management systems (17.13) | • Maintenance of biological diversity and productivity of marine species and habitats (17.7)<br>• Improvement of coastal human settlements, especially in housing, drinking water and treatment of sewage, solid wastes and industrial effluence (17.6)<br>• Restoration of altered critical habitats (17.6) |

is concentrated and directly affects the adjacent waters, coastal waters (estuaries, lagoons, and shallow waters generally) where the effects of land-based activities are dominant, offshore waters mainly out to the edge of national jurisdiction (usually and as of today in the Mediterranean, 12 miles offshore), and high seas beyond the limit of national jurisdiction (Cicin-Sain 1993) (Table 1).

## *2.2 Evolving Through Separate Groups and Institutions*

Besides Chap. 17, Agenda 21 also contains two separate chapters on conservation of biological diversity (Chap. 15) and protection of quality and supply of freshwater (Chap. 18), which has led to separate groups and institutions focusing on biodiversity conservation or freshwater issues and the promotion of integrated water resources management (IWRM). The emphasis placed on the titles of these three chapters did not help in fully integrating them. Yet the quantity and quality of freshwater inflow into coastal areas are critically important for maintaining seawater quality and marine biodiversity, as well as the function of coastal wetlands and estuaries. Therefore, the challenge is to ensure that biodiversity conservation, ICM, and freshwater issues become more integrated and mutually supportive. In addition to national policies, that should be the task of Regional Seas Programmes such as OSPAR or the Mediterranean Action Plan which is the first to have an ICZM Protocol, a legally binding documents between Mediterranean riparian countries.

To paraphrase the goals and approaches of ICM and biodiversity conservation, the aim of ICM is to 'promote the people, while trying to preserve the place', and the aim of biodiversity conservation is to 'preserve the place, while engaging the people' (Best 2003). ICM places an emphasis on the people, and ICM practitioners usually function as impartial, neutral brokers for communities and various users, whereas conservation practitioners are typically advocates for the environment. Coastal practitioners must ensure that communities learn about and understand the term biodiversity in an inclusive and positive manner, and as an integral component of both environmental and human health. The publication of the Millennium Ecosystem Assessment report[3] much facilitated this task in proposing a scheme articulating biodiversity with the ecosystem goods and services, the spinal cord of the ecosystem-based approach as defined throughout the twelve principles contained into the Convention on Biodiversity (Table 2).

On the other hand, five years after issuing its ICZM Recommendation (2002), the evaluation report from the European Commission to the European Parliament and the Council emphasized the following: 'When launching its strategy to implement the EU ICZM Recommendation, the Commission indicated that coastal areas are particularly in need of an integrated territorial approach, but that, in essence, such good territorial governance is relevant for other areas facing multiple pressures and conflicting interests. This is increasingly the case for the seas and oceans. Notwithstanding the continued need for ICM on-shore, further emphasis will need to be placed on the implementation of ICM across the land-sea boundary and in a regional seas context' (CEC 2007).

Therefore, responsible management of any marine area should integrate ICZM, or more generally speaking ICM and the ecosystem approach as well as applying the same principles from the coast to the offshore waters. Then, instead of using different acronyms underpinned by the same principles, it would be most advisable to use the 'labelling' of 'integrated coastal and ocean management' (ICOM) as it was recommended in 2009 throughout a national consultation ('Grenelle of the sea') in France. It is not about inventing a new concept but rather about reconciliation of biodiversity conservation and maritime knowledge and activities development towards the same final goal of the coasts and seas sustainable development.

ICOM is therefore a multi-scale ('nested') ecosystem-based approach to managing defined coastal and marine areas, protected or not, understood as complex and

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[3] https://www.millenniumassessment.org/documents/document.356.aspx.pdf.

**Table 2** Relationship between ICZM (EU ICZM Strategy) and the CBD Ecosystem Approach principles. (Adapted from Haines-Young and Potschin 2011)

| ICZM Strategy for Europe | CBD Ecosystem Approach |
|---|---|
| Adopt a broad overall perspective (thematic and geographic) | Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems (operational guidance: ensure inter-sectoral cooperation)<br>The ecosystem approach should seek the appropriate balance between, and integration of conservation and use of biological diversity |
| Work with natural processes | Ecosystems must be managed within the limits of their functioning<br>Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach |
| Adopt a long-term perspective | Recognizing the varying temporal scales and log-effects that characterize ecosystem processes, objectives for ecosystem management should be set for the long term |
| Use participatory planning | The objectives of management of land, water, and living resources are a matter of societal choice<br>The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices |
| Gain support and involvement of all relevant administrative bodies | The ecosystem approach should involve all relevant sectors of society and scientific disciplines (operational guidance: enhance benefit-sharing) |
| Use a multi-scale combination of instruments | The ecosystem approach should be undertaken at the appropriate spatial and temporal scales |
| Reflect local specificity | Management should be decentralized to the lowest appropriate level |
| Implement adaptive management during a gradual process | Management must recognize that change is inevitable (operational guidance: use adaptive management practice) |

dynamic interconnected systems that encompass many interactions between people and ecosystems, and must be managed as an integrated whole.

It is an iterative process of formulating, implementing, and refining a comprehensive and holistic vision of how humans should interact in an ecologically sustainable manner with the environment where their activities take place. Very much in the spirit of the Aichi Target N°11,[4] it includes any area-based management initiative fostering

[4]By 2020, at least 17% of terrestrial and inland water areas, and 10% of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services are conserved

integrated management in a defined area, including community-based management, co-management, integrated coastal management, and its maritime spatial planning extension, and the management of marine protected areas (MPAs). Regarding the latter, it implies that an MPA is first of all a marine managed area (MMA) and, contrary to some authors' worry, there should not be any 'opening of a Pandora's box of claims that almost any management intervention should be 'counted' (Spalding et al. 2016), from the moment the principles and processes of an integrated and ecosystem-based management approach are thoroughly applied'.

In that regard, the International Seabed Authority (ISA) Marine Environment Plan (for the moment, only one exists in the central Pacific, Clarion-Clipperton nodule-rich area) and the recent multiplication of 'very large marine protected areas' could be considered as experimental areas combining maritime activities (current and future) and environmental protection covering a variety of ecosystems at a very large (oceanic-like) scale. At the same scale, and benefitting from decades of experience, one may also look at the ICOM lessons drawn from the Great Barrier Reef socio-ecosystem designed as a 'marine park' (Great Barrier Reef Outlook Report 2014).[5]

The governments (central and local) of most countries usually categorize human activities into sectors (including conservation) and then establish different government agencies to manage each sector without taking into account the fact that, from the top of the watershed to the offshore waters, they are addressing a complex and totally interconnected suite of social-ecosystems. ICM and by extension ICOM has been developed in response to this fragmented approach.

'Integrated' refers to the necessity of a multi-sector approach, and 'ecosystem-based' to the necessity of an ecosystem approach within well-defined areas into which humans are an integral part, meaning that they have to work with (and not against) coast and seas natural processes in a mutual relationship between man and nature. This means also that governing human behaviour is at the heart of ICOM including all kind of marine protected areas.

By working together in a strategic way, ICOM and biodiversity conservation practitioners can mutually support efforts to promote conservation of coastal resources and their habitats and the well-being of the people who depend upon them (Table 3). Mutual efforts should be directed not only within and around MPAs but also beyond MPAs for greater impact along a nested governance approach, at local, national, regional, and international scales.

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through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.

[5] http://elibrary.gbrmpa.gov.au/jspui/bitstream/11017/2855/1/GBR%20Outlook%20Report%202014_Web280714.pdf.

**Table 3** Integrating the strength of ICOM and biodiversity conservation. (Adapted from Best 2003)

| Theme | ICOM | Biodiversity conservation |
|---|---|---|
| Focus | Emphasis on development: promote the people, preserve the place | Emphasis on conservation: preserve the place, engage the people |
| Goals | Improve the governance process, economy, health, social well-being, and environmental quality to maintain ecosystem productivity | Conserve biological diversity and ecosystem function |
| Public role | Neutral brokers | Environmental advocates |
| Site selection and project design | Development and issue-based approach (i.e. decentralization, strengthen local communities, and authorities | Global biodiversity assessments and threats-based approach |
| Site-based approaches and strengths | Emphasis on governance process helps establish legal, decision-making and enabling environments across local, sub-national and national scales; establishing strong national ICM policies, framework, and institutions that support local efforts and reduce external threats to MPAs | Emphasis on establishing and strengthening management schemes in MPAs; land acquisition, concessions, and debt-for-nature swaps; target critical marine biodiversity and ecosystems (habitats) in need of immediate protection; international funds and resources |
| International approaches and strengths | Promote international awareness of the need for integrated approaches to coastal management and capacity building; mainstream ICM into development plans | Change global trade policies and transform businesses; reduce threats from global economic drivers, such as unsustainable fishing and tourism; strengthen international conventions |
| Scaling-up approaches and trends | Coastal watershed and basin-scale management; establish strong national ICOM policies, frameworks and institutions; use local government units to replicate efforts; establish authorities to integrate across land and marine resources | Establish functionally connected networks of MPAs; Eco-regional and seascape approaches to biodiversity threats |

## 3 The Case of MPAs in France

Like in many countries, there is a variety of different kind of MPAs in France depending on the objectives for the area to be managed (Table 4). It goes from no-take areas, where the primary motivating force is a restrictive access strategy to protect a whole area (Parc national), a resource or an habitat (e.g. Natura 2000, Protection de Biotope), to multi-use MPAs where the most important objective may be the preservation of traditional use, sustainable use of a particular resource, or a combination of these (Conservatoire du Littoral). Large multiple-use MPAs (Parc Natural Marin) are more recent (2006) and are usually designed to achieve a broad range of objectives for the purposes of integrated ecosystem-based management (as developed above), where the limits of protection in a geographical sense are based on regional ecosystem boundaries (e.g. the Gulf of Lion in the Mediterranean) or a compromise using the EEZ boundaries (e.g. New Caledonia).

International MPAs designation has to be added to the above categories though they usually are composed of already legally existing national MPAs as described in Table 4: biosphere reserves, world heritage sites, Ramsar sites, and MPAs depending on regional seas conventions.

Though it has been for a long time neglected (and it is particularly true on land where protected areas are usually much older than at sea or along the coast), like for the ICM approach, MPA practitioners must recognize that the systems they are studying and managing are socio-ecological systems including people, communities and, mostly in the overseas territories but not only, unique traditional cultures. These

**Table 4** Type of MPAs and comparative design/implementation processes (AAMP 2012)

| Process stages | National Natural Reserve | National Park | Marine Natural Park | Natura 2000 Site | Conservatoire du Littoral (CdL) | Biotope Protection Decree |
|---|---|---|---|---|---|---|
| Opportunities | Ministerial level | Prime Minister level | Study decree | Ministerial list of areas of interest | CdL strategy on Maritime Public Domain | |
| Diagnostic (Baseline) | *Till now, whatever the kind of MPA, this stage is altogether covered with the following one on boundaries and objectives definition* | | | | | |
| Boundaries and objectives definition | Creation decree | Creation decree adopting the park charter | Creation decree | Ministerial designation | Maritime Public Domain effective management | Ministry of fisheries decree |
| Mid-term management plan | | | Management plan adoption | Adoption of Objectives document | Adoption of management plan | |
| Short-term implementation | Adoption of management plan with annual action plan | | | | | |

cultural parameters are especially important to consider in areas having significant populations of indigenous peoples with traditional connections to the marine environment (Henocque and Kalaora 2012) like it is the case in French Polynesia where the MPA acronym becomes easily marine managed area (MMA) or locally managed marine area (LMMA). This acronym change is not just a detail but is highly significant of the 'adaptive management cycle' where, pragmatically along the results of regular assessment, the adopted plan is reviewed to eventually make changes in case the committee in charge decides it is necessary. In the name of the Polynesian traditional 'rahui' practice, such changes can even concern the MPA geographic area hence moving with the socio-ecosystem dynamic.

In what follows, we proceed to a more specific analysis of protection management processes and activities with examples in France, more particularly for two of the main attributes of ICM covering the two pillars of integrated management: governance and knowledge.

## *3.1 Consultation is not Participation*

Whatever the MPA or MMA, the key to success and broad acceptance (ownership) is a clear articulation of the management problems within and outside (at the next larger scale) the area at stake. Therefore, the needed assessment (diagnostic) and issues/opportunities identification should be done with scientists and practitioners working in concert with local communities, user groups, and management authorities.

In general, in the Natural Marine Parks, it has been clearly recognized that economic viability is the most pressing concern in sustaining coastal communities and/or populations, particularly those linked to fisheries; sustainable development (including biodiversity conservation) of these groups should therefore constitute an important component of the participation process, another essential feature of the ICSM approach.

In all the models, local involvement is paired with public participation. NGOs and community or any specific group (professional, youth, education, recreation, etc.) organizations are, among others, increasingly playing a major role in coastal and marine areas management initiatives around the world. In most of the cases, communities have typically participated in such initiatives through public meetings, hearings, and inquiries, and as representatives on advisory committees or councils. In many countries, public involvement is a legislated requirement for the development of and implementation of any sector or field management programmes.

Interestingly and on a routine basis, in the UK, over 60 voluntary Coastal Partnerships (Table 5) have developed since the 1990s (Stojanovic and Barker 2008). They commonly employ a coordinating officer and, in some cases, a small team (of up to five staffs) delivering core services plus projects depending upon funding availability. Other defining features of the Coastal Partnerships tend to be: a regular forum or conference bringing together decision-makers with sectoral interest groups to debate current issues; the use of topic/focus groups to carry out specific

**Table 5** Definition of varied forms of Coastal Partnership (Stojanovic and Barker 2008)

| Coastal initiatives | Categories defined by the English Coastal Partnerships Working Group in 2007 |
|---|---|
| CP | Coastal (including estuary) Partnership or forum bringing together all sectors to advocate sustainable management of a coastal area based on ICM principles. www.coastalpartnersips.org.uk |
| AONB/HC | Area of Outstanding Natural Beauty: a partnership or initiative set up to manage a designated landscape in the coastal zone. www.countryside.gov.uk/LAR/Landscape/DL/aonbs/index.asp or non-statutory, Heritage Coasts www.countryside.gov.uk/LAR/Landscape/DL/heritage_coasts/ |
| EMS | European Marine Site initiative set up to prepare and implement an EMS Management Scheme for a designated Special Protection Area/Special Area of Conservation. www.ukmarinesac.org.uk/uk-sites.htm |
| MNP/VMNR | Marine National Park or Voluntary Marine Nature Reserve set up to manage/protect an offshore park, reserve or protected area |
| CG | Coastal Group assisting production of shoreline management plans (SMPs) for flood and coastal erosion risk management. www.defra.gov.uk/environ/fed/policy/CoastalGroups.htm |
| Other | A variety of other initiatives which include local authority strategies for the coast, ad hoc partnerships based on topics such as beach care, litter or marine wildlife |

Not all of these programmes are operating across all of the constituent nations of the UK. Furthermore, the devolved administrations have their own approaches to engaging with Coastal Partnerships through the Scottish Coastal Forum, Wales Coastal and Maritime Partnership and Northern Ireland Coastal Forum

tasks such as problem solving, report writing or policy development; and development of communication mechanisms such as workshops, websites, newsletters, and consultations to generate wide involvement from government, private, and voluntary sectors. These structures have provided the momentum to formulate and implement voluntary coastal and estuary management plans and strategies. They are brought together into a national network through the Coastal Partnership Working Group (2006),[6] which reports to the Annual Coastal Partnerships Forum.

### *3.2 Knowledge and Understanding for System Thinking*

Whatever the defined managed areas, identification of issues should be based on the gathering and integration of existing knowledge (scientific and local) with additional studies where it is needed in order to share the available knowledge and promote a common understanding of ecosystem changes over time. However, as shown by the various regional or more local (essentially ecological) diagnostics preceding the creation of an MPA, few if any coastal and marine ecosystems are well enough

[6] http://www.coastalpartnershipsnetwork.org.uk/about-us/.

understood (in terms of ecological and socio-economic variables) to allow accurate predictions to be made about the quantitative outcomes that can be expected from any management action. It is very probable that none of the changes now seen in any of the France metropolitan and overseas MPAs were or could be predicted on the basis of their area initial diagnostic. It is why there is always a tension between well-structured and legally well-delimitated MPAs and the need to make them flexible and adaptive, to make them initiatives that learn from experience minimizing uncertainty through adjusting management plans in response to new information and changing environmental conditions (Agardy et al. 2003). It should be the main role of an MPA 'technical committee' (rather than the usual 'scientific committee'), allowing the managers, local actors, and scientists to be together involved in scrutinizing the effectiveness of the management strategy. A typical example is given by the maritime space management plan or 'PGEM' in Moorea (French Polynesia) where, six years after its inception, it has been unanimously decided to change the boundaries of the MPAs it includes, following the traditional practice of mobile no-take areas ('rahui) as it was once common for agriculture.

But efficient flexibility and adaptation much depend on the monitoring system in place, the performance of which will as well depend on the comprehensiveness and quality of the baselines which often are missing. This raises the question of the production of 'useful information' from existing data and the general acceptance of that information through a public validation process that may help to ensure its credibility. Generally speaking, any kind of assessment (environmental impact assessment; strategic environmental assessment; cost-benefit analysis; risk assessment, etc.) should not be seen as formula for making decisions but to inform the political debate through a meaningful participation process.

It has been shown through a survey (Terrigeol 2015) about the state of ecological monitoring of the Natura 2000 sites on the Atlantic seafront that it poorly helped in assessing the activities implementation and their impact. Besides the international, national, or regional ornithological monitoring, local monitoring system is specific to each site, generating heterogeneous set of data that cannot be compared at larger scale with a limited access for the public. The management plans ('*Document d'objectifs*') were also often missing specific targets and corresponding state indicators, something that is now under consideration, more particularly in the frame of the Marine Strategy Framework Directive implementation at the scale of maritime ecoregions.

Even where information is limited, much can be achieved by consulting informed people, including specialists, government officials, resource users, and coastal stakeholders. But in the same time, attention needs to be given to synthesiZing and sharing research findings with a broad audience, necessitating more effective communication not only between researchers but between researchers, managers, coastal stakeholders, and the public. In the end, what counts is not to make a comprehensive assessment of the status of the coastal and marine ecosystems elements but to identify the major threats and issues that have to be tackled. Among those, climate change risk assessment, the likeliness and potential impacts of sea-level rise, increased frequency of storm events, acidification of seawater, desertification of arable land, and the associated declines in ecosystem function should be considered at multiple scales and on the short- (10 years), mid- (30 years), and long-term (100 years) periods.

## 4 Towards a Bigger Vision: Connecting Conservation

### *4.1 Ecologically or Biologically Significant Areas: An Inter-institutional Process*

After several years of intense debates, the Parties to the Convention on Biological Diversity (CBD) decided in 2010 (COP10) '*to cooperate, on a regional or subregional basis, to identify and adopt, according to their competence, appropriate measures for conservation and sustainable use in relation to Ecologically or Biologically Significant Areas (EBSAs)*' (Table 6), and for that purpose, '*to organize a series of regional workshops, with a primary objective to facilitate the description of ecologically or biologically significant marine areas through application of agreed scientific criteria as well as other relevant compatible and complementary nationally and inter governmentally agreed scientific criteria*'.

Then, from 2011 to 2014, the Secretariat of the CBD held nine regional workshops involving experts from 92 countries and 79 regional and international bodies (Bax et al. 2015). Two-thirds of the world ocean have been thus covered with identification of 204 areas in national and international waters along the internationally agreed criteria (Table 6).

The intense identification work and gathering of data (though with a lot of gaps) have first led, and for the first time, to an inter-institutional collaboration, more particularly between regional convention organizations and regional fisheries organizations where they exist. The coverage of identified EBSAs concerns national, transboundary, as well as areas beyond national jurisdiction, and as such is informing future ecosystem-based management, including marine spatial planning, in these regions.

It is important to recall that Ecologically or Biologically Significant Areas (EBSAs) are not marine protected areas (MPAs) but areas that may require specific management measures (e.g. through environmental impact assessment procedures) including enhanced conservation and possible establishment of MPAs. Some Parties like Japan (Yamakita et al. 2015) have already used the EBSAs criteria to inform national MPA processes, although the EBSA programme was initiated to support area-based management in areas beyond national jurisdiction.

As an example of future integration for management, the Central Pacific Equatorial Productivity Zone, identified as an EBSA, is a huge area that spread across the entire Pacific, from West to East, which corresponds to tuna ocean route hence important for the South Pacific tuna longline fleet, and overlaying the Clipperton-Clarion Fracture Zone (CCZ), the well-established International Seabed Authority (ISA) managed 'Area' for polymetallic nodules. This is a typical and most concrete example of

**Table 6** EBSAs criteria, definition, and example (adapted from Bax et al. 2015)

| CBD scientific criteria | Definition | Example |
|---|---|---|
| 1—Uniqueness or rarity | 'Area contains either (i) unique, rare or endemic species, populations or communities, and/or (ii) unique, rare or distinct habitats or ecosystems, and/or (iii) unique or unusual geomorphological or oceanographic features' | Sargasso Sea, hydrothermal vents, endemic communities around submerged atolls or seamounts |
| 2—Special importance for life-history stages of species | 'Area that is required for a population to survive and thrive' | Breeding grounds, nursery, feeding, wintering, resting areas |
| 3—Importance for threatened, endangered or declining species and/or habitats | 'Area containing habitat for the survival and recovery of endangered, threatened, declining species, or area with significant assemblages of such species' | The same as above but regarding threatened, endangered or declining species |
| 4—Vulnerability, fragility, sensitivity, or slow recovery | 'Area that contains a relatively high proportion of sensitive habitats, biotopes or species that are functionally fragile or with slow recovery' | Habitat forming species (e.g. corals, sponges); long-lived species with low reproductive rates (e.g. sharks), area vulnerable to pollution (e.g. ice covered) |
| 5—Biological productivity | 'Area containing species, populations, or communities with comparatively higher natural biological productivity' | Frontal areas, upwellings, hydrothermal vents, seamounts |
| 6—Biological diversity | 'Area contains relatively higher diversity of ecosystems, habitats, communities, or species, or has higher genetic diversity' | Fronts, convergence zones, seamounts, cold coral communities, deep-water sponge communities |
| 7—Naturalness | 'Area with a comparatively higher degree of naturalness as a result of the lack of or low level of human-induced disturbance or degradation' | Mostly deep-sea habitats when not yet damaged by deep-sea fishing trawls |

the big challenge ahead of us: ISA did develop an 'Environmental Management Plan' based on an MPA network to safeguard biodiversity and ecosystem function at depth (Wedding et al. 2013), but the upper ocean used by fishers and identified as an EBSA is not included, despite the inevitable surface activities that would occur in case of polymetallic nodules industrial exploitation. Based on this information, gained by international consensus, ISA will have now to complement the existing

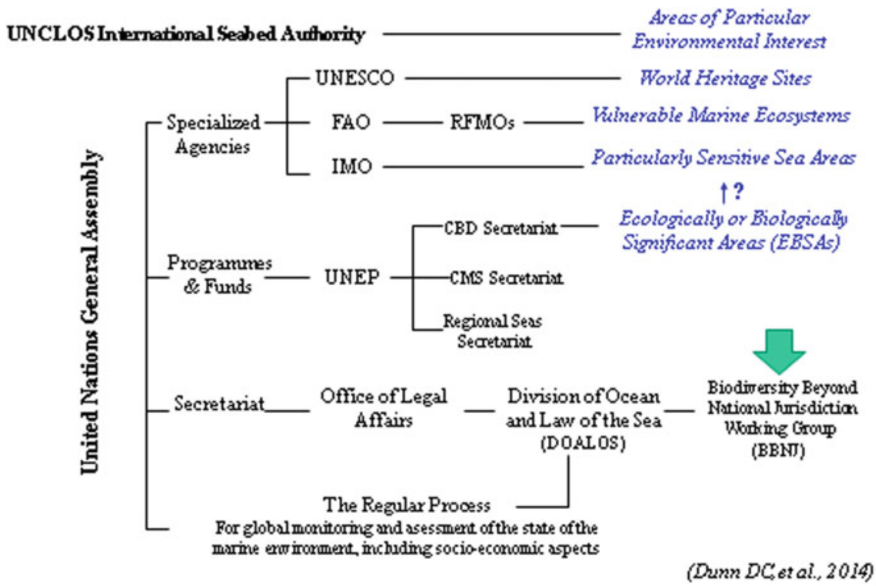


**Fig. 2** EBSAs criteria, a possible common currency across international conservation agreements, sectoral management bodies, and states (Dunn et al. 2014)

'Environmental Management Plan' considering the pelagic system so that future environmental impact assessments (including baselines) cover the bottom and the whole water column up to the surface.

The above criteria (Table 6) used to identify EBSAs are not unique to the CBD. As we said before, there are many other area-based management tools depending on international conservation and sectoral agreements and their management bodies (Fig. 2).

These conservation-oriented area-based management tools have a number of common criteria, cross-cutting those of the EBSAs which then could be used as a rational framework for regional, ecosystem-based, marine spatial planning (MSP) processes, where a variety of management tools, spatial and dynamic, can be applied by competent authorities (Dunn et al. 2014).

The question becomes then the implementing bodies which, realistically, under the varied international agreements, are the existing regional organizations like for example in the North-East Atlantic under the OSPAR Convention (Convention for the Protection of the Marine Environment of the North-East Atlantic) and NEAFC (North-East Atlantic Fisheries Commission) which, on a 'collective arrangement', set up the first network of MPAs and fisheries closures including EEZ and areas beyond national jurisdictions (ABNJ).

While the formal negotiation for a new international legally binding instrument under the United Nations Convention on the Law of the Sea (UNCLOS) Framework is ongoing (Wright et al. 2016), the EBSA process could be part of a global mechanism for the future implementing agreement to UNCLOS on marine biodiversity in ABNJ where the international organizations like FAO (and its RFMOs), IMO, ISA, regional seas conventions, together with states could contribute to a coherent set of action plans to prevent significant adverse impacts due to human activities in international waters and within the EEZ of each country within the same region.

## *4.2 Very Large Marine Protected Areas: Experimenting Large-Scale Integrated Management*

This evolution could first be experimented in specific but sufficiently large areas which are the multiplying large-scale marine protected areas (LSMPA) as it is the case in the Pacific.

Thanks to the 1982 UN Convention on the Law of the Sea (UNCLOS), the new 200 miles EEZs dramatically increased the territory of Pacific Island nations, particularly archipelagic ones. For example, Fiji's 18,272 km$^2$ of land provided an EEZ of 1,290,000 km$^2$, Kiribati's 690 km$^2$ of islands translated into an EEZ of 3,550,000 km$^2$, while Federated States of Micronesia's 701 km$^2$ of land equated to an EEZ of 2,978,000 km$^2$. Till now, the main revenues generated from these huge new 'territories' are derived from fishing and fishing license fees (Bambridge and d'Arcy 2014), but with the development of new activities like deep-sea mining, they should become more diversified in the future.

Beyond their official basic function of marine conservation, LSMPA like the Great Barrier Reef Marine Park, the oldest and most experienced one, has shown that they are totally in agreement with the Aichi Target 11's spirit by applying the concept of ecosystem-based management in a multi-use context and multi-tier scheme, combining local community near-shore management with national and regional frameworks. Because of their expansion from the coast to offshore waters (for the moment, till the EEZ outer boundaries), LSMPA might facilitate this kind of integration in the different governance and management regimes, from the coast to the deep sea. In the case of the West Pacific, the regional 'cement' could be the 'Framework for a Pacific Oceanscape', its principles, scope, and vision.[7]

Till now, there is no legal framework for the creation of LSMPA in areas beyond national jurisdiction (ABNJ), and it will be one of the challenges in the starting negotiating process under the UN General Assembly (UNGA). Practically, the ground for their identification is already well prepared with the EBSAs identification process covering most of the seas and oceans though EBSAs are not MPAs or any marine managed area yet. Good example of states using efforts underway at regional level is given by the OSPAR Commission and the Sargasso Sea Commission though it remains to be seen if existing institutional agreements and structures are sufficient

[7]Framework for a Pacific Oceanscape: a catalyst for implementation of ocean policy. Our Sea of Islands—Our Livelihoods—Our Oceania. http://www.forumsec.org/pages.cfm/strategic-partnerships-coordination/pacific-oceanscape/pacific-oceanscape-framework.html.

to meet global commitments to reconcile, at a regional scale including the deep sea in international waters, biodiversity conservation and maritime development (Jonas et al. 2014), or if additional mechanisms may be required besides the necessary but insufficient role (as regards the water column) played by the International Seabed Authority (ISA) in the 'Area' (the bottom of the sea in ABNJ).

Whatsoever, the complexity of these arrangements highlights the need for LSMPAs to exchange within an enabling regional framework like the Pacific Oceanscape Initiative endorsed in 2009 by 23 Pacific Island nations and territories to conserve and sustainably manage the waters of these 'large ocean states'. For example, the Natural Park of the Coral Sea (in French, *Parc naturel de la mer de Corail*) was formally established by legislative decree in 2014. It is about a 1.3 million $km^2$ multi-use MPA (as all the Natural Marine Park in France) covering all of New Caledonia EEZ. It is considered as the first contribution to the Pacific Oceanscape Initiative by a Melanesian country including ridges, deep sediment basins, seamounts, coral reefs, and volcanic structures, with the deepest site at—7919 m. Even before its official institution, an agreement between the Cook Islands and New Caledonia was signed during the ministerial session of the 3rd International Marine Protected Areas Congress in Marseille in 2013 (Friedlander et al. 2016). This collaboration agreement was directly inspired by the already ongoing collaboration between the Papahänaumokuäkea Marine National Monument (PMNM) and the Phoenix Islands Protected Area (PIPA) of the Republic of Kiribati. The Cook Islands will bring their expertise in the field of integrated marine governance and management whilE New Caledonia will share its experience as a Marine World Heritage practicing multidisciplinary research and multi-sectoral management in the corresponding areas. No doubt these agreements will soon be part of the global 'Network of the World's Large-Scale Marine Managed Areas' founded in 2010[8] to focus on the practice of this new large-scale marine conservation.

## 5 Conclusion—Towards People's Well-Being

The above considerations clearly address any coastal and marine managed area, including marine protected areas (MPAs), within the context of a larger ICOM policy and plan, be it at local, sub-national, national, or regional level. Such an overall integrated approach fulfils the grand objective of Aichi Target 11. In regard to the continuous development and expansion of maritime activities along the coast, in territorial waters, in the EEZ and beyond, in the high seas (international waters), the issue is not so much about the percentage of protected areas but the percentage of successful managed areas set as networks and balancing the development of uses with the protection of biodiversity.

MPAs certainly must remain a critical component in such articulated management, keeping in mind that conditions beyond MPAs will also be critical for the sustainable

[8] http://bigoceanmanagers.org.

futures of ecosystems hence human beings. In the end, it is therefore not 10% of the ocean but 100% of the ocean that should be managed along different orders of magnitude and governance regimes. Already, the 'Marine Promise of Sydney' (Wenzel et al. 2016) raised the stakes in 2014 stating that '*The ultimate aim is to create a fully sustainable ocean, at least 30% of which has no-extractive activities*', reiterated then in 2016 at the international workshop of marine scientists and MPA practitioners in Rome, and the last IUCN World Congress in Hawaii. Towards the 2020 close horizon, a strategy to 'Inspire a New Generation' (Nicoll et al. 2016) is needed to achieve the required changes in awareness, attitudes, and behaviours across wide constituencies.

To tackle the biggest threats to the ocean, i.e. climate change and acidification, overfishing, coastal development and habitat loss, land-based pollution, marine debris, and other potential activities like deep-sea mining, considering their cumulative and may be synergistic effects (IUCN 2014), we have to be much more ambitious than just covering 10% of the ocean with even well-managed networks of MPAs. They will have a meaningful impact only if they are embedded into a nested (polycentric) ICOM system including 'regulatory measures, partnerships, governance, technologies, community empowerment, and capacity building to ensure the overall sustainable use of ocean resources, including a new international agreement for the effective governance and management of the high seas'.

Keeping with the sense of urgency, we cannot afford any more the luxury of looking at protection and development measures separately. They are both part of the new paradigm which consists in 'incorporating MPAs and ocean management into sustainable development programmes' in a joint multi-scale coordinated effort between all levels of government, non-government organizations, industry, community groups, and the public in general. To do that, only one consideration prevails: the long-term cost of development, the full long-term cost including the sustainability of ecosystem services and people's well-being.

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# Short and Preliminary Communications

# Educating for an Integrated Management of Coastal Zone: An Example of a Course Initiating to an Applied Multidisciplinary Approach

**Catherine Mariojouls, David Montagne, Sophie Boulanger-Joimel, Philippe Sahuc and Bernard Fournier**

**Abstract** The growing utilization of coastal zones has become for our societies a priority problem, which requires a multidisciplinary approach. A related question is: *How can we educate for a global management of these zones*? and there is a temptation to answer that a quasi-encyclopedic knowledge is needed. The French curriculum for "agronomist engineers", through multidisciplinary education, prepares for a wide range of jobs related to agro-food sector, environment, and life sciences. We include coastal zones in that wide scope for several reasons: water quality, as marine waters are the final receptacle of continental watersheds; food production, as coastal zones are placed for marine aquaculture and fisheries; management of natural sites, both on marine and land sides; public policies, including ICZM. We created, in 1997, a course about coastal zone as part of second year of curriculum (eq. Master course, 1st year), to initiate future agronomist engineers to a multidisciplinary approach applied to integrated management of coastal zone. The shortness of the course (160 h) obliges to select clearly education skills: we give a large role to the application, through a case study with fieldwork (5 weeks among 6), in a new zone every year; the course uses knowledge and methods taught in common core, completed by specialized lectures (24 h). The students, by groups of four, investigate subjects chosen as the main questions for coastal zone management in the studied region. Interestingly, the selected subjects along the 19 editions show evolutions linked with those of the key questions on French coastal zones.

**Keywords** Coastal zone · Global management · Education · Multidisciplinary approach

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## 1 Introduction

The growing utilisation of coastal zones has become for our societies a priority problem. A related question is: *How can we educate for a global management of these zones?*

Taking into account the complexity of the concerned questions raised by the management of coastal zones, and the need for scientific knowledge from many disciplines, there is a temptation to answer that a quasi-encyclopedic knowledge is needed.

In fact, educating the complexity has found an answer in multidisciplinary and interdisciplinary approaches. As defined by Spelt et al. (2009), interdisciplinary thinking is the capacity to integrate the knowledge of two or more disciplines to produce a cognitive advancement in ways that would have been impossible or unlikely through single disciplinary means.

The French curriculum for "agronomist engineers" (Master of Science in Engineering in life sciences, agriculture, forests, food sciences, environmental sciences) is based on a multidisciplinary education that prepares for a wide range of jobs related to agro-food sector, environment, and life sciences. We include coastal zones in that wide scope because important components of the coastal zone socio-ecosystem are concerned: (i) water quality, as marine waters are the final receptacle of continental watersheds; (ii) food production, as coastal zones are placed for marine aquaculture and fisheries; (iii) conservation and management of natural sites, both on marine and land sides; and (iv) public policies, including Integrated Coastal Zone Management (ICZM).

We created in 1997 the project course "Littoral: Interface Land-Sea", as a part of the second year of curriculum for agronomist engineers (eq. Master course, 1st year), to initiate our students to a multidisciplinary approach applied to the study and the management of the coastal zone. For the conception of the course, we indeed have used the experience of teaching about complex questions in the field of agriculture studies, mixing multidisciplinary approach, systemic approach, and case study enabling the contribution of stakeholders and the understanding of "real-world" (Lossouarn et al. 2004).

## 2 Objectives of the Project Course

The objectives of this course are: (i) to extend the scientific knowledge from land to coastal areas; (ii) to extend the watershed approach to the final environment, i.e., the coastal marine waters; (iii) to study the coastal zone as a multi-activities zone (with peculiar attention to primary productions), in their relationships and conflicts for resources use; (iv) to study the particularities of natural sites and their protection and management; and (v) to understand planning and management tools for a coastal zone, and to question the integrated management of a coastal zone.

# 3 Contents of the Course

## 3.1 General Principles

The course is multidisciplinary and associates the competencies of academics from life and environment sciences, technical sciences, and human sciences. It relies on general former education completed during one week with lectures—about marine and coastal environment, aquaculture and fisheries, sociology, law and public policies for coastal and marine areas-, and on a case study for five weeks, including two weeks of fieldwork. In the six weeks, during four weeks we divide the students into subgroups working on different "interest themes" parts of the whole case study. During the fieldwork, the local stakeholders play a major role as they are asked by professors to share with students their knowledge and expertise during visits and talks or to express opinions during inquiries. We include herein "local stakeholders" all actors in the studied territory: professionals in primary activities—fisheries, aquaculture, agriculture- and related associations, representatives of other activities (tourism, leisure, harbors), public administration at various scales, research staff, extension services, environment's protection bodies, and NGO, general public (in case of street inquiry).

As for education skills, beyond the multidisciplinary approach, through the case study, we associate the "learning by doing" with the "learning by teaching": we entrust the students with a function of apprentice in a consultant work, bringing involvement, and for the students in each sub-group, bringing responsibility and empowerment about the specific interest theme towards the whole class to which they will bring their "expertise".

## 3.2 Finding the Case Study and Preparing the Field Work

For preparing the case study, the professors identify a coastal zone with an interesting situation and possible contacts. Ideally, they find a privileged partnership with a local body, as a public regional or local administration, or a development body, who will be a source of information and contacts, and may express directions for themes studied during the fieldwork, so that the students' work will benefit to it. About three months before the course, the professors go in the zone and meet "resource stakeholders" in order to acquire knowledge and do the first assessment on the situation of this coastal zone, allowing to identify 5–8 interest themes that will be studied by sub-groups (4 students). They collect bibliography. Finally, they prepare an agenda for the visits during the first field week, and for each interest theme, they identify and contact resource stakeholders for the interviews by students during the second field week.

Every year the case study is in a new zone, ensuring a fresh contact between the class and the zone stakeholders, and for the latter, a reasonable involvement. Over

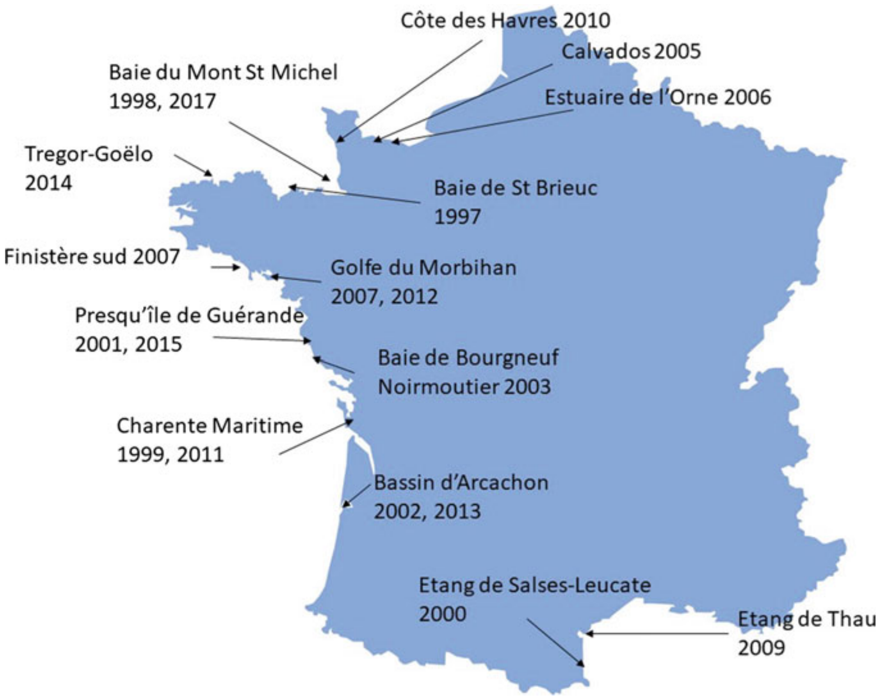


**Fig. 1** Location of the areas studied for the project course from 1997 to 2017

19 editions of the course, we have been in 14 zones scattered over the French coast as shown in Fig. 1.

It is fair to recognize that this preparation of fieldwork is of great interest for the professors, but also represents a significant amount of work.

### *3.3 Schedule and Tasks*

The course lasts 6 weeks (160 h) with the following planning:

Week 1: multidisciplinary program of lectures, applied to coastal zone.
Week 2: first fieldwork, visits for the whole group, to gain knowledge of the zone and build a common culture.
Week 3: preparing the fieldwork by sub-groups on interest themes.
Week 4: second fieldwork, interviews or inquiries by sub-groups (4 students/subgroup, 1 interest theme), daily analysis and debriefing by sub-group with a professor.

Weeks 5–6: analysis of collected information by sub-groups, preparation of oral presentation and report by sub-group. Final brain-storming for the whole class about the key-question "is there an ICZM in this zone?"

After the end of the course, the students' reports, and a booklet of summaries, are sent to all local partners with our sincere acknowledgements for their involvement, and the wish that the students' work may bring some interesting analysis and viewpoints on the studied coastal zone.

## 4 Analysis of Interest Themes Over 19 Courses

In the list of interest themes over 19 editions of the Project course "Littoral: interface land-sea" (Table 1), we can distinguish:

- Some «classical theme» about activities (shellfish farming, fisheries, agriculture, tourism, other uses, etc.) and inter-relations, water quality from land to sea, natural environment and protection, sharing space, planning tools, demography, and urbanization;
- A progressive entry of new subjects such as: «role of associations for environment protection", «erosion and sea-level rise», «new marine activities (seaweed culture, windmills)», «exotic species».

These new subjects correspond to new trends in coastal zones uses and challenges growing concern among populations about environment protection, new activities facing difficulties in their development because of opposition from present activities and inhabitants, changes in the ecosystems, growing risks caused by consequences of climate change.

## 5 Discussion

Looking back on our experience of 19 sessions of the Project course "Littoral: interface land-sea", we find that the education skills we mobilized are in line with recommendations from several authors. Olsen (2000) about education for the governance of coastal ecosystems speaks of a challenge and insists on the need for a double approach: scientific principles and principles of participatory democracy. In our course, we have tried to mix teaching of scientific knowledge and societal approaches.

Several authors have published papers about the education on sustainability, or on sustainability sciences. Between coastal zone management and sustainability, we find in common several traits: complex interactions between natural and human systems, need for scientific knowledge from various disciplines, need to understand real situations. Therefore, these papers allow taking a step back on our experience in higher

**Table 1** Analysis of interest themes over 19 courses

| | Baie de St Brieuc | Baie du Mt St - Michel | Charente Maritime | Etang de Thau | Presqu'île de Guérande | Bassin d'Arcachon | Baie Bourgneuf – Noirmoutier | Finistère Sud | Estuaire de l'Orne | Golfe du Morbihan | Calvados | Etang de Thau | Côte des Havres | Charente Maritime | Golfe du Morbihan | Bassin d'Arcachon | Trégor-Goëlo | Presqu'île de Guérande | Baie du Mt St-Michel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2017 |
| Shellfish Culture sector | X | X | X | X | | X | X | X | | X | X | X | X | X | | X | X | X | X |
| Tradition or modernity in oyster culture | | | | | | | | | | | | | | | X | | | | |
| Fisheries and supply chain | XXX | X | | X | | | X | X | | | | X | X | | | | | | |
| Valorisation of local products | | X | | | X | | | | | | | | | | | | | | |
| Water quality from land to sea | X | X | XX | | X | | X | X | | X | | X | | X | X | X | | X | X |
| Protection of natural environment on land | XX | X | X | X | X | X | X | X | X | | X | X | X | X | | X | X | X | |
| Tourism | | X | | X | | X | X | X | X | X | X | | | | | | | | |
| Agriculture in coastal zone | | X | | | X | X | | X | X | X | X | | X | | X | X | X | | |
| Patrimony | | X | | X | | | | | | | | | | | | | | | |
| Sharing marine space | | | X | X | | | | | | X | | | | | X | | | | X |
| Uses of coastal wet zones | | | X | | | | X | | X | | | | | | | | | | |
| Sharing coastal space | | | | X | | X | | | | | | | | | | | | | |
| Tools for planning & management of coastal zones | | | XX | | | | | | X | | | | X | | | | X | | |
| Urbanization of coastal zones | | | | | XX | | | | | | X | | | | | | | | |
| Erosion, sea level rise, management | | | | | | X | | | | | | | X | | | X | | X | X |
| Coastal population, territory, identity | | | | | | | | | | | | | | | | X | X | | X |
| Associations for environment protection | | | | | | | | | | X | | | | | | | | | |
| New marine activities | | | | | | | | | | | | | | X | | | X | | |
| Green seaweeds | | | | | | | | | | | | | | | | | X | | |
| Exotic species | | | | | | | | | | | | | | | | | | | X |

education about coastal zone management. Jabareen (2011) proposes a new conceptual framework to teach sustainability assuming the multidisciplinary nature of sustainability, broken down in ten concepts. Brundiers et al. (2010) demonstrate how real-world learning opportunities contribute to the acquisition of key competencies in sustainability. Yarime et al. (2012), through the analysis of education academic programs on sustainability, show that while interdisciplinarity is necessary, there is a need for another component, an active collaboration from stakeholders throughout society allowing transdisciplinarity in practice. We find a real convergence with our experience for educating to coastal zone management, using multidisciplinarity teaching and real-world case study, effectively bringing key-competencies for understanding coastal zone challenges and needs for management. However, the construction of such an education program remains a challenge and is fragile, as it relies on the availability of local stakeholders, on the ability of academics to build a link between real-world situation and science for the students, and on the acceptance by students to enter a demanding work.

## 6 Conclusion

Our experience along the 19 editions of this Project course “Littoral: interface land-sea” is a great satisfaction for both the students and the professors: the students, who draw a lot of learnings from the experience to analyze a real situation and some kind of pride to feel able to do so; and the professors to see their students showing a remarkable capacity to work on complex questions with a full involvement leading to in-depth study and analysis. Rare are the students who do not enter the game, but it remains a challenge to prepare a case study so interesting that we can convince the students to “board in the experience” to do such a practical work, with the needed scientific rigor.

While the coastal zone study and management stay as a difficult field, in its components and variability, a multidisciplinary approach coupled with a case study appears as efficient in education of master students to create a first level of knowledge, which may be followed by a specialized course for some of them. For our students, future “agronomists engineers”, this course has been an opening to a new perspective including the coastal zone, and for a number of them, a first part of the route to careers in the coastal zone management.

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# How to Reduce the Impacts of the French Mediterranean Longline Fisheries on the Megafauna? Preliminary Results of the SELPAL/RéPAST Projects

**François Poisson, Sophie Arnaud–Haond, Luisa Métral, Blandine Brisset, Jim Ellis, Sophy McCully, Delphine Cornella, and Bertrand Wendling**

**Abstract** During the last decade, particular attention has been paid worldwide to the problem of by catch and discards in fisheries. Collaborative research between fishermen and scientists is important to fisheries management. Partnerships with commercial longline fishermen were developed to enable them to participate in two research projects in order to integrate their information, experience and expertise. These programmes, financed by the fishing industry and regional councils were designed to describe the activity of the fisheries, to assess the scale of fishery effects on the various *taxa*, to study ecology and explore spatial population genetic structure in the western part of the Mediterranean Sea of the blue shark (*Prionace glauca*) and stingray (*Pteroplatytrygon violacea*) and finally to propose mitigation measures to reduce impacts on elasmobranches, sea birds and sea turtles. Communication, education, post-implementation monitoring and long-standing collaboration are the key factors to success. This presentation shows the progress realized to date.

**Keywords** Longline fisheries · By-catches · Mitigation measures · SELPAL and REPAST projects

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# 1 Introduction

SELPAL (Longline selectivity) and REPAST (Pelagic Sting ray) are two collaborative projects defined to reduce the impacts of longline fisheries on different species such as sharks, rays, sea turtles, sea birds as well as marine mammals. These projects have been undertaken from 2013 for SELPAL (2013–2017) and from 2015 for REPAST (2015–2016) and are characterized by close cooperation between scientists (Ifremer/Marbec and Cefas) and marine professional fishers (AMOP: Association Méditerranéenne des Organisations de Producteurs). These two projects are implemented to reduce the by-catches and discards associated to the pelagic longline fishing activities.

The pelagic longline fishery is, worldwide, an important cause of by-catches of various threatened species. However, the composition and the volume of these by-catches differed a lot according to the type of longline used: surface or deep; the fishing strategy; the kind of hook and baits used, the areas prospected and fishing crews. Thus, the objective of these two projects is to define some mitigation measures in order to decrease the mortality of by-catches and increase our knowledge on the biology of the non-targeted and threatened species through a multi-species approach. The results obtained will be described in a leaflet for the longline community of fishers.

# 2 Data Collection

Eighteen fishing boats on a total of 44 longliners were involved (41% of the longliners fishing fleet) in that experiment. Thus, 407 fishing operations have been documented. The information collected dealt with the following:

- Fishing gear: kind and size of hooks;
- Positions of the fishing gears between the setting and hauling processes;
- Fishing effort;
- Duration of the fishing sets;
- Catches retained on board or released;
- Size of the catches;
- Status of the by-catches: dead or alive;
- Interactions with sea birds and sea turtles.

# 3 Main Results

Overall, the main composition of catches from the 407 fishing operations is the following one: 53% of stingrays (*Pteroplatytrygon violacea*); 37% of Atlantic bluefin tuna (*Thunnus thynnus*); 6% of blue shark (*Prionace glauca*) and 4% of swordfish (*Xiphias gladus*). Some catches of moonfish (*Mola mola*) are also recorded.

Figure 1 shows the catch composition of different fishing operations made in the Mediterranean Sea between 2012 and 2016. It shows that the catch composition is different according to the fishing areas: mainly catches of bluefin tuna and stingrays in the Gulf of Lions; some significant catches of swordfish, blue shark off the East of the Gulf of Lion and Corsica associated with important catches of stingrays.

Some practical information has been gathered during these fishing operations on the impact of the shape of the hook (J or circle hook) on the mortality of the individuals. Preliminary information shows that the hook shedding is faster with à J-hook than a circle hook (Fig. 2).

It was also important to cut the line as close as possible to the eye of the hook in order to avoid some severe injuries as shown in Fig. 3.

Other practical information on the manipulation of by-catches in order to maximize the chance to keep the animals alive has been collected. These informations are summarized and popularized in a leaflet: "Responsible Fisher Guide—Best practices

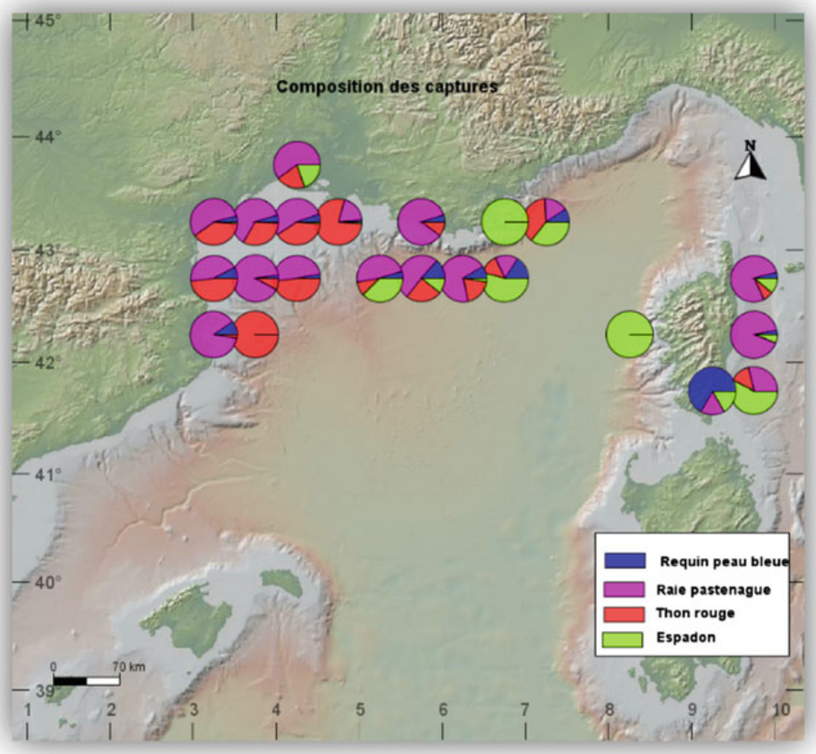


**Fig. 1** Catch composition of longline sets between 2012 and 2018 in the Northeastern part of the Mediterranean Sea (requin peau bleue: blue shark, Raie pastenague: stingray, thon rouge: blue fin tuna, espadon: swordfish)

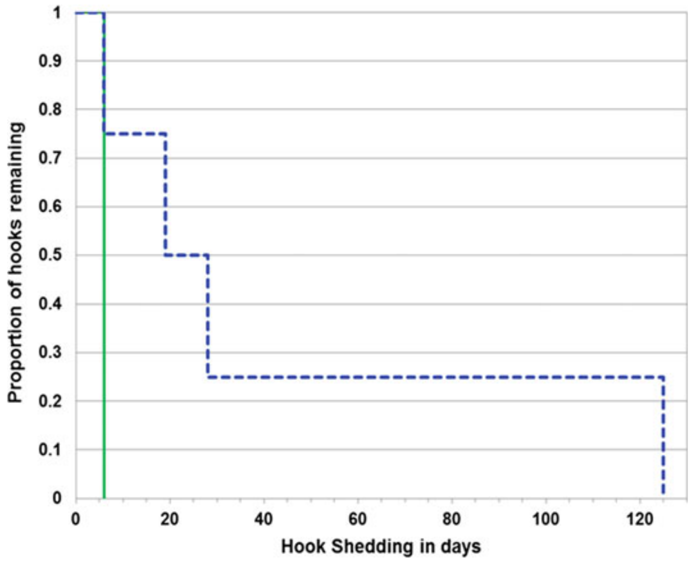


**Fig. 2** Hook shedding in days with a J-hook ( -) or a circle hook ( ----) from a sample of 10 stingrays kept in tanks of the Seaquarium and the Marineland

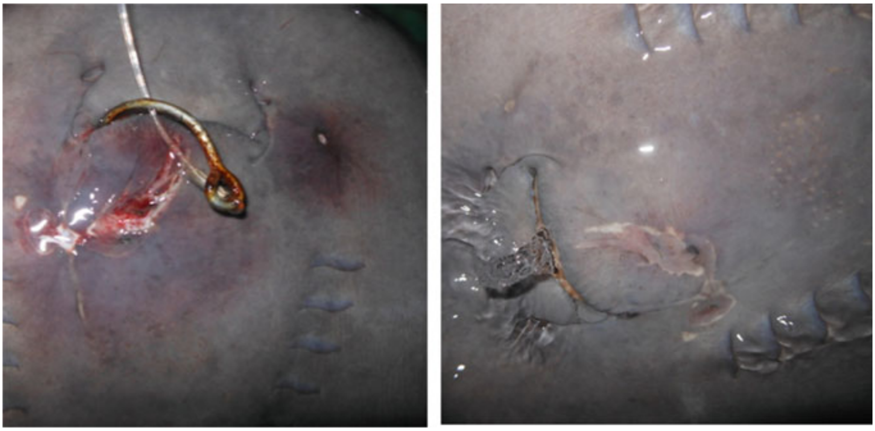

**Fig. 3** Hook and its fishing line bitten by a stingray. The picture on the left shows the injury caused by the fishing line. On the right, the wound healing two weeks after

to reduce the mortality of vulnerable species accidentally caught by the French longline fishery in the Mediterranean Sea" (Poisson et al. 2016). That book described the best fishing equipment, the necessary tools on board and the manipulation of the individuals accidentally caught to avoid a too strong impact on the survival of by-catches after released.

## 4 Perspectives

These first scientific surveys have provided some preliminary but important elements on the way to mitigate the impact of longline fishery on the mortality of vulnerable species caught accidentally.[1] These results have to be confirmed and especially on the following points:

- The way to remove the hooks without jeopardizing the life of the individual caught;
- The estimation of the mortality after release;
- The modifications of the fishing equipment in order to reduce the interactions between longline fishing activity and sensible species (birds, turtles, sharks and rays and marine mammals);
- Increase the dissemination of the best practices among the fisher communities and
- Ensure a technical watch to define new tools to secure a better release of the individuals.

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[1]See Poisson et al. (2019) for further explanations.

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