OCEANOGRAPHY AND MARINE BIOLOGY SERIES

SEAS AND OCEANS SET

Tools for Oceanography and Ecosystemic Modeling

Edited by
André Monaco and Patrick Prouzet

iSTE

WILEY

Tools for Oceanography and Ecosystemic Modeling

From the ***Seas and Oceans*** Set

coordinated by
André Mariotti and Jean-Charles Pomerol

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First published 2016 in Great Britain and the United States by ISTE Ltd and John Wiley & Sons, Inc.

ISTE Ltd
27-37 St George's Road
London SW19 4EU
UK

www.iste.co.uk

John Wiley & Sons, Inc.
111 River Street
Hoboken, NJ 07030
USA

www.wiley.com

Library of Congress Control Number: 2016939646

British Library Cataloguing-in-Publication Data
A CIP record for this book is available from the British Library
ISBN 978-1-84821-778-2

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Foreword

We have been asked by ISTE to stimulate work in the area of the environment. Therefore, we are proud to present the “Seas and Oceans” set of books, edited by André Monaco and Patrick Prouzet.

Both the content and the organization of this collection have largely been inspired by the reflection, initiatives and prospective works of a wide variety of national, European and international organizations in the field of the environment.

The “oceanographic” community in France – which is recognized for the academic quality of the work it produces, and is determined that its research should be founded on a solid effort in the area of training and knowledge dissemination – and internationally was quick to respond to our call, and now offers this set of books, compiled under the skilled supervision of the two editing authors.

Within this community, there is a consensus about the need to promote an interdisciplinary “science of systems” – specifically in reference to the Earth’s own “system” – in an all-encompassing approach, with the aim of providing answers about the planet’s state, the way it works and the threats it faces, before going on to construct scenarios and lay down the elementary foundations needed for long-term, sustainable environment management, and for societies to adapt as required. This approach facilitates the shift of attention from this fundamental science of systems (based on the analysis of processes at play, and the way in which they interact at all levels, and between all the constituent parts making up the global system) to a “public” type of science, which is finalizable and participative, open to decision-makers, managers and all those who are interested in the future of our planet.

In this community, terms such as “vulnerability”, “adaptation” and “sustainability” are commonly employed. We speak of various concepts, approaches or technologies, such as the value of ecosystems, heritage, “green” technologies, “blue” chemistry and renewable energies. Another foray into the field of civilian science lies in the adaptation of research to scales which are compatible with the societal, economic and legal issues, from global to regional to local.

All these aspects contribute to an in-depth understanding of the concept of an ecosystemic approach, the aim of which is the sustainable usage of natural resources, without affecting the quality, the structure or the function of the ecosystems involved. This concept is akin to the “socio-ecosystem approach” as defined by the Millennium Assessment (http://millenniumassessment.org).

In this context, where the complexity of natural systems is compounded with the complexity of societies, it has been difficult (if only because of how specialized the experts are in fairly reduced fields) to take into account the whole of the terrestrial system. Hence, in this editorial domain, the works in the “Seas and Oceans” set are limited to fluid envelopes and their interfaces. In this context, “sea” must be understood in the generic sense, as a general definition of bodies of salt water, as an environment. This includes epicontinental seas, semi-enclosed seas, enclosed seas, or coastal lakes, all of which are home to significant biodiversity and are highly susceptible to environmental impacts. “Ocean”, on the other hand, denotes the environmental system which has a crucial impact on the physical and biological operation of the terrestrial system – particularly in terms of climate regulation, but also in terms of the enormous reservoir of resources it constitutes Oceans covering 71% of the planet’s surface, with a volume of 1,370 million km^3 of water.

This set of books covers all of these areas, examined from various aspects by specialists in the field: biological, physical or chemical function, biodiversity, vulnerability to climatic impacts, various uses, etc. The systemic approach and the emphasis placed on the available resources will guide readers to aspects of value-creation, governance and public policy. The long-term observation techniques used, new techniques and modeling are also taken into account; they are indispensable tools for the understanding of the dynamics and integral functioning of the systems.

Finally, treatises will be included which are devoted to methodological or technical aspects.

The project thus conceived has been well received by numerous scientists renowned for their expertise. They belong to a wide variety of French national and international organizations, focusing on the environment.

These experts deserve our heartfelt thanks for committing to this effort in terms of putting their knowledge across and making it accessible, thus providing current students with the fundaments of knowledge which will help open the door to the broad range of careers that the area of the environment holds. These books are also addressed to a wider audience, including local or national governors, players in decision-making authorities, or indeed "ordinary" citizens looking to be informed by the most authoritative sources.

Our warmest thanks go to André Monaco and Patrick Prouzet for their devotion and perseverance in service of the success of this enterprise.

Finally, we must thank the CNRS and Ifremer for the interest they have shown in this collection and for their financial aid, and we are very grateful to the numerous universities and other organizations which, through their researchers and engineers, have made the results of their reflections and activities available to this instructional corpus.

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For a Systemic and Transdisciplinary Approach to the Environment

1.1. Introduction

In terms of research and technologies, the last ten years have been marked by an undeniably increased awareness of the problems posed by the evolution of our natural environment and societies. In the face of the visible changes of the dynamics of systems and the uses of resources, we called upon science to provide the elements necessary to understand these changes and to pave the way for the future by providing those tools that can help us make decisions.

Furthermore, the researchers working in the wide field of the environment have become familiar with the several initiatives, methods, and programs resulting from the reflection of the international community on the notion of "earth system research for global sustainability" (ESRGS); [REI 10] identify five "great challenges of future earth" which link global change to sustainable development. In France, the research and development programs follow the main directions of public policies, especially those of the National Research and Innovation Strategy (NRIS, Paris, 2009) of the Ministry of Higher Education and Research, to cope with and adapt to the accelerated development of economic, social and environmental pressures.

Internationally, programs are deeply rooted in several bodies and actions, including the international council for science (ICSU) and the joint programming initiative (JPI), which focus on water, climate, agriculture or

Chapter written by André MONACO, Patrick PROUZET and Patrick VINCENT.

Tools for Oceanography and Ecosystemic Modeling, First Edition. Edited by André Monaco and Patrick Prouzet.

the sea, and the International Group of Funding Agencies for Global Change Research (IGFA)/Belmont Forum[1], a group of funding agencies for global research on environmental change. The "Belmont" challenge aims at "providing the knowledge necessary to action aiming to adapt to and reduce harmful changes in the environment and extreme events". The priorities of collaborative research action (CRA) have to do with the safety of water resources and the vulnerability of coastal areas. These organizational concepts and priorities can be found in national research institutions in Europe as well as in the United States. We could even start to worry about the standardization of the research calls from authorities concerned.

Whatever the research field may be, every one of these programs advises a multi- inter- transdisciplinary approach which details the historical development of environmental sciences. This transversality represents and denotes, quite simply, an increasing amount of disciplines being integrated and applied to the environment, in particular social studies and finally, an interaction with the users and policy makers who use the research results in management strategies (see section 3.1). There is even talk of a "co-design" of research programs involving all the actors and participants to the projects. This stage really still seems out of reach. Nevertheless, the literature offers such a variety of terms, concepts and paradigms that it has become difficult for the lay person to get his or her bearings (Figure 1.1).

Figure 1.1. *Semantic proliferation of environmental research. See color section*

1 http://www.igfagcr.org/index.php/belmont-forum.

After this quick reminder about the development of environmental research, and while there is an increasingly wider range of occupations and professions in the environmental field, we have to make this observation: the future practitioners, i.e. students at different stages in their education, who are increasingly specialized in their sector, seem almost completely dissociated from these national and international considerations and projects. This explains the current difficulties faced when attempting to concretely apply the scientific knowledge into the complex problems posed by changes in the environment (Figure 1.2).

This remark constitutes the basis for the "Seas and Oceans" collection, which draws from the most recent reflections and national and international directives in terms of earth and environmental sciences to propose: i) a systemic approach to the ocean and its interfaces; ii) an order in which the volumes are published, which simulates the strategies advised for the organization of environmental studies; in other words, starting with the way the marine system works and ending with ocean governance, passing by various cases of vulnerability (Figure 1.3). To ensure this transition between the environment and the socio-economic sector, we have focused on the living resource which best integrates the functions and the changes in the natural environment and its usages.

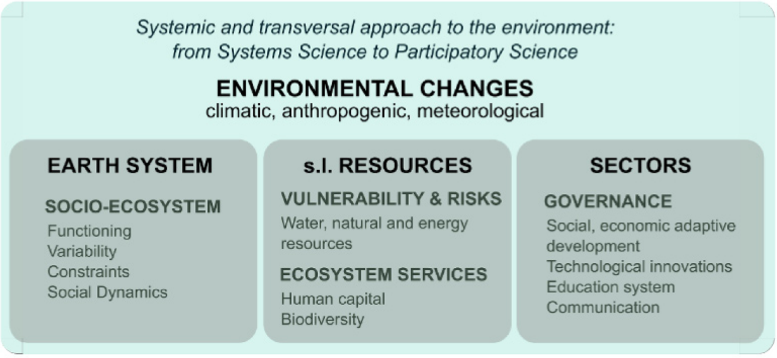

Figure 1.2. *Conceptual framework for a systemic and transversal approach (from ANR-ESS SSC). See color section*

This transition, through the resources that make up a vulnerable human capital, is essential and raises awareness among the public with less scientific knowledge since it is closely linked to society and its uses. For example, the "earth overshoot day", when our planet has consumed more than what it produces yearly, makes it possible to raise public awareness about the pressure that our societies exert on these resources and somehow represents the degree of pressure that we exert on the environment. In French, this is called *jour du dépassement global*, i.e. the date on which theoretically the Earth's renewable resources have been depleted[2]: the first "earth overshoot day" dates back to the December 31, 1986, when the world first consumed in a year more than the planet could offer. However, in 2015 it was on August 3 that we consumed the renewable resources of a whole year.

1.2. A complex and vulnerable ocean system

The *Seas and Oceans* set of books that we have coordinated has been defined by an editorial board[3] of experts in different scientific domains covering a wide range of subject fields, making it possible to tackle the complexity of marine ecosystems but also their vulnerability[4]. The contribution of experts in economics and social studies has also allowed us to see how human societies have exploited, but also sometimes destabilized, marine resources and how these societies could adapt to the change factors resulting from different natural and anthropogenic pressures. The value of resources has not only focused on traditional activities like fishing, aquaculture or maritime transport; it is also derived from the exploitation of the diversity of goods and services offered by the marine environment: renewable forms of energies, pharmacology of marine organisms, microalgae and biotechnology. Figure 1.3 describes the structure of the set schematically.

Its goal is to provide a body of work that allows us to get a better grasp of how the ocean system works in order to more precisely analyze the vulnerability of ecosystems and become more aware of the risks run by a

2 This date is calculated by the ONG, or Global Footprint Network, which came up with the concept of the ecological footprint (Wikipedia).

3 The members of the editorial board were P. Bertrand (CNRS/INSU), G. Boeuf (MNHN/UMPC), J. Boncoeur (UBO/AMURE), P. Cury (IRD/CRHMT), L. Eymard (UMPC/LOCEAN), P. Gros (Ifremer/DM), Y. Henocque (Ifremer), M. Heral (ANR/Envt-Ress. Biologiques), R. Kalaydjian (Ifremer), M. Lafaye (CNES), L. Legendre (UMPC/LOV), A. Mariotti (UMPC), A. Monaco (CNRS/INSU), J.-C Pomerol (UMPC), P. Prouzet (Ifremer/DS), P. Roy-Delecluse (CNRS/INSU), and M.-H. Tusseau-Vuillemin (Ifremer/DS).

4 Combination of the probability of exposure to a pressure, of the sensitivity to pressure, and of the restoration potential.

liquid environment that covers more than two-thirds of our planet, the resources of which are increasingly being constrained by the global change. The latter does not only take into account the effects induced by climate change, but also those caused by the increasingly harmful consequences of our formidable technological power, which we find difficult to control [LAR 01, JON 97].

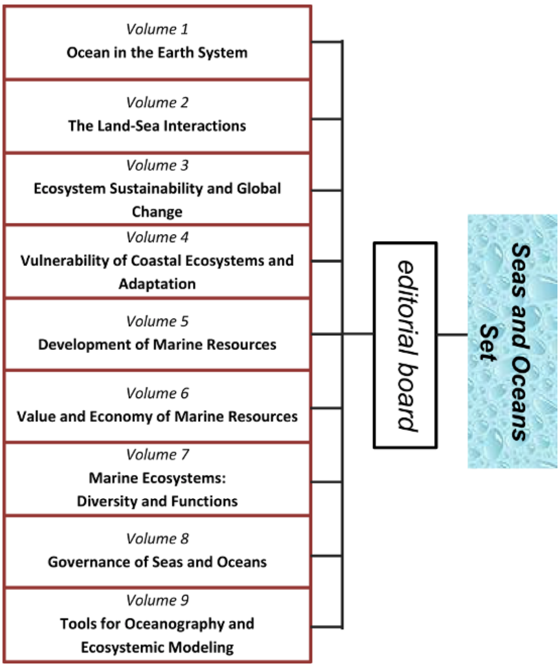

Figure 1.3. *Schematic overview of the structure of the Seas and Oceans set*

Our actions, usually performed in an exceedingly sectorial context (not much thought is given to the synergy of the effects of our actions upon the functioning and quality of the environment), have consequences and impacts on different levels – local, regional or global – which are illustrated in the various chapters of this set of books[5].

The authors have been chosen in relation to the general subject treated: each contributes in his or her own specialty, creating a work of

5 Hans Jonas, quoted by [LAR 01], mentions an actual cosmic power of man: “Technology places man in a role which only religion has sometimes assigned to him: that of steward or guardian of creation”.

multidisciplinarity across several chapters and volumes. Nonetheless, if interdisciplinarity is difficult to implement, it is perhaps more effective when it comes to oceanography, due to the necessary pooling of large and expensive means of exploration (ships, satellites, etc.), analysis and modeling platforms, multi-parametric and long-term networks and observation stations, often gathered in working sites or research networks. In total, the contributions of more than 120 specialists in the most diverse fields in relation to the marine environment – physics, chemistry, biogeochemistry, biology, ecology, economics, sociology, fishing, public policy analysis, resource exploitation and technology – have been addressed while making sure to link them together to show that the approach is not only pluri- or interdisciplinary, but also and necessarily, transdisciplinary.

All temporal and spatial scales are considered, since they are often inseparable if we want to understand the dynamics of an environment with no boundaries but whose exchange interfaces are very significant areas. The interest of long-term observations and measurements is well-established when it comes to evolution; if models and scenarios are often marred by uncertainties, it is often because of a lack of references in the past. This necessity is understood and acknowledged, but it implies the commitment of institutions and communities, which is not especially compatible with administrative rules and political actions.

Therefore, in the logic of the transversal approach ranging from the functioning and state of the ocean system to its management (Figure 1.3), 8 volumes, which provide an overview of the latest developments, have already been published. However, this accumulation of data would not have been possible without the development of observational techniques on all scales of the system. This is the subject matter of this last volume (9), which is concerned with the tools linked most closely to the themes dealt with in the set, including modeling strategies for ecosystem dynamics and supporting management of living resources and fisheries.

Volume 1: *Ocean in the Earth System* addresses the interactions of this system with the atmosphere and the biosphere. Seawater chemistry is seen from the perspective of the exchanges of heat flows, fluids, terrigenous and biological elements. The interactions between the marine components of biogeochemical cycles are described in great detail.

Volume 2: *The Land-Sea Interactions* covers the hydrological and geochemical exchanges that maintain a natural land-sea sytem. The intensification of human pressures on this interface increasingly leads to physical and chemical disequilibria (radioactive pollution, plastic waste) and ecological misfunctions (eutrophication) which, along with climate warming, are major components of global change.

Volume 3: *Ecosystem Sustainability and Global Change* deals with the ocean as a source of amazing biodiversity and an important reserve of food resources. The activity of marine organisms affects the concentration of chemical elements in the biosphere, hydrosphere and geosphere, as well as affecting biogeochemical mechanisms. The book analyzes the state and evolution of these resources, by defining some indicators as well as the impacts of global change on the dynamics of the living exploited resources.

Volume 4: *Vulnerability of Coastal Ecosystems and Adaptation* highlights different examples and types of risks: chemical, biological, climatic or linked to extreme events. It mentions the importance of the toxic chemical and biological pressures particularly exerted on estuary, littoral and coastal waters. These environments, whose quality has strongly deteriorated, are subjected to changes, at various speeds, linked to natural catastrophes (storms and tsunamis) or sea-level rise. All of this makes the coast a heritage site that is undergoing a transformation and a system study that's significant particularly for the assessment of the vulnerability and adaptation of societies to change factors.

Volume 5: *Development of Marine Resources* sketches a relatively comprehensive outline of what marine resources can contribute in the future through the development of marine biotechnologies, the pharmacology of marine reef organisms and renewable forms of marine energy channeling the force of currents or winds. This work also mentions some perspectives that can be more or less unrelated.

Volume 6: *Value and Economy of Marine Resources* presents the diversity of goods and services provided by the ocean and proven to be indispensable to human communities. Use of these services and exploitation of goods will have to be developed in a responsible and sustainable manner. New approaches and scenarios based on the analysis of the aquaculture and fishing production chain are developed to ensure an ecological economy linked to the use of living marine resources. An overview of EU maritime economy and policies is also presented.

Volume 7: *Marine Ecosystems: Diversity and Functions* illustrates biological diversity and the variety of habitats, structures and foodwebs in different oceans and systems: the phytoplankton, the first level of ecological and climatic dynamics via the carbon cycle; the coral ecosystems and their associated coastal seagrass, among the most diverse on the planet; and the deep ecosystems, oases around hydrothermal vents on mid-ocean ridges. In addition, the authors address the problem of preservation of resources, living and non-living and the services rendered to our societies endangered by environmental change. Thus, concepts and strategies emerge as ecological resilience.

Volume 8: *Governance of Seas and Oceans* tackles how society participates in making decisions about the marine environment from a legal perspective mainly, presenting Law of the Sea as key determining factor. It deals, therefore, with matters of ship transport, marine pollution, management and exploitation of renewable and non-renewable resources, legal or socioeconomic stakes linked to the development of forms of renewable marine energy or to the implementation of protected marine areas. The sustainable development of seas and coastlines is also dealt with by mentioning the integrated management of these areas in a context of globalization which has resulted in the increased importance of maritime issues in terms of flows and resources. In this context, importance of the partnership among the actors of the maritime sector and the awareness of their knowledge and expertize are vital to ensure the sustainable development of the maritime sector.

The objective of the present volume (9) is not to describe all the tools employed in oceanography or the history of their development, but to provide an overview of the tools, technologies and strategies developed before assessing the complexity and vulnerability of the marine environment to global change. It focuses on the observation and study of living organisms: the use of acoustics to assess the abundance and behavior of schools of fish, the instrumentation of marine animals enabling us not only to study their migration, but also to see some characteristics of the environment they explore. A chapter is also dedicated to the technological and experimental methods developed to study and sample fishing stocks, the reliability and performances of which have to be tested to gauge how qualitatively or quantitatively representative the samples taken are. It deals with the strategies employed to model marine ecosystems, for example by laying the metabolic foundations for population dynamics and showing how to model the complexity of food chains. The ecosystemic approach to fisheries is exhaustively described through its history and goals but also the content that characterizes it. Lastly, it raises the question of how to model the complexity and shows the interest in combining models coming from different domains in a systemic approach.

1.3. Suitable observation tools

Research, technology and innovation are inseparable and their development has gone hand in hand with the emergence of issues linked to the environment. Since 1977, the international council of scientific union (ICSU) and its scientific committee on problems of the environment (SCOPE) have defined monitoring as "the collection for a predetermined purpose of systematic, inter-comparable measurements or observations in a space-time series of any environmental variables which provide a synoptic view or a representative sample of the environment (global, regional, national or local). Such a sample may be used to assess existing and past states and to predict probable future trends in environmental features" [HOL 77]. No changes need to be made to this definition of a monitoring strategy triggered by problems of pollution, especially marine pollution, caused by the most diverse products of human activity. [QUE 11] examined the question of chemical monitoring exhaustively in 2011; the same author is updating the study within the framework of the *Seas and Oceans* set currently.

Step by step, the strategies and technologies devoted to the survey of the chemical quality of water and of marine organisms have evolved to adapt to an ecosystemic and more global approach to the environment, with respect to the new challenges associated with climate, but also in conjunction with public policies. In any case, the development and diversification of observation technologies have kept up with the increasing awareness of the demand of society and demand for decision support with the development of the concepts of vulnerability, social acceptability of risk, adjustment to change and sustainable management. To address all these issues, research will have to take into account the complexity of conceptual models integrating at the same time life sciences and social sciences and humanities.

As a consequence of this evolution, we have seen a proliferation of conventions, jurisdictions and scientific programs too numerous to go through but traceable throughout the volumes of the collection. [QUE 11] makes an inventory of these protection instruments and of a certain number of international conventions and treaties. As for the marine environment, we will mention the global network global ocean observing system (GOOS) and, on a European level, the water framework directive (WFD) and the marine strategy framework directive (MSFD). Decision-making tools have led to a regional organization of long-term observations, so that the planet Ocean has been divided into Regional Seas United Nations environment program (UNEP).

In the last volume of the set, after a presentation of the vast panoply of observations, measurement technologies and strategies that support the progress of research and its applications, we chose to prioritize the tools employed in ecosystem approaches that have do with living organisms and to the operational transition closest to the socioeconomic demand.

1.3.1. *For a systemic vision of the ocean*

The systemic approach that takes shape in a modeling process relies on four basic concepts: complexity (together with its notions of haziness, uncertainty, unpredictability, etc.), system (the set of elements interacting dynamically and organized around a purpose: ranging between physical and social systems), globality (the interdependence and coherence of the elements of the system), interaction and feedback (the relationship between the components of the system taken two by two). Through the remaining seven chapters of this volume, we will show that the systemic vision requires a 4D approach that includes long-term observation.

It is important to take complexity into account as it goes beyond the mere description of the set of elements making up the system studied. Complexity means that "the whole is more than the sum of its parts". According to Edgar Morin, "complexity not only includes interacting quantities of unities which challenge our calculating capabilities; it also includes uncertainties, indetermination and random phenomena". As a result, our societies will have to learn (or re-learn) how to live in an uncertain world.[6]

In this context, one of the roles of science will consist of assessing the nature of the risk involved and its plausibility. Given the complex nature of the system, this will only be feasible with an approach which is at least interdisciplinary to guarantee that the methods of one discipline will be

6 After the French Revolution, the perception of risk for our "modern societies" has shifted from divine fate to right to security [SÉB 06].

transferred to another. It will also be necessary to go even further by developing a transdisciplinary vision that can allow us to better grasp this complexity and the assessment of the risk involved by opening all disciplines “to that which they share and to that which lies beyond them”[7]. We will have “to piece together the knowledge acquired to overcome the crazed myopia of the retreat into oneself”, since, according to Edgar Morin, “a piece of knowledge is only pertinent if able to find its place within a context and the most sophisticated knowledge, if completely isolated, stops being pertinent” [MOR 98].

As for environmental management, we are still far from adopting this systemic vision since, in terms of research, we hesitate to leave our disciplinary perspective behind and, in terms of expertise, our approach still remains too sectorial. Hans Jonas[8] highlights this last point: “We control the technological operations on nature, but we have no control on the whole of the process, which raises the problem of the mastery of our (technological) mastery”.[9]

1.3.2. *To assess our vulnerability to global change*

System approach constitutes the conceptual framework for the socio-ecosystem approach defined by the Millennium Assessment[10]. This requires an articulation between research, assessment, decision and management, according to an outline which may be based on the one set up for the protection and restoration of the North Sea (Figure 1.4)[11].

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7 Article 3 of the Chart of Transdisciplinarity – CIRET – November 1994 – http://ciret-transdisciplinarity.org/chart.php.

8 Quoted by [LAR 01].

9 On a political level, according to [LAR 01]: “When we want to introduce nature into politics and more generally to draw the attention of human communities to the fact that our relationships are not merely a matter of technological objectification, but involve moral and even philosophical problems, we refer to catastrophes”.

10 The Bergen declaration in March 2002 adopts the following definition of an ecosystem approach: “integrated management of human activities based on the knowledge about the ecosystem dynamics in an effort to achieve a sustainable use of the goods and services associated with the ecosystem, and to maintain its integrity”.

11 Drawn from the OSPAR Commission report, 2006: Report on North Sea Pilot project on Ecological Quality Objectives, p. 22.

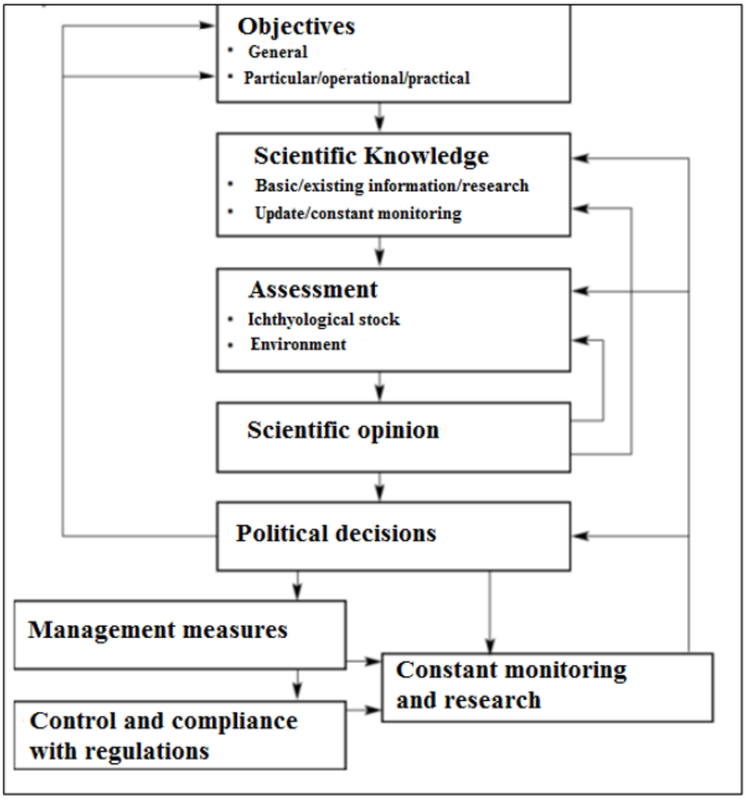

Figure 1.4. *Conceptual framework proposed for the management, protection and restoration of the North Sea [OSP 06]*

This framework changes our perspective on management by turning it from a mono-specific vision in a stable system to a multi-specific one in a complex and changeable system. It also incorporates decision support, which refers to the notion of expertise as well as to the notions of risk prevention and social acceptability of risk.[12]

Decision support requires the availability of operational tools which allow us to assess the state of ecosystems, to analyze their evolution as a result of global change, and to predict the impacts in response to different societal scenarios.

12 See Volumes 3 and 4 [MON 14a, MON 14b].

1.3.3. *The contribution of operational oceanography*

Operational oceanography (see section 1.3.3.1), which enables us to integrate large volumes of data derived from different observations[13] to supply digital models, constitutes a significant component of the control panels devised in accordance with DPSIR structure.[14] It makes it possible to provide a more realistic view of the characteristics of the oceans and of their development.

1.3.3.1. *Summary of operational oceanography and its development*

Operational oceanography (OO) allows us "to predict the state of the ocean system; to produce instantaneous values and realistic statistics of the target parameters, even in the absence of direct measurements of these parameters; to rerun past events while integrating data unavailable in real time, so as to generate in a deferred fashion the best possible descriptions of phenomena and situations; to simulate future situations according to several scenarios with the potential to support public decisions".[15]

OO expanded during the early 1990s and has stimulated research in different fields: treatment of *in situ* observations and satellite imagery, digital modeling and data assimilation[16], validation and oceanographic interpretation of the information produced, technological development of several physical, chemical and biogeochemical sensors.[17]

Satellite networks generate significant streams of data. For example, the altimetric measurements taken by the TOPEX/POSEIDON satellite since 1992, then by its successor JASON-1, launched in 2001 and finally by JASON-2, put into orbit in 2008, have covered more than 90% of the surface of the oceans with data streams of 50,000 pieces of information per day and a local altimetric precision of less than 5 centimeters. This enables us to monitor with precision the evolution of sea levels.

13 See Chapter 2.

14 Driving Forces, Pressures, States, Impacts, Responses: framework adopted by the European Environment Agency.

15 For more detailed information, one should read the final report on Operational Oceanography Foresight dating back to 9/10/2013 written by Bahurel *et al*., [BAH 13] p. 40.

16 A method that allows us to combine a model with observations.

17 See Chapter 2.

These considerable streams of data and observations (in 2007 the network of profiling floats Argo[18] with 3,000 active floats took 100,000 temperature and salinity profiles) have favored the development of digital calculation abilities in relation to the modeling and assimilation of data, which has made it possible in France, since 2001, to produce a first forecast thanks to MERCATOR Océan (www.mercator-ocean.fr).

In 2007, the PREVIMER project (www.previmer.org) made it possible to make coastal forecasts (Figure 1.5) on metropolitan and ultramarine littorals.

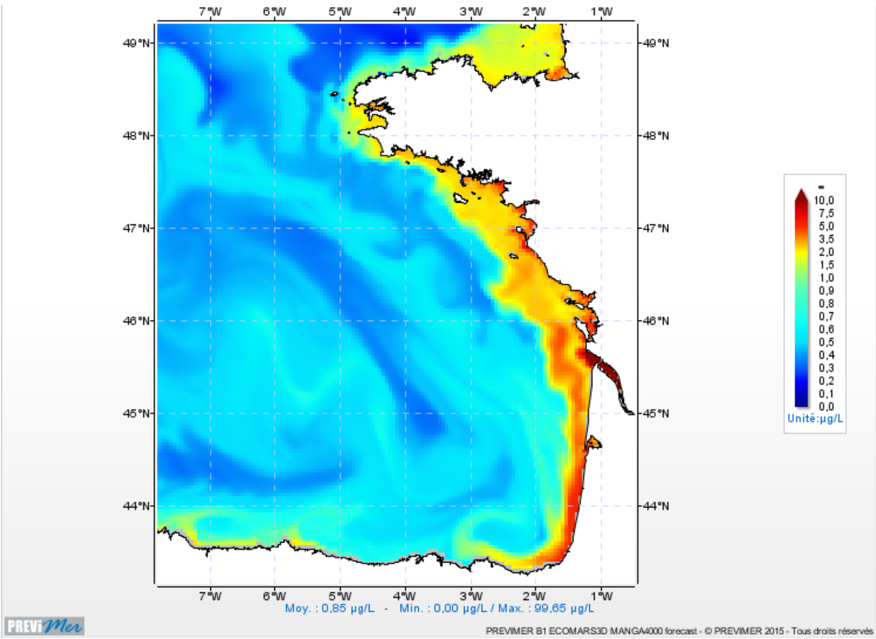

Figure 1.5. *Example of PREMIVER cartographic output showing the concentration of chlorophyll-a in surface waters (2/10/2015). See color section*

On a European level, EuroGOOS, set up in 1994, allows the development of OO on a European scale. The European program COPERNICUS/GMES (global monitoring for environment and security) aims at assessing the

18 In 2001, this network of floats enabled the launch of CORIOLIS (www.coriolis.eu.org) which allowed us to obtain the satellite and *in situ* data provided by oceanographic research and aimed at physical oceanography.