Navigating the Future IV

Position Paper 20

European Marine Board
Advancing Seas & Oceans Science

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European Marine Board

The European Marine Board provides a pan-European platform for its member organizations to develop common priorities, to advance marine research and to bridge the gap between science and policy, in order to meet future marine science challenges and opportunities

The European Marine Board (established in 1995) facilitates enhanced cooperation between European organizations involved in marine science (research institutes, research funding bodies and nationally-based consortia of third-level institutes) towards development of a common vision on the research priorities and strategies for marine science in Europe. In 2013, the Marine Board represents 36 member organizations from 20 countries.

The European Marine Board provides the essential components for transferring knowledge from the scientific community to decision makers, promoting Europe's leadership in marine research and technology. Adopting a strategic role, the European Marine Board provides a unique forum within which marine research policy advice to national agencies and to the European Institutions is developed, with the objective of promoting the establishment of the European Marine Research Area.

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Navigating the Future IV

Position Paper 20

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European MARINE BOARD
Advancing Seas & Oceans Science

Foreword

It is six years since the Marine Board published *Navigating the Future III* (Marine Board Position Paper 8, November 2006). Much has happened in the intervening period, both in terms of scientific progress, and in the development of the European science and maritime policy landscape. In just a two year period from 2007 to 2008, the EU delivered the Integrated Maritime Policy, a European Strategy for Marine and Maritime Research and the Marine Strategy Framework Directive, with its ambitious target of good environmental status of European marine waters by 2020. Since then, the global financial crisis has placed economic recovery at the top of the EU policy agenda, with the adoption of the Europe 2020 strategy (2010) and the EU Blue Growth strategy (2012). The European Commission proposals for the forthcoming Horizon 2020 programme reflect these policy developments by organizing a large part of the programme according to high-level societal challenges such as food and energy security, sustainable transport, human health and climate change. Seas and oceans research has high relevance across all of these challenges.

Navigating the Future IV provides a blueprint for the next phase of seas and oceans research in Europe. To ensure coherence with policy developments, several chapters focus directly on societal challenges. The paper demonstrates the key role of marine science and technology in supporting blue growth in sectors such as marine biotechnology, marine energy, aquaculture, fisheries and deep sea mining. But applied, problem-oriented research must be complimented by an improved knowledge of the natural system upon which these economic sectors depend. Understanding the principles governing marine ecosystem functioning and resilience and how marine environments are changing in response to natural and human pressures, will be paramount for achieving sustainability in growing maritime sectors. Hence, we must continue to support fundamental research and to reward scientific excellence; these are the ingredients for generating the transformative knowledge and technologies which can shape our future.

This document can be viewed as a compendium of marine science policy briefings, with each chapter designed so that it can stand alone. To achieve this required the input of a very large number of experts from a broad range of scientific fields and from throughout Europe. I would like to express my sincere gratitude to those who contributed generously of their time and intellect to make this document a reality. I thank the Marine Board members for their active participation in the process over a lengthy gestation period. I also thank our partner marine science networks and consortia for their important contributions. Finally, I pay tribute to the members of our Marine Board Secretariat, who have worked tirelessly to compile and edit a vast amount of material into a coherent and well-structured position paper.

All European citizens have a stake in the protection and sustainable management of our valuable marine ecosystems and resources. Looking ahead, it is clear that there needs to be a closer partnership between science, policy, industry and the general public to ensure consensus in achieving successful stewardship of Europe's marine waters. The marine science community is already engaging much more closely with other stakeholders and long may this continue. I sincerely hope that this extensive paper will be of assistance to those charged with formulating the strategic priorities and funding calls which will support the next phase of seas and oceans research in Europe in the years to come.

Kostas Nittis
Chair, European Marine Board
June 2013

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Navigating the Future: Progress and challenges in marine science and science policy

Credit: R. Prien, IOW

1.1 Introduction

When compared to the terrestrial habitat in which we live, the seas and oceans which dominate the surface our planet are, as yet, relatively unexplored and poorly understood. We lack an in-depth understanding of the critical role that our oceans play within the broader Earth and climate systems, and of the factors which threaten our marine environments with potentially serious consequences for our health and well-being. We also lack a full appreciation of the intrinsic benefits afforded to European citizens from the seas which surround our continent and of the enormous opportunities for European societies and economies to further benefit from marine products and services. To truly progress this knowledge, European scientists across a broad range of disciplines and domains must make a quantum leap towards holistic approaches and integrated research on a scale which will help us to much better understand, protect, manage and sustainably exploit the seas and oceans which surround us. This is a Grand Challenge; not just Europe, but for human society as a whole.

The seas and oceans are an intrinsic part of the earth and climate systems. They cover 70% of our planet, provide 95% by volume of its biosphere, support more than 50% of global primary production and harbour an enormous diversity of life adapted to extremely broad-ranging environmental conditions. The oceans are a driver of our climate but are also affected by climate change and ocean acidification. They are under increasing pressure from human activities and pollution, and growing coastal populations. The combination of natural and human-induced changes taking place in our seas and oceans including, for example, rising temperatures, the melting of Arctic sea ice, ocean acidification, increasingly extreme weather events, transfer of non-indigenous marine species, changes in biodiversity and species distribution, and depletion of fisheries stocks, may have potentially profound impacts on our societies and economies in the medium-term. European research focused on the seas and oceans is central to addressing these challenges by delivering knowledge and tools to enable Europe to prepare for, and adapt to, these changes.

Credit: IFREMER

The oceans are a driver of climate but are also being substantially impacted by human-induced climate change and ocean acidification.

But marine research is not only restricted to dealing with threats. It is equally targeted at delivering opportunities for people and for industry. The growth of new and existing industries such as marine renewable energy, marine biotechnology, fisheries and aquaculture and sustainable maritime transport must be supported by research and innovation, involving a range of actors to develop technologies and best practices in support of a thriving European maritime economy.

The last decade has seen a wealth of activity across many fields of science focused on seas and oceans questions and challenges. Some major international initiatives have helped to fast-track progress by creating global scientific networks and collaborations. The Census of Marine Life[1] (2000-2010), for example, transformed our knowledge of marine biodiversity. Other major international programmes include GLOBEC[2] (global ocean ecosystem dynamics), IMBER[3] (marine biogeochemical cycles), CLIVAR[4] (ocean atmosphere, a core project of the World Climate Research Programme), and GEOTRACES[5] (role of trace metal micronutrients in biogeochemical cycles). Looking ahead, the marine research community will have a major role to play in the ICSU Future Earth programme[6]. Future Earth is a 10-year (2012-2022) international research initiative that will develop the knowledge for responding effectively to the risks and opportunities of global environmental change and for supporting transformation towards global sustainability in the coming decades. Fundamental to all of these programmes is the recognition that we need cross-disciplinary research and international collaboration to effectively address some of the major scientific questions and societal challenges associated with the seas and oceans.

The technologies and collaborations across the full range of ocean observation activities have advanced significantly in recent years, bringing Europe closer to the visionary goal of an integrated ocean observing system, delivering data and information products for research, industry and societal benefit.

Credit: Sybille d'Orgeval, CNRS

[1] www.coml.org
[2] www.globec.org
[3] www.imber.info/index.ph
[4] www.clivar.org
[5] www.geotraces.org
[6] www.icsu.org/future-earth

At European level, the 7th **Framework Programme** (FP7, 2007-2013) has played an important role in promoting pan-European collaborative research in marine science and technology, reducing the fragmentation of available research capabilities (human and infrastructure capital) and supporting the coordination of research activities, strategies and programmes. In doing so, FP7 has built upon important instruments developed and implemented in the previous Framework Programme, FP6 (e.g. Networks of Excellence, Integrating Infrastructure Initiatives, ERA-NETs, etc.). FP7 also saw the introduction of the Ocean of Tomorrow initiative (see Box 1A) an innovative new instrument to support cross-thematic ocean research challenges.

The marine research community is now turning its attention to the next European Framework Programme, **Horizon 2020**, which will run from 2014 to 2020, anticipating a strengthening of support to marine and maritime research, building on the success of previous programmes. While the legislative acts for Horizon 2020 are to yet formally adopted by the European Parliament and Council (foreseen before the end of 2013), the European Commission proposals for Horizon 2020 published at the end of 2011 present an approach focusing on societal challenges requiring a much greater involvement of industry partners from various sectors to help bridge the gap between research and the market. Horizon 2020 will include measures aimed at further developing the **European Research Area (ERA)** with a view to creating a single European market for knowledge, research and innovation.

Credit: European Marine Board

Dr Kostas Nittis, Chair of the European Marine Board (2010 -) addressing the 2nd SEAS-ERA Open Forum in Brussels, 06 February 2013. The Forum presented regional Strategic Research Agendas (SRAs) for the Black Sea, the Mediterranean Sea and the Atlantic, developed through the SEAS-ERA project. The research priorities for the Baltic Sea were presented by the BONUS initiative. The event was organized by the European Marine Board as a partner in the SEAS-ERA project.

BOX 1A. The EU FP7 Ocean of Tomorrow initiative

The Ocean of Tomorrow initiative was developed in the course of the 7th Framework Programme (FP7) to allow for the launch of cross-thematic calls on major seas and oceans research challenges. Ocean of Tomorrow calls were implemented jointly between different themes of FP7 because they addressed major cross-cutting issues requiring cooperation between various scientific disciplines and sectors. The approach aimed to promote sustainable and innovative solutions to make better use of the potential of our marine environment.

Under FP7, three Oceans of Tomorrow calls were launched with a total budget of €134 million (€34 million for FP7-OCEAN-2010, €45 million for FP7-OCEAN-2011, and €55million for FP7-OCEAN-2013). The 2013 Ocean of Tomorrow call was the third and last cross-thematic call of its kind under FP7, effectively linking with the Horizon 2020 proposal, in which the importance of cross-cutting approaches is embedded from the outset. FP7-OCEAN 2013 represented one of the biggest ever EU investments in cross-cutting marine and maritime research.

Although the Ocean of Tomorrow cross-cutting initiatives have progressively increased in size, the majority of FP7 marine and maritime research actions have been supported within the different thematic priorities and specific programmes. This approach to marine and maritime research, strategically combining thematic and cross-thematic projects, is also embedded in the EU proposal for Horizon 2020.

For more information and links to projects funded under the Ocean of Tomorrow initiative, please consult http://ec.europa.eu/research/bioeconomy/fish/research/ocean/index_en.htm

The large majority of the investment of public funding in marine research (and European research in general) is made at member state level. The national research programmes of most EU member states may struggle in the future to support the level of research necessary to tackle some of today's major societal challenges such as addressing climate change and achieving energy security. Such challenges require a larger collaborative approach. The introduction of the ERA-NET instrument in FP6 and continued in FP7 was designed to bring national research funding agencies together to better align their programmes and investments. In the marine domain, the FP7 SEAS-ERA[7] project is building on the progress made by several FP6 marine ERA-NETS to create a strong network of funding agencies and closer cooperation and alignment of activities.

To complement the key role of the Framework Programmes in supporting collaborative European research, the European Commission has catalysed the development of Joint Programming Initiatives, designed to provide a framework for member countries to combine funding and resources to address shared research challenges. The Joint Programming Initiative, Healthy and Productive Seas and Oceans[8] (JPI Oceans), has been established to address the research and policy-oriented challenges presented by the seas and oceans and will provide a major consolidating framework for national investments in marine science in the years to come (see Box 1B).

Credit: European Marine Board

The SEAS-ERA partners meeting in Brussels on 07 February 2013. SEAS-ERA is a FP7 ERA-NET project bringing together 20 national funding agencies from 18 countries. ERA-NETs promote better alignment of national research investments in thematic areas. SEAS-ERA (2010-2014) has both a pan-European and a regional sea basin perspective and is delivering strategic analysis of funding programmes, infrastructures and human capacities in addition to common programmes and joint funding calls.

[7] www.seas-era.eu

[8] www.jpi-oceans.eu

BOX 1B. Joint Programming Initiative on Healthy and Productive Seas and Oceans - JPI Oceans

On 6 December 2011, EU Research ministers formally launched the Joint Programming Initiative on Healthy and Productive Seas and Oceans (JPI Oceans) as one of ten JPIs (as of June 2013) which have been taken forward since the launch of the Joint Programming process in 2008.

JPI Oceans is a long-term strategic partnership, between participating EU Member States and Associated Countries dedicated to improving coordination and integration of marine research investments in Europe and to reducing existing fragmentation and duplication of efforts. This is considered necessary to strengthen Europe's capacity to address the many challenges and opportunities presented by Europe's seas and oceans.

One of the main objectives of JPI Oceans is to develop a joint Strategic Research and Innovation Agenda (SRIA) starting from a common vision and, based on this SRIA and vision, to implement joint activities in which countries can be involved on a voluntary basis (variable geometry). This should lead to a more coherent and integrated European approach to investing in marine and maritime research and technology development.

As of mid-2013, 18 European countries have membership on the Management Board of JPI Oceans: Belgium, Denmark, Finland, France, Germany, Iceland, Italy, Ireland, Lithuania, The Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Turkey and United Kingdom. The European Commission is a non-voting member of the Management Board.

Arvid Hallén, Director-General, Research Council of Norway
Credit: JPI Oceans

For more information, visit: www.jpi-oceans.eu

1.2 Review of marine science and maritime policy progress (2006-2013)

Since publication of the last Navigating the Future paper in 2006, Europe has delivered important policy instruments to support the sustainable utilization, management and protection of its marine waters. Policy developments have been largely dominated by the establishment of the **Integrated Maritime Policy (IMP)** in 2007 which was preceded by an extensive stakeholder consultation process. The IMP was an important step forward in developing a more coherent approach to managing maritime activities across a range of sectors and policy areas with the aim of achieving the full economic potential of Europe's seas and oceans, while protecting their ecological integrity for future generations. The IMP includes a range of cross-cutting policy objectives in areas such as marine data and knowledge, Maritime Spatial Planning (MSP), Blue Growth (see Box 1C), regional (sea basin) coordination and integrated maritime surveillance. To advance these goals, the European Commission has supported a range of implementation actions in the period since 2007.

Lars Horn, Chair of the Marine Board from 2006-2010, participating in a discussion on "Future Directions for the EU Integrated Maritime Policy", European Maritime Day, 20 May 2010, Gijon, Spain.

The environmental pillar of the IMP, the **Marine Strategy Framework Directive (MSFD)**, came into force in June 2008. The MSFD requires that members states with marine territories put in place appropriate targets and measures towards achieving good environmental status (GES) in Europe's marine waters within a defined timeframe and according to eleven key descriptors of environmental status. It is widely accepted that there are significant knowledge gaps which may hinder the full implementation of the MSFD. Coordinated marine research targeted at addressing these gaps will be essential to underpin the stated objective of achieving GES in European waters by 2020. The Ocean of Tomorrow 2012 coordinated calls were focused largely on addressing the knowledge gaps concerning implementation of the MFSD. The EU FP7 STAGES[9] project is addressing the structural aspects of transferring knowledge from science to inform policy and decision making in support of MSFD.

The EurOCEAN 2007 Conference culminated in the launch of the Aberdeen Declaration, which called for a dedicated EU strategy for marine and maritime research to underpin the next phase of European coordination on seas and oceans research. In September 2008, the EU adopted the **European Strategy for Marine and Maritime Research**[10] as the research pillar of the IMP. This strategy constitutes a separate element of the European Research Area (ERA) and represents one of the first attempts to fully establish the ERA within a specific research sector.

More recently, the EC **Marine Knowledge 2020 initiative**[11] aims to establish a framework and a range of actions to bring together and make available marine data from different sources for use by industry, public authorities and researchers. This reflects the shift in perspective to a view that data should not necessarily be collected for one specific purpose, but should be used many times and by several users. Marine Knowledge 2020 provides a unifying framework for all ongoing activities on marine observation within the EU. At the core of the Strategy is the European Marine Observation and Data Network (EMODnet), a single entry point for accessing and retrieving marine data derived from observations, surveys or samples from the hundreds of databases maintained on behalf of agencies, public authorities, research institutions and universities throughout the EU. The European

[9] www.stages-project.eu

[10] COM(2008) 534 final – available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52008DC0534:EN:NOT

[11] To support this process, the European Commission published a Communication in 2010 (EC COM(2010) 461 final) and a Green Paper in 2012 as a basis for a public consultation to understand stakeholders' opinions on options for future governance of the EU's "Marine Knowledge 2020" initiative and on the possible involvement of the private sector.

Marine Board helped to shape the vision and clarify the options to develop the EMODNet through a joint Marine Board-EuroGOOS Vision Document, *EMODNet, The European Marine Observation and Data Network,*[12] published in 2008.

Recognizing the specificities of each large sea region in the EU, macro-regional growth and development strategies are being developed by the European Commission that are specifically designed to address the particular challenges and opportunities of Europe's regional sea basins. The first such strategy, the EU Strategy for the Baltic Sea Region[13] (EUSBSR), was launched in 2009. In May 2013, the Commission published an Action Plan for a Maritime Strategy in the Atlantic area (COM(2013) 279 final)[14]. Cross-disciplinary and collaborative research is at the core of the requirements for successful implementation of each of these strategies.

Credit: MARUM

Marine research has the capacity to deliver new products and services, meeting the needs of the Europe 2020 strategy and the EU Blue Growth agenda.

BOX 1C. The EU Blue Growth Initiative

The EU **Blue Growth Initiative** is a long-term strategy to support growth in the maritime sector as a whole by harnessing the untapped potential of Europe's oceans, seas and coasts for jobs and growth. In support of the strategy, the Commission published a Communication in 2012 entitled *"Blue Growth opportunities for marine and maritime sustainable growth"* (EC COM(2012)494 final) which recognizes that considerable investments in science and technology will be necessary to realize growth in the blue economy and to create new and innovative ways to allow Europe to recover from the recent financial crisis.

The Blue Growth Communication identifies five sectors with a high potential for growth and where research will be critical: (i) blue energy; (ii) aquaculture; (iii) maritime coastal and cruise tourism; (iv) marine mineral resources; and (iv) marine Biotechnology. Additional support at EU level for the development of these areas can stimulate long-term growth and job creation in the blue economy, a key priority of the Europe 2020 strategy. The importance of research has been emphasized throughout the Blue Growth study and is at the heart of the Blue Growth Strategic Framework. The major challenge in the context of science and technology support to blue growth now is to upscale EU research to facilitate development and innovation via a clear market orientation.

In October 2012, European Ministers with responsibility for maritime affairs adopted the **"Limassol Declaration"**[15] at a conference organized by the Cypriot Presidency of the European Union. Five years after the launch of the EU Integrated Maritime Policy, the Declaration sets a marine and maritime agenda for growth and jobs. Ministers called for enhanced innovation and marine and maritime research to ensure targeted and cross-cutting research aimed at realizing the high growth potential of the blue economy, in particular through Horizon 2020.

The Limassol Declaration provides a strong maritime pillar in support of the **Europe 2020 Strategy**, Europe's economic development strategy aiming to generate smart, sustainable and inclusive growth. Its call for enhanced innovation and research is being delivered through 7 flagship initiatives of which the **Innovation Union** is one. With over thirty action points, the Innovation Union aims to improve conditions and access to finance for research and innovation in Europe, to ensure that innovative ideas can be turned into products and services that create growth and jobs. **Horizon 2020** will serve as the main financial instrument implementing the Innovation Union goals with a view to securing Europe's global competitiveness.

[12] Available from www.marineboard.eu/publications/

[13] See also http://ec.europa.eu/regional_policy/cooperate/baltic/index_en.cfm#2

[14] EU EC COM(2013) 279 final Action Plan for a Maritime Strategy in the Atlantic area: Delivering smart, sustainable and inclusive growth.

[15] Available at http://ec.europa.eu/maritimeaffairs/policy/documents/limassol_en.pdf

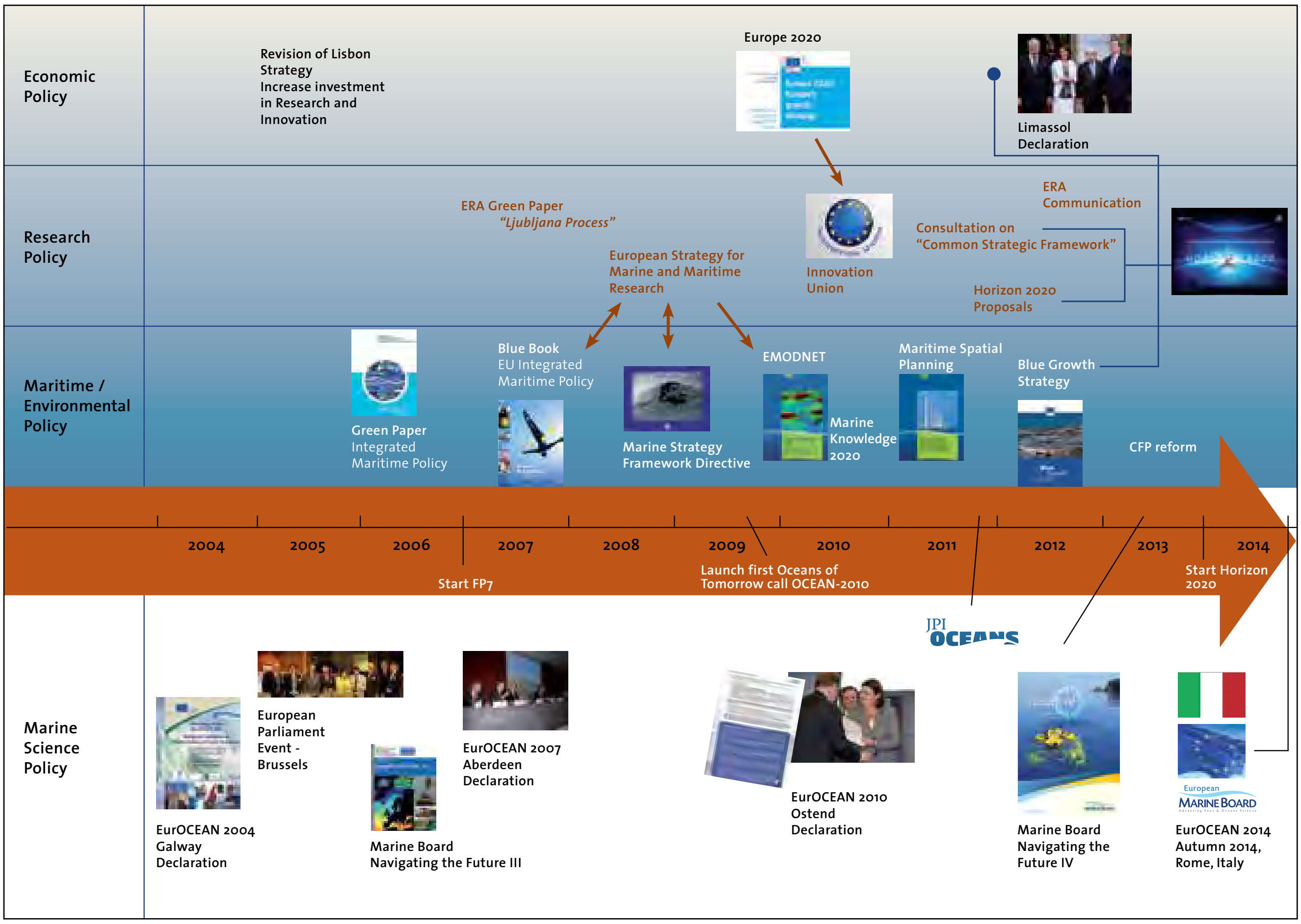


Figure 1.1. Overview of some of the major developments shaping the marine science policy landscape from 2004 to 2013

Much progress has also been made in the framework of the European Union energy and climate change policies. For example, the **European Strategic Energy Technology Plan (SET-Plan)**[16] , the technology pillar of its energy and climate change policies, was adopted by the European Union in 2008 with a view to transforming the way we produce and use energy towards a low carbon future. An Ocean Energy Joint Programme of the European Energy Research Alliance (EERA), one of the SET-Plan implementation mechanisms that was launched in 2011, aims to develop coordinated European ocean energy research that will underpin the development of the emerging ocean energy sector. More recently, in March 2013, a public consultation was launched (EC COM (2013) 169 final)[17] by the Commission on a 2030 framework for climate and energy policy encompassing two major components on carbon capture and storage (CCS) and renewable energy.

A landmark agreement between the Council of Ministers and European Parliament on the reform of the Common Fisheries Policy (CFP) represents another major policy development in 2013. The overarching aim of the reformed policy is to end overfishing and make fishing sustainable. A key element of the policy entails the banning of discards, one of a suite of measures designed to bring fish stocks above sustainable levels. The new policy should enter into force by 01 January 2014 with a progressive implementation of the new rules.

[16] SETIS (2013) SET-Plan Review of Implementation Mechanisms for the period 2010-2012

[17] EU EC COM/169 final Green Paper: A 2030 framework for climate and energy policies.

1.3 The EurOCEAN Conferences

The European Marine Board has actively contributed to the above policy developments through responses to consultations, publication of statements, thematic papers and the organization of strategic meetings and conferences. The **EurOCEAN Conferences** have been especially influential, providing a forum for policy makers and strategic planners both at European and member state level to interface with the marine research community and marine and maritime stakeholders to consider, discuss and respond to new marine science and technology developments, challenges and opportunities.

The **EurOCEAN 2007 Conference** (Aberdeen, Scotland, 22nd June 2007), took place during the final phase of a public consultation process on the EU Green Paper, *"Towards a future for the Union: A European Vision for the Oceans and Seas",* and provided a unique opportunity for the European marine and maritime science communities to respond through the Aberdeen Declaration. The overarching goal of the Aberdeen Declaration was to embed marine science as a central pillar of a future Integrated Maritime Policy (IMP) for Europe and to call for a European Strategy for Marine and Maritime Research as an integral part the IMP, which was ultimately adopted in 2008.

Credit: European Marine Board

Mr. Joe Borg, EU Commissioner for Maritime Affairs and Fisheries with Lars Horn, European Marine Board Chair (2006-2010) at the EurOCEAN 2007 conference in Aberdeen.

More recently, midway in the Seventh Framework Programme (2007 – 2013), the **EurOCEAN 2010**[18] Conference (Ostend, Belgium, 12-13 October 2010) was organized by the Belgian EU Presidency, the European Commission and the European Marine Board. This Conference highlighted the crucial importance of marine science in effective maritime policy making and the key role it can play in supporting European economic recovery, growth and innovation. It also identified priority marine and maritime research challenges and opportunities in areas such as food security, global environmental change, renewable energy, marine biotechnology, maritime transport and marine spatial planning. The conference adopted the Ostend Declaration (summarized in Box 1D) with a call from the European marine science community for specific actions from the Member States and the European Union in support of essential marine science and technology research challenges in the coming decade (2010-2020). EurOCEAN 2010 was held at a crucial time to influence the development of the future EC Common Strategic Framework for EU Research and Innovation Funding (Horizon 2020) and mobilize support from member states for more collaboration and coordination in marine sciences. These events have also contributed towards influencing national marine research strategies and funding programmes.

[18] http://eurocean2010.eu/eurocean

BOX 1D. EurOCEAN 2010 and the Ostend Declaration

In October 2010, more than 400 marine scientists and science stakeholders from across Europe gathered in Ostend, Belgium, for the EurOCEAN 2010 Conference. The conference discussed future priorities for European marine research in the coming decade and unanimously called for a broader recognition that **“The Seas and Oceans are one of the Grand Challenges for the 21st Century”**. The latter is the headline of the Ostend Declaration which was adopted on the second day of the EurOCEAN 2010 Conference (13 October 2010), following an extensive consultation with the marine and maritime research community and relevant stakeholders in Europe in the months leading up to the event.

The Declaration underlines the crucial role of marine and maritime science and technology in providing knowledge and understanding of the seas and oceans and their biodiversity, and in creating new opportunities and technologies to support existing and new policy objectives (e.g. Europe 2020, the Integrated Maritime Policy for the European Union, the European Research Area, the Common Fisheries Policy, the Marine Strategy Framework Directive) and related grand challenges including food, energy and health, as highlighted in the 2009 Lund Declaration.

The Ostend Declaration called upon the European Union and its Member and Associated States to:

- Actively support the Joint Programming Initiative on “Healthy and Productive Seas and Oceans”;
- Support the development of a truly integrated and sustainably funded “European Ocean Observing System”;
- Establish appropriate mechanisms to keep under review current marine and maritime research programmes and projects with a view to enhancing their impact by (i) exploiting the results of this research; and (ii) identifying existing and emerging gaps.

The Ostend Declaration concluded that it is essential to prioritise initiatives and programmes to enhance Innovation, Training and Career Development, and International Cooperation.

Presentation of the Ostend Declaration to Máire Geoghegan-Quinn, EU Commissioner for Research, Innovation and Science and Wim de Vos, representing the Belgian EU Presidency, following its adoption at the EurOCEAN 2010 conference (13 October 2010). From left to rigth: Lars Horn (Chair of the European Marine Board (2005-2010), Research Council of Norway), Wim De Vos (representative of the Cabinet of Sabine Laruelle, Belgian Federal Minister for SMEs, Independents, Agriculture and Science Policy), Máire Geoghegan-Quinn (European Commissioner for Research, Innovation and Science), Kostas Nittis (Chair of the Ostend Declaration Drafting Group, Hellenic Centre for Marine Research, Greece) and Edward Hill (National Oceanography Centre, United Kingdom).

An audience of 450 European marine scientists, science policy makers and stakeholders adopted the Ostend Declaration at the EurOCEAN 2010 Conference.

For more information about EurOCEAN 2010, the Ostend Declaration and the EurOCEAN series of conferences, consult http://eurocean2010.eu

1.4 The European Marine Board: At the interface between science and policy

The European Marine Board acts at the interface of science on the one hand, and both science policy and maritime policy on the other. As such, the Board is a long-established European science policy interface (SPI, see chapter 13) focused on the seas and oceans (see Figure 1.1). Since 2007, the European Marine Board has experienced one of the most productive periods in its history with the publication of a wide range of thematic position papers, organization of a series of Marine Board open fora, EurOCEAN conferences in 2007 and 2010, active participation in more than seven EU Framework Programme projects (MarinERA, AMPERA, MARIFISH, SEAS-ERA, CLAMER, CSA MARINEBIOTECH and STAGES), and much more. All of these activities have taken place in the context of a very dynamic European marine science landscape that - as outlined above - has changed considerably since the Marine Board entered the stage in the early 1990s. In this new landscape, the European Marine Board will continually adapt its strategy and *modus operandi* so that it can continue to influence and contribute to an exciting new era in marine science and technology.

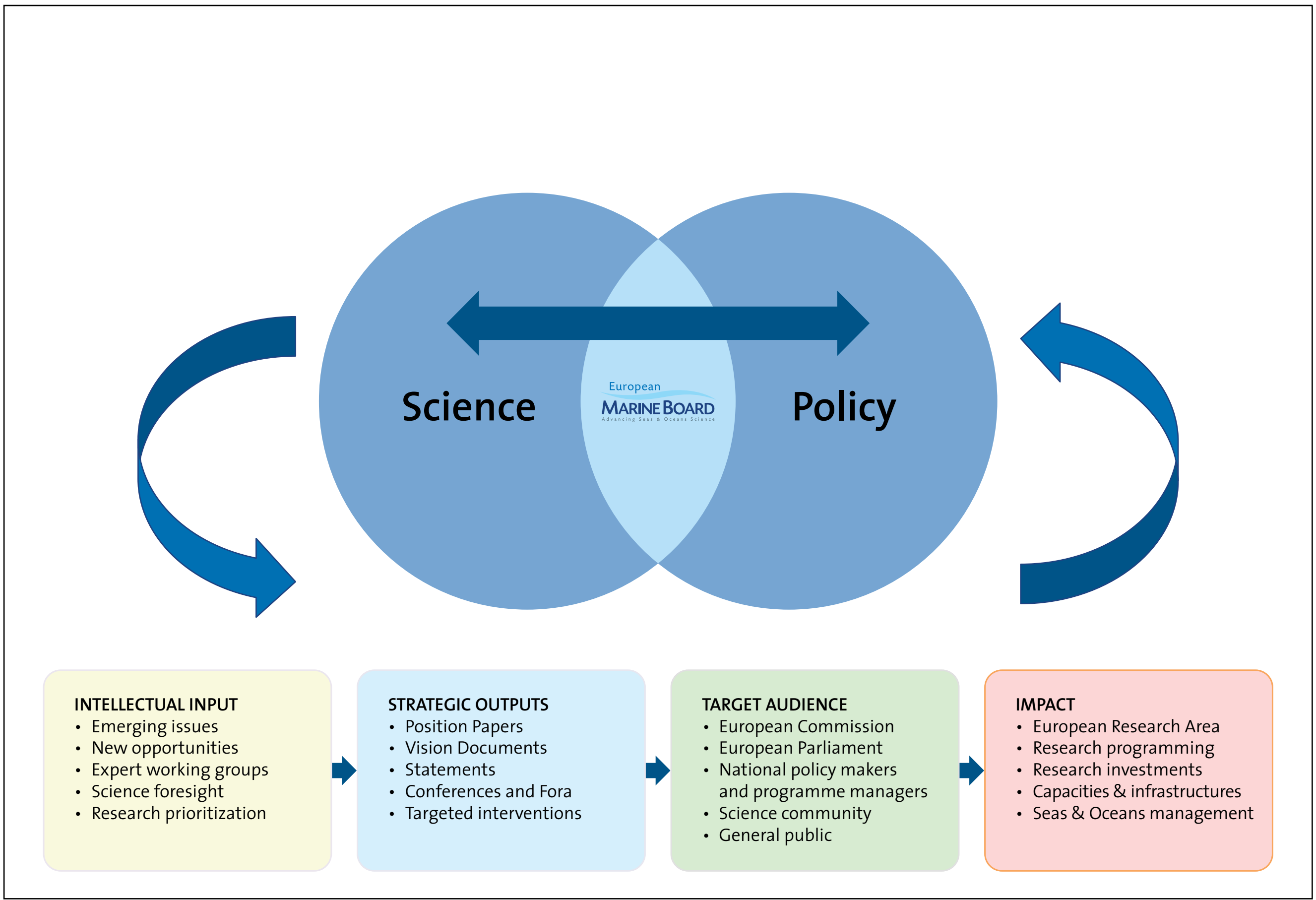


Figure 1.2. Since its establishment in 1995, the European Marine Board has acted as a science-policy interface for marine science and technology, translating and transferring scientific expert advice to policy makers (e.g. the European Commission) and policy needs and priorities to the scientific community

1.4.1 About this document

Navigating the Future IV (NFIV) is the 20th position paper of the European Marine Board. Unlike other position papers which are focused on a specific theme, Navigating the Future reports are intended to span the full range of research focused on the seas and oceans and to address both applied science, which can contribute to Europe's blue growth agenda, and fundamental science which is crucial to provide an understanding of marine ecosystem functioning and the provision of marine ecosystem goods and services which benefit society. As an important goal, Navigating the Future papers identify emerging issues and topics of strategic importance which require a research-based response. The papers also address strategic issues by identifying critical support functions and enabling actions ranging from next generation marine observation and data services to human capacities and ocean literacy. The papers are written from a European perspective, but in a global context, and identify the most important research challenges and priorities which should be the focus of European programmes in the next 5-10 years. With its publication and launch in mid-2013, Navigating the Future IV is well-placed to influence and inform the development of work programmes of the Horizon 2020 programme, scheduled to begin in January 2014.

Credit European Marine Board

The Navigating the Future IV process began with a Brainstorming Worksop at the European Marine Board offices in Ostend, Belgium on 03-04 March 2010. Thirteen marine experts from a range of fields and locations across Europe worked together over the course of two days to formulate the outline structure and scope of the Navigating the Future IV paper.

A feature of Navigating the Future IV is that the document is organized largely according to societal challenges. Thus the chapters are not associated with particular areas of science, but focus on issues such as climate change, food security (fisheries and aquaculture), energy security (marine energy both renewable and non-renewable), and human health. The cross-disciplinary scientific approaches for addressing these challenges are then elucidated. This reflects the recent paradigm shift in science policy whereby, in order to justify expenditure in the face of limited budgets, research funding agencies are increasingly required to demonstrate the societal impact of their research investments. This requirement is then passed to the scientist, on whom there is an increasing onus to demonstrate the impact of proposed research. An important consideration, however, is that this should not be restricted to "economic impact". It is clear that marine research has a key role in delivering new products, processes and services which can deliver a direct economic impact, meeting the EU Blue Growth agenda. However, research must also address more fundamental questions in a way which may not deliver immediate economic gains, but which will form the basis for a much longer-term sustainable management of our seas and oceans. Thus, Navigating the Future IV provides a blueprint for how seas and oceans research can contribute to the development of not just a "smart economy" but, more importantly, can underpin our progress towards becoming a "smart society", of which economy is just one - albeit important - component.

The European Marine Board actively disseminates its publications to marine science policy makers (those charged with formulating science policy and implementing research funding programmes at national and EU level), the science community and science stakeholders. Marine Board publications provide strategic advice on the priorities for future seas and ocean research, and include position papers, future science briefs, vision documents and science commentaries.

This document is not an exhaustive inventory of research challenges, needs and priorities associated with the seas and oceans. Such an exercise would run to several volumes. In addition to this introductory chapter, Navigating the Future IV contains thirteen thematic chapters. Each one is designed to act as a science policy briefing on the topic in question and can thus be read in isolation of the others. This results in some necessary repetition, whereby certain issues are addressed in several chapters. Where there is overlap, efforts are made to cross-reference so that the reader may consult other relevant chapters. Thus, while it is hoped that as much of the document will be read by as many people as possible, it is designed to be used selectively, allowing readers to consult specific topics of interest, as required.

While Navigating the Future IV spans the full range of marine research and policy challenges, by definition the formulation of research priorities requires the selection of some issues over others. There will be important areas of research that are not included in this document but which will merit support. Moreover, the European Marine Board, through its continual horizon-scanning function, recognizes more than any organization that new challenges, opportunities and associated research priorities will emerge over time. The Board will play a role in identifying and highlighting these. In the meantime, it is intended that this document should assist both the scientific community and those charged with the development and implementation of national and European research programmes by profiling many of the most important priorities for marine research in the coming decade.

2

Understanding marine ecosystems and their societal benefits

Credit: Turkish Marine Research Foundation (TÜDAV)

2.1 Introduction and current state of knowledge

For centuries, knowledge of the oceans has been restricted to coastal regions and to the surface layers. The deep waters of the oceans and the ocean floor were unknown until the first oceanographic expeditions in the late nineteenth century. It is only in the last few decades, with the development of new observation techniques and large international research programmes, that we are witnessing major advances in our knowledge of the marine environment and marine ecosystems. These advances have served to illustrate the sheer complexity of the ocean, the enormous and changing diversity of marine life, and the interplay between ecological, biogeochemical and physical processes which drive the ocean ecosystem. Hence, there remains an enormous challenge to further map and study marine environments, to understand complex marine processes and to predict future changes resulting from human and natural pressures. Given the importance of marine ecosystem goods and services to human life (climate regulation, bioremediation, primary production and oxygen generation, supply of food, etc.), this is a challenge of major societal relevance. This chapter examines the current state of our knowledge about the functioning of marine ecosystems and their component parts, identifies the societal relevance of improving our understanding of marine ecosystems, and makes recommendations on priorities for future research and strategic actions.

Credit: R. Prien, IOW

Deployment of a plankton net from a research vessel. Information on biological components of marine ecosystems, in particular in deep waters, is still mainly gathered by traditional technology including plankton nets, dredges, grabs, trawling etc. The analysis of biological samples is very time consuming and expensive, but still unavoidable as alternative methods are still in the experimental stage. These include the *in situ* use of genomics (mostly a concept still), flow cytometry for viruses and small cells, video and image analysis for zooplankton and benthos, and sonar for fish and larger vertebrates.

2.1.1 Biodiversity and ecosystem dynamics

Over the past decade several large initiatives have greatly increased our knowledge of marine biodiversity and its role in marine ecosystems. Perhaps foremost is the Census of Marine Life[1], a decade-long international programme that ended in 2010, in which the exploration of marine biodiversity was a primary objective, and within which European scientists made a significant contribution. Of the several large projects funded by the European Union, HERMES, HERMIONE[2] and CORALFISH[3] have greatly advanced our knowledge of the continental margins of Europe, including the ecology of cold water corals and canyons. The EU FP6-funded network of excellence, MarBEF (Marine Biodiversity and Ecosystem Functioning)[4], brought together European scientists and contributed to the development of the Ocean Biogeographic Information System (OBIS)[5], in which millions of geo-referenced species records have been assembled, and WORMS, the World Register of Marine Species[6], which is now the basis for the catalogue of marine life.

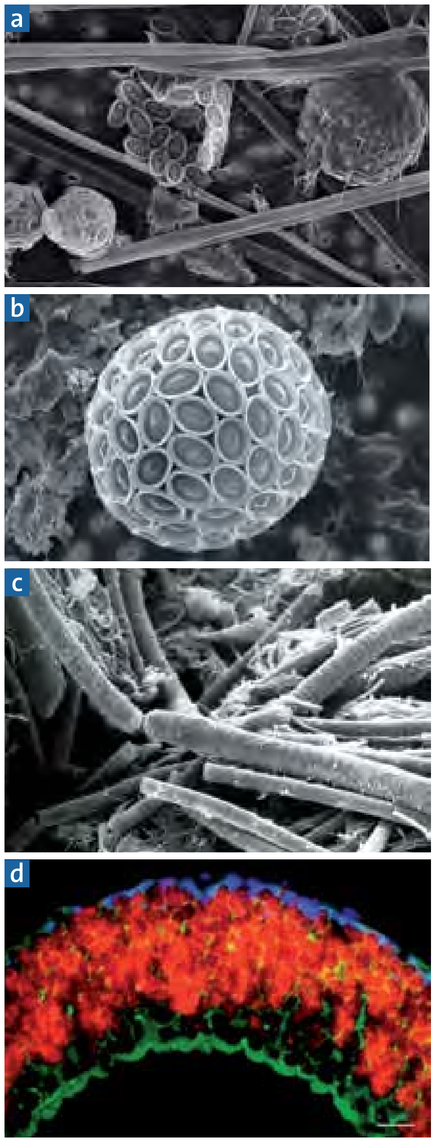
Thus, there have been major advances in the discovery of new species and in building an information architecture to store and make available the growing amounts of biodiversity and associated data. However, the significant funding of biodiversity research in recent years has not addressed the continuing decline of available expertise in taxonomy, the basic science of biodiversity. Moreover, the exploration of marine biodiversity is unfinished. It is estimated that at least 70% of marine eukaryote species are yet to be described. The Census of Marine Life found that every second specimen collected from waters deeper than 3,000m belonged to a previously undescribed species (Crist *et al.*, 2009). The challenges and priorities for biodiversity research in Europe are discussed in more detail in the Marine Board Future Science Brief 1, Marine Biodiversity: A Science Roadmap for Europe (Heip and McDonough, 2012).

[1] www.coml.org
[2] www.eu-hermione.net
[3] www.eu-fp7-coralfish.net
[4] www.marbef.org
[5] www.iobis.org
[6] www.marinespecies.org

The numerous and varied methods of data collection employed during the Census of Marine Life

Credit: Census of Marine Life, E. Paul Oberlander/WHOI.

Biodiversity is not restricted to the macrobiota. For a billion years, microorganisms were the only component of life in the oceans, and they still play a fundamental role in underpinning marine ecosystem functioning. Over the past 15 years, important advances have enabled description of the diversity of microorganisms in a variety of pelagic and benthic environments under various environmental conditions and pressures. Marine microorganisms (or microbes) comprise *Bacteria, Archaea,* viruses, *Fungi* and the whole community known as "phytoplankton", represented by photosynthetic protists often termed microalgae. These microscopic but hugely abundant organisms are the engine of all ecological processes in the oceans, accounting for the cycling of matter through the processes of primary production and decomposition. Our understanding of these phenomena has greatly improved



Credit: R-A. Sandaa
Credit: R-A. Sandaa
Credit: Lucas Stal
Credit: Anna Blazejk

in recent years. New concepts such as the microbial loop (or microbial food web – the role of microbes in transferring organic carbon from the marine environment to higher trophic levels) have been developed and studies have increasingly documented the range of interactions between organisms in food webs. More recently, new approaches have enabled the quantification of *in situ* microbial activities (who is doing what?) to address the study of communities in terms of the overall functioning of ecosystems. However, as with the macrobiota, microbial diversity is still largely unknown. Understanding the links between microbes and higher trophic levels is an important challenge for marine ecology and the two systems (the microbial and the macrobial) are yet to be connected from a conceptual point of view.

Images of algae (a, b) and a microbial mat (c) using Scanning Electron Microscopy (SEM) and an epifluorescence image of the symbiont-containing region of a worm, *O. crassitunicatus* (d).

An understanding of marine foodwebs is also critical to any understanding of marine ecosystems. Marine food webs are usually analysed in different components. For example, some scientists may study primary production (either *in situ* or using satellite data), others study crustacean grazing, and others study vertebrates (e.g. fisheries biologists). Some focus on the water column, others the benthos. The benthic domain is, in turn, being studied by separate approaches ranging from coastal to deep sea benthos, intertidal to sub-tidal, or hard and soft substrates. However, all of these compartments are linked both by circulation patterns and by life cycle strategies. Understanding one compartment as if it were independent of all others does not make sense from an ecological perspective, because ecology is the science of interactions in the natural world. The next phase will require the different and well-studied compartments to be linked. This will involve a cross-disciplinary approach involving life cycles, life histories, food webs and biogeochemistry (Boero, 2010).

2.1.2 The basic elements of ocean life

The chemistry of seawater is a fundamental control on ocean ecosystems. The supply of chemical nutrients to the sunlit upper ocean allows life to flourish in the oceans and the mixture of nutrients that is supplied sets the nature of the ecosystem. The discipline of biogeochemistry was initially mainly concerned with quantifying stocks and fluxes of the major elements, carbon (C), nitrogen (N), phosphorus (P) and silica (Si) in the open ocean and coastal zone. The knowledge of the distribution and cycling of ocean macronutrients – nitrate, phosphate, and silica – is now well developed. However, an understanding of macronutrient cycles is insufficient to assess the chemical controls on ocean biology. This is because of the vital role played by micronutrient metals in the enzyme pathways required by life. Metals such as iron (Fe), zinc (Zn), cobalt (Co), cadmium (Cd), and manganese (Mn) are essential for life, but are often present in seawater in extremely low concentrations (trace elements). Partly because of this low concentration, and also because of the relatively recent recognition of the importance of micronutrients, understanding of micronutrient cycles lags far behind that for the macronutrients. This lack of understanding of micronutrient cycles is the fundamental limitation on our assessment of the chemical controls on ecosystem health and biological carbon uptake in the oceans. It is the primary focus of the international GEOTRACES[7] programme.

The important role of biodiversity - and of microorganisms in particular - in marine biogeochemistry has been increasingly identified, first within pelagic biogeochemistry under the concept of functional types (such as Plankton Functional Types or PFTs), the ‘function’ representing here a set of biogeochemical processes responsible for the dynamics of a given element. Finally the multi-element approach of biogeochemistry has resulted in the need for consideration of diversity within the functional types themselves, in terms of the diversity of ecological responses. As with microbial ecology, biogeochemical approaches need to be linked to the rest of ecosystem functioning.

[7] www.geotraces.org

As a consequence of anthropogenic CO_2 emissions, oceans are becoming warmer (global warming) and more acidic (ocean acidification). A growing body of evidence demonstrates the negative impacts of temperature, pH/pCO_2, and other consequences of human activity (e.g. over-fishing, habitat destruction, hypoxia, etc.) on marine ecosystem resilience. Over the last ten years, these questions have attracted considerable attention from the scientific community, generating collaborative and multidisciplinary efforts (e.g. EPOCA, the first European Consortium on Ocean Acidification; BIOACID, the UK-OA programme) and the creation of state-of-the-art experimental facilities and best practices (e.g. EPOCA Best Practice Guide for Ocean Acidification Research). Understanding the potential consequences for marine species and ecosystems and identifying strategies to limit or mitigate these impacts are key scientific challenges of the 21st century.

Credit: Leibniz Center for Tropical Marine Ecology/ G. Shmidt

2.1.3 Ecosystem modelling

There have been significant advances in the modelling of marine systems with a view to gaining a more in-depth understanding of ecosystem functioning, assessment of ecosystem status, and a more accurate estimate of ecosystem responses to external perturbations, including anthropogenic pressures and regime shifts. Models have been developed and applied in an operational oceanography arena (short-term prediction of physical and biogeochemical dynamics); in support to ecosystem based and environmental management (eutrophication, marine spatial planning, ecosystem approach to fisheries and aquaculture); and to explore the potential impacts of climate change. The capability to model biogeochemical cycles and to use coupled transport-biogeochemical models of the global ocean has been steadily increasing, helped by major initiatives such as the US Joint Global Ocean Flux Study (JGOFS)[8].

[8] www.whoi.edu

Similarly, there has been an increase in the capacity to model the dynamics of higher trophic level organisms, their life cycles, their interaction with the physical environment and, possibly, fishing, along with their interaction within marine food webs (GLOBEC). These efforts naturally merged in recent and numerous attempts to develop end-to-end models able to integrate physical, biogeochemical and ecological processes into a single comprehensive modeling framework. End-to-end models offer the potential to integrate and contrast the effects of natural and anthropogenic changes, including fishing and climate change, while considering both direct and indirect effects within a truly ecosystem perspective. (IMBER[9]; Eur-Oceans[10]; FP7 MEECE[11] project; Rose *et al.,* 2010; Shin and Cury, 2004; Fulton, 2011; Libralato *et al.,* 2008; Lehodey *et al.,* 2006).

There have been significant advances in the modelling of marine systems with a view to gaining a more in-depth understanding of ecosystem functioning, assessment of ecosystem status, and a more accurate estimate of ecosystem responses to external perturbations, including anthropogenically-driven ones. Nevertheless, scientific field-work and ocean observation will always remain essential, not least to validate and constrain model predictions.


Credit: HCMR

2.1.4 The "omics" revolution

Omics is a recently coined catch-all term referring to the range of biological investigation techniques with the suffix "-omics." Omics approaches are an expansion of genomics, i.e. high throughput sequencing of genomes, to all other approaches involving the production of large amount of data applied to the study of cells or organisms. Besides genomics (DNA data), omics approaches include transcriptomics (RNA data), proteomics (protein data), metabolomics (metabolite data), and many others (glycomics, interactomics, etc.). Genomic sequencing has a very promising potential to uncover evolutionary and ecological processes and the capacity of species to adapt to changing environmental conditions. The analysis of expression profiles (transcriptomics), for example, might shed light on organismal responses to environmental conditions (e.g. McLean, 2013). Using metagenomics, DNA is extracted from the water to assess the overall genetic diversity of the biota (although this technique does not distinguish between different taxa). This allows rapid advances in the understanding of ecosystem function.

[9] www.imber.info

[10] www.eur-oceans.eu

[11] www.meece.eu

The use of genomics in the marine sciences is relatively recent compared to other fields such as medicine and agronomy but has developed rapidly during the past 10 years As a result of large European projects such as the FP6 Network of Excellence, Marine Genomics Europe, we now have access to large genomic resources and related enabling technologies that allow advances in environmental genomics and biodiversity (barcoding, metagenomics, functioning of ecosystems) and global change research (e.g. the role of the biological "black box" in biogeochemical cycles).

2.1.5 About this chapter

This chapter is designed to examine the key scientific and societal questions and challenges which underpin the need to attain a more complete understanding of marine ecosystems. While the societal importance (and indeed necessity) of research on marine ecosystem understanding is elucidated, and some relevant policies are mentioned, it is not designed to be an exhaustive account of the policy requirements or research gaps and priorities in this very extensive field. That would require a major position paper in its own right. Instead, it aims to highlight some of the key research gaps and make some recommendations for future marine ecosystems research in a European context.

The text of this chapter was largely developed by a working group convened under the auspices of the EU FP7 EuroMarine project. EuroMarine has also published its own "EuroMarine Research Strategy Report" (Boyen *et al.,* 2012), which contains the input of the same scientific working group. Hence, there is a strong coherence between this chapter and the EuroMarine report.

2.2 Key societal and policy challenges

To achieve a sustainable management and use of our seas and oceans is one of the great challenges of our time. Human use of the European marine environment by marine and maritime sectors is increasing and diversifying. This is resulting in patterns of human-induced changes in marine life which need to be understood and quantified. So too must we know more about the impact of these changes on the ecosystem, its structure (e.g. biodiversity) and function (e.g. food chains, biogeochemistry), its capacity to provide marine ecosystems goods and services (e.g. sequestration of carbon impacting the earth climate) and the social and economic consequences that then arise. The current and emerging pressures are multiple and interacting, including impacts from transport, renewable energy devices, exploitation of living and mineral resources (and noise associated with these and other activities), pollution discharges, together with environmental changes (including climate change). These pressures result in further changes in marine ecosystems including invasions, outbreaks and shifts in species distribution and productivity.

Anticipating the future consequences of these pressures and vectors of change in marine life and the development of adaptation and mitigation measures (such as the introduction of new technologies and structures, new ballast water practices, ocean and off-shore wind, wave and tidal energy devices and new fishing strategies) is a grand challenge in itself, but also one which can help us to address other grand challenges including climate change, food and energy security and human health.

At EU level, the policy landscape for marine and maritime affairs has advanced markedly since publication of the previous Navigating the Future (III) position paper in 2006. Adopted in 2007, the EU Integrated Maritime Policy (IMP)[12] aims to provide answers as to how decision making and the conciliation of competing interests in marine and coastal areas can reverse environmental degradation and at the same time support the development of sustainable maritime economy (as prioritized in the EU Blue Growth agenda[13]). In addition, the EU Marine Strategy Framework Directive (MFSD)[14] , the environmental pillar of the IMP, requires the development of regional conservation and management plans by defining long-term targets and measures to achieve and maintain good environmental status (GES) of European marine waters.

On 30 May 2013, the EU Council of Ministers and Parliament reached a landmark agreement paving the way for a new Common Fisheries Policy (CFP) set to come into effect on 01 January 2014. The overarching aim of the reformed policy is to end overfishing and make fishing sustainable through implementation of an ecosystem based approach to management. Regional EU strategies such as the recent EU Maritime Strategy for the Atlantic Region[15], recognize that the EU's marine waters are made up of, or adjoin, several different sea basin areas and maritime regions, each with its own unique set of natural features, environmental and human pressures, governance frameworks and cultural characteristics. The EU and member states must also support and adhere to international agreements and conventions including the Convention on Biodiversity (CBD) and the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) as it takes shape in the coming years. At the heart of successful implementation of all of the above (and many more) conventions, policies and legislative instruments will be the requirement for sound scientific advice.

This places an onus on policy makers to be more proactive in seeking and utilizing scientific input in their decision making, and on scientists to be more proactive in engaging with policy makers and seeking to transfer scientific knowledge to meet societal needs. A particular challenge will be to develop a more systematic approach to synthesizing knowledge from many different disciplines and experts into integrated advice for policy makers. Developing more effective mechanisms to communicate risk and uncertainty will also be crucial.

[12] An integrated maritime policy for the European Union; http://ec.europa.eu/maritimeaffairs/policy

[13] COM(2012) 494. Blue Growth: Opportunities for marine and maritime sustainable growth

[14] Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive, MSFD)

[15] COM(2013) 279. Action Plan for a Maritime Strategy in the Atlantic Area

Ultimately, the unstructured and *ad hoc* mechanisms that currently constitute the marine science policy interface in Europe will need to be replaced by a more effective, stable but flexible structures, specifically designed to improve the transfer of scientific advice to policy and decision makers (see chapter 13 on effective science policy interfaces).

The diversity of organisms in marine habitats provides a range of ecosystem services and benefits of significant value to European society. The benefits include food (fish, shellfish); reduction of climate stress (carbon and other biogas regulation); living and genetic resources (for fisheries, aquaculture and blue biotechnology); coastal protection; waste detoxification and removal, disease and pest control; tourism, leisure and recreation opportunities; a focus for engagement with the natural environment; physical and mental health benefits; and cultural heritage and learning experiences. Energy from waves and tides and biofuels from macro- and microalgae are likely to become mainstream in the near future. Many of the benefits are accrued directly by coastal dwellers and visitors, but also indirectly by people living in all parts of Europe.

More than any other section of society, the scientific community is aware of the environmental limits of our natural environment to continue to supply humans with goods and services which we generally take for granted and largely fail to protect. These goods and services have a significant value to human society, or put another way, their removal would come at immense cost and likely result in significant human suffering.

The seminal paper by Costanza *et al.* (1997) indicated to marine scientists that the importance of marine ecosystems could be expressed in terms of monetary value and that habitats within marine ecosystems were among the most valuable globally. Since then efforts were made in MarBEF and other EU and national projects to understand in more detail the variety of ecosystem services provided by marine ecosystems, their monetary value as well as their wider social and health values for which monetary valuation is not always appropriate. Efforts have also been made to introduce these value measurements into decision support tools and other measures to support management and policy making. Evidence is growing that human induced changes in biodiversity and ecosystem functioning can, in turn, impact strongly on services and direct economic benefits to society, such as productive fisheries, aquaculture and tourism (Worm *et al.,* 2006 and Beaumont *et al.,* 2007). An agreed a framework which can be used to take account of environmental goods and services via their monetary and non-monetary value in decision making is urgently needed and will require a collaboration between scientists and policy makers, who will be the end users.

Credit: F. Boero

The Polychaeta or polychaetes (often called bristle worms) are a class of (mostly marine) annelid worms with more than 10,000 known species. Polychaetes are characterized by fleshy protrusions on each body segment that bear many bristles which are made of chitin. Polychaetes are widespread and occur throughout the Earth's oceans at all depths

2.3 Research priorities and recommendations

Credit: ImagDOP/ Jorge Fontes

Credit: Marisa Silva, CIIMAR

The following list of high-level recommendations highlights some of the key priorities for future marine scientific research targeted at promoting a better understanding of marine ecosystems. The list is not meant to be exhaustive. Moreover, none of these priorities represents a new approach, but rather an emphasis for more work and progress in answering questions which have been around for some time and which already form the focus of considerable scientific effort. Nonetheless, it is clear that the long-term societal and policy objective of a thriving but sustainable maritime economy in Europe will require a much greater understanding of marine ecosystems, their structure and functioning, the benefits they provide, their current state, their resilience to pressures, vectors of change, and mechanisms to assess and improve ecosystem health.

1. **Discover, describe and characterize marine biodiversity**
   In 2012 the Marine Board published a future science brief entitled, *Marine Biodiversity: A Science Roadmap for Europe* (Heip and McDonough, 2012)[16] . The paper examined the European contribution to recent progress in marine biodiversity research in a global context. It also identified future research needs and priorities for gaining a more complete knowledge of marine biodiversity, how it is changing in space and time, and the role it plays in ecosystem function and the provision of benefits to humans. The roadmap provided 10 research priorities and 6 strategic recommendations to guide future marine biodiversity research in Europe. It is not intended to repeat here all of those recommendations which can be found in the previous report; the reader is asked to consult this report for full detail. However, in the context of this chapter it is useful to highlight a small subset of these recommendations:

   - Improve the baseline knowledge of marine biodiversity in European marine environments from genes to ecosystems and at all relevant temporal and spatial scales.
   - Stimulate the production of new or updated electronic monographs on all European taxa and of updated and cross-boundary regional field guides to European fauna and flora.
   - Create a better understanding of the factors which generate, maintain and deplete biodiversity in marine environments.

   While we have made major progress in marine biodiversity research in recent years, there is still much work to do to in characterizing marine biodiversity in European waters, much of which may be considered of an unglamorous or somewhat old-fashioned nature, not necessarily requiring the latest laboratory techniques or field technologies. The Future Science Brief placed particular emphasis on worrying decline in taxonomy expertise in Europe and the dangerous widening of the gap between traditional and molecular approaches to taxonomy, rather than the necessary closer alignment of these approaches. Among its strategic recommendations, the paper stressed that future European training in marine science needs to take account of this by developing a new cohort of experts in classical taxonomy and in tandem with this, a much greater coordination in the use of phenotypic (based on observable physical characteristics of organisms) and genotypic (based on genetic or molecular characteristics of organisms) taxonomic approaches. Further discussion on education and training in marine science can be found in Chapter 13.

[16] www.marineboard.eu/images/publications/Marine%20Biodiversity-122.pdf

2. **Characterize and understand human benefits derived from the seas and oceans (marine ecosystem goods and services) and the human and natural pressures which threaten them**

   It is already evident that global change (climate, ocean pH, hypoxia, sea-level rise) is occurring and impacting upon marine biodiversity. What is less clear is how these pressures currently impact directly or indirectly on marine ecosystem functioning and delivery of marine ecosystem services or how they will do so in the future. In this framework, it is important to understand the sources of impact. In many cases, it is probable that ecosystems are subjected to multiple pressures which act in synergy. The identification of single pressures, and of their effects, is not sufficient to account for possible cumulative effects.

   It is clear that some parts of the ecosystem are systemically important in governing its resilience and functioning. The species, habitats and functions that are critical to maintain and enhance the delivery of marine ecosystem services need to be identified, particularly in sub-tidal zones.

   Capability needs to be developed to quantify and model the key features important for delivering ecosystem services; to quantify changes in ecosystem services and the consequent changes in ecosystem values (monetary, societal and health); and to understand the causes of these changes including impacts of environmental change and human activity. This will help to define and prioritise management mechanisms and policy strategies for their protection and restoration.

   Building on our growing understanding of the spatial and temporal scales of marine biodiversity variability, information is needed on the spatial and temporal scales at which marine ecosystem processes that underlie ecosystem services currently occur, how these relate to the scales at which services are delivered, and what the linkages are between them. The same marine ecosystem services tend to be delivered by different habitat types (e.g. sediment, rock or pelagic) regardless of where they are (i.e. intertidal, coastal shelf, transitional waters, deep-sea). The organisms and their biological activity and functions differ between these habitats and locations, but most marine environments deliver most marine ecosystem services. The amount of service, and hence the benefit derived, will vary according to the habitat/location in question. Thus a key goal for quantifying ecosystem service delivery, is to provide ecosystem service and benefit data at the disaggregated level of marine habitat/location type.

   What has been done on land with Natura 2000 is still to be done in the marine realm, and marine habitats are still to be mapped with the same accuracy as those on land. Furthermore, the concept of habitat is almost invariably restricted to the sea bottom, embracing mainly the benthic domain. The water column is the most widespread habitat of the planet and is entirely heterogeneous, especially in coastal habitats. The presence of gyres, eddies, fronts, temporary currents etc. defines specific conditions that are conducive to different expressions of ecosystem functioning.

This aspect is partly covered by the definition of fishing grounds, but needs to be fully integrated into the definition of habitats, also in the light of the creation of networks of Marine Protected Areas, which is the focus of the EU FP7 project, CoCoNet[17].

Trade offs between ecosystem services

A complex diversity of ecological functions and processes underpin the provision of marine ecosystem services. For example, the different services of waste regulation, climate regulation and nutrient cycling are underpinned by very similar ecosystem functions and biological processes such as fixation and subsequent food web transfer of carbon and nutrients and bioturbation in sediments. These functions also underpin cultural services, such as leisure and recreation, which depend on clean, functioning seas that are rich in biodiversity.

There are trade-offs among different ecosystem services but the consequences of these are still not sufficiently elucidated to inform policy and marine management. For example, attractive seascapes, inshore fishing boats, and the local food they provide, enhance local tourism and cultural services. Yet fishing also affects other components of the ecosystem, damaging food webs and seabed habitats. Hence, the provisioning service of fishing can negatively affect delivery of other services. Seabirds and mammals are important for tourism and recreation, but compete with humans for fish as food or are trapped in fishing nets, indicating trade-offs between food provision, cultural services and conservation.

Furthermore we need to develop function-value relationships between marine ecosystem services, the benefits they generate and their values so that we can understand how changes in marine ecosystem processes and functions will affect the social and economic values of those ecosystems. Economic and social data on impacts of ecosystem change on significant markets such as fisheries, aquaculture and tourism is very limited. There are even fewer non-market valuation studies and the importance of marine ecosystems in providing human health benefits is barely explored (see Chapter 6). In order to determine the socio-economic impacts and trade-offs, a much greater integration between economists, natural and social scientists will be required.

3. **Investigate how species and populations adapt to changing marine environments**

Understanding how marine organisms adapt to environmental changes over spatial and temporal scales relevant to current processes of global change is of primary importance. Facing environmental changes, living organisms can escape, acclimate through phenotypic changes, or adapt to the new conditions. Experiments on short-generation organisms (e.g. microorganisms) and empirical studies using genomic approaches shows that evolutionary changes can occur on relatively short time-scales, a phenomenon called 'contemporary evolution'. Documenting evolutionary processes is challenging because of the interplay between environment and genetic variations in shaping the evolutionary trajectories.

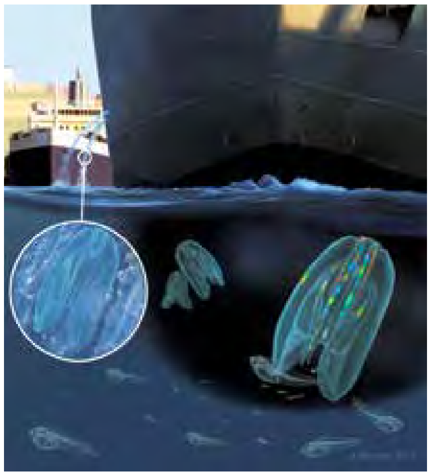
[17] www.coconet-fp7.eu

The genetic, epigenetic, physiological and demographic mechanisms by which native or introduced marine species may adapt (hybridization, selection for an increased plasticity, demographic disequilibrium) need to be documented.

Next-generation sequencing technologies can help to address these issues on ecologically-relevant models (e.g. species that are either endangered, exploited, engineered or introduced). Experimental studies combining selection, crossing design, omics toolkits and theoretical models implementing particular marine species traits and characteristics (e.g. complex life cycles, role of oceanic currents) are necessary to provide important insights about adaptation processes in the wild. Examples of particular questions to be addressed include:

- What is the extent and rate of the potential for evolutionary change in natural populations?
- How might the evolution of species traits impact on environment and biodiversity changes?
- What are the mechanisms by which species adapt to environmental changes (e.g. new mutants or selection on pre-existing variation) or diversify (e.g. 'magic' genes)?
- To what extent are ecotypic variations adaptive?

In will be important to quantify critical evolutionary parameters (e.g. effective size), to better understand the diversification drivers in the sea (e.g. cryptic species, effects of secondary contact; hybridization processes) and to investigate intra-specific variation of major life-history traits (e.g. pelagic larval duration, reproductive success) in monitoring programmes and ecology research. An exclusively genetic, or omics approach to understanding these phenomena will be insufficient. These approaches must be combined with a deep understanding of the natural history of the organisms in question.



Credit: A. Gennari

The dumping of ballast water from ships is one of the primary causes for the transfer of non-indigenous marine species. This problem is being tackled with a combination of technology and regulation

4. Define the controls and limits of ecosystem resilience, including predictive capacities and regime shifts and adaptation in the context of global change

There is a small but growing body of empirically derived theory concerning the nature of marine biodiversity-ecosystem functioning relationships. The role of biodiversity in providing resilience in the provision of ecosystem services needs further elucidation; i.e. the extent to which marine biodiversity facilitates resistance to change in the delivery of marine ecosystem services, as well as the ability of marine biodiversity to recover and restore delivery of services. There may be a uniform relationship between biodiversity and the provision of marine ecosystem services or there may be crucial non-linearities ('tipping points') at which delivery is no longer possible. These relationships need to be defined. Much of the research in this area has relied upon experiments with simplified species assemblages from estuarine and intertidal habitats. This approach must now progress to analysis in natural conditions and across a wide variety of marine habitats, particularly non-coastal and sub-tidal.

To support policy and management, we also need to develop a predictive capacity to anticipate the impacts of human activity on the provision of marine ecosystem services and benefits.

Models of marine systems exist but they need to better incorporate biodiversity and ecosystem services, and they need to be made operational. Bio-economic modelling is needed to support policy implementation.

The timing and magnitude of a perturbation (natural or human disturbance) may push communities towards a new alternate stable state, resulting in a divergent succession pattern that once established, can persist indefinitely over more than one generation. In the context of global change and overfishing, it is pivotal to understand the role of rare species and that of positive interactions among species. Interactions (especially those that are positive) may contribute to overcome the loss of ecosystem functions.

5. **Develop a functional and dynamic definition of ecosystem health which conforms to scientific understanding and principles and is usable in a policy context (via the EU Marine strategy Framework Directive)**

A healthy ecosystem was defined by Costanza and Magean (1999) as one that is in good condition and is functioning well, or one that has the ability to maintain its structure (organization) and function (vigor) over time in the face of external stress (resilience).

The measure of ecosystem health to which all Member States of the European Union are bound through the Marine Strategy Framework Directive is termed "Good Environmental Status" (GES) to be achieved in all European marine waters by 2020. In the Council Directive, GES is defined as:

"the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for uses and activities by current and future generations",

The FP6 marine Networks of Excellence, and particularly MarBEF, offered a new framework under which ecosystem health should be re-defined in order to be more efficient for both scientific and managerial applications: Biodiversity and ecosystem functioning (BEF) (Heip *et al.,* 2009). This new definition takes into account explicitly the intra-specific components of biodiversity (i.e. individual variation at phenotypic and genome levels) which affects species interactions, population dynamics and community trajectories. Species traits and their functional attributes as parts of or elements which can affect the ecosystem processes (e.g. biogeochemical cycles), and uncertainty, must be seen as integral parts of the ecosystem dynamics and its evolution under the BEF framework. The development of new methodologies and metrics (indicators) for the efficient and accurate measurement of ecosystem health has become an urgent need for the effective implementation of the EU Directives and policies (e.g. Marine Strategy Framework Directive, Marine and Maritime Policy). However, the relationship between biodiversity and ecosystem functioning is still far solved and requires further investigation by the scientific community (Boero and Bonsdorff, 2007).

2.4 Tools and infrastructures for marine ecosystem science

2.4.1 Omics

The omics technologies have revolutionized biological science and have opened up hitherto unimagined opportunities in all research fields. Research on the ecosystem impacts of global change demands an increased understanding of genetic and molecular mechanisms behind eco-physiological changes and evolutionary adaptations of organisms. In marine ecology, while 'standard' molecular and genetic approaches are well known, the newer technologies are taking longer to make an impact. However, the emergence of the use of omics allows scientists to answer fundamental marine ecology questions that are highly relevant in the light of environmental changes, such as:

- What is the relationship between community structure and ecological function in marine ecosystems?
- How can a species and the phylogenetic relationship between taxa be identified?
- What are the factors responsible for the limits of the ecological niche?
- What explains the variations in life-history patterns among species?

This research is hampered by the restricted availability of experimentally amenable genetic model organisms. Current model species do not well represent natural ecosystems. The biology of these species in nature is poorly mapped and they have been adapted to lab conditions over many generations. Typically, most have small genome sizes, extremely short generation times, and are easily handled in the lab environments. New model species with high ecological relevance (e.g. representing key functions in the ecosystem) are urgently needed. Tools needed to support advanced research in evolution, ecology, biotechnology and medicine include permanent cultures of ecotypes and inbred lines, full genome sequence information, genetic tools for functional genomics, pipelines for phenotypic characterization, and a database providing access to relevant genetic and ecological data. Omics approaches on their own cannot account for the complexity of ecological processes, and cannot replace the knowledge of natural history aspects of the structure and function of marine ecosystems. Thus omics must be employed in harmony with more traditional ecological approaches to maximize the potential for holistic understanding of biodiversity and ecosystem functioning.

Credit: François Schmitt CNRS

2.4.2 New modelling approaches, capabilities and tools

The increasing demand for understanding and predictions of ecosystem response to anthropogenic pressures and climate change highlights the need to develop and improve descriptive and predictive capabilities of a hierarchy of ecological models up to the full development and use of a suite of integrated, next generation end-to-end models. This includes:

- Development of biogeochemical models and coupled biogeochemical transport models able to better describe observed system dynamics;
- Full development of integrated end-to-end models, accounting also for bio-ecological aspects, along with biogeochemical ones;
- Models that integrate across social, economic, environmental and ecosystem dimensions and quantify interaction and trade-offs among ecosystem services;
- Models able to consider a broader range of ecosystem services, including cultural services, and possibly social and economic adaptation; and
- Models addressing multiple scales, from global patterns down to regional and local scale and from short term up to long time horizons of 50 to 100 years, and more.

In addition, it is necessary to develop:

- Methods to account for organism acclimation and adaptation and for the occurrence of changes in ecosystem structures;
- Methods to combine outputs from different models and to merge model output and ecological observation;
- Methods to study and understand the role of positive species interactions; and
- Methodologies and indexes for summarize ecosystem status and functioning.

Efforts to assess and possibly reduce model uncertainties will also be required.

Credit: Leibniz Center for Tropical Marine Ecology/E. Borell

Marine ecosystems are highly non-linear and, especially during a global change period as the present one, changing conditions are conducive to regime shifts that are often labelled as inherently unpredictable (Hastings and Wysham, 2010). Models, in this framework, are more useful to assemble evidence in a coherent way, enhancing understanding of past events (history) and to depict possible future scenarios, based on the identification of possible indicators of regime shifts and tipping points. The challenge for modelling is great, and it is crucial not to fall into the trap of oversimplification of the systems which are the focus of modelling efforts. Field and modeling approaches must proceed hand in hand.

2.4.3 Advanced methods and systems for marine ecosystem observation

Marine ecosystems are largely invisible to observation techniques relying on electro-magnetic radiation (light), including the human eye and remote sensors on board planes and satellites. Despite this limitation, satellites have become indispensable tools for quasi-synoptic observations of the ocean and serve as the reference frame for most other observations. Other remote sensing instruments are used on board planes, balloons and even kites and drones for observations on smaller spatial scales. Instruments relying on light, such as video and still cameras, can also be lowered from ships or other platforms (traps, landers, AOV's, ROV's) but only cover very limited areas or volumes as light is rapidly absorbed in water. Many observation tools in the deeper water layers therefore rely on sound and the capabilities and applications of sonar technologies have advanced markedly over the past decade (see Chapter 11). Multibeam and side-scan sonar have become indispensable tools for mapping the sea floor, and increasingly allow detection and mapping of benthic communities that form hard structures.

Credit: ESA

The EnviSat satellite has been used to monitor events such as marine phytoplankton blooms and sand dust.

Many different platforms and sensors are used for the observation of physical, chemical and biological properties of marine waters and sediments which form a major part of ocean observation. Platforms can be either fixed such as buoys or (oil) rigs, or moving such as research vessels and ships of opportunity, Remotely Operated Vehicles (tethered to an operator) and Autonomous Underwater Vehicles (unconnected), landers, gliders and floats. Biologging, the observation of animal movement and environmental conditions by attaching a sensor in a tag implanted in the body of a marine animal, is also an area of growing interest and application.

Credit: R. Prien, IOW

IOW-MARNET station Drass Sill, located in the Baltic Sea

One restriction of many measurement platforms is that the sensors they carry are restricted to physical and chemical parameters, mainly pressure, temperature and salinity, thus providing only limited information relevant to ecosystem health. Europe has only a limited number of ROV's available for research in deeper water which are capable of sampling or observing biological components. Information on these biological components of marine ecosystems is still mainly gathered by traditional technology, plankton nets, dredges, grabs, trawling and so on, but the use of ROVs is increasing. The analysis of biological samples is therefore very time consuming and expensive, but still unavoidable as alternative methods are still in the experimental stage. These include the *in situ* use of genomics (mostly a concept still), flow cytometry for viruses and small cells, video and image analysis for zooplankton and benthos, and sonar for fish and larger vertebrates.

Because of the many different methods and applications, the challenges to develop a comprehensive yet affordable observatory system are enormous. The use of these very different tools as well as the linking of information obtained from them is not part of systematic efforts, and with the exception of the Argo floats, there are no in situ sensor systems that have global coverage and can therefore supplement satellite observation at the global scale. Nonetheless, regional and even local observations can be very important to monitor and explain smaller scale phenomena. A good example is the Continuous Plankton Recorder operated by SAFHOS that has given extremely useful information on the changes of distribution of plankton in the eastern Atlantic and more recently in other areas of the world. But a Europe-wide strategy for ocean observation, although begin discussed for over twenty years, is not yet fully defined let alone implemented. There has been major progress with the developments such as the Marine Knowledge 2020[18] initiative (which includes the EMODNET) and the work of the EC Expert Group on Marine Research Infrastructures[19]. The 2010 Ostend Declaration[20] called for the development of a truly integrated and sustainably funded European Ocean Observing System (EOOS) to re-establish Europe's global leading role in marine science and technology, to respond to societal needs by supporting major policy initiatives such as the Integrated Maritime Policy and the Marine Strategy Framework Directive and to support European contributions to global observing systems. If we are to gain a comprehensive understanding and knowledge of marine ecosystems, and support long-term efforts towards sustainable management of European marine waters, a fully integrated EOOS is an imperative. The marine science community must continue to work with the EC and Members States, and now also with commercial interests, to make the EOOS a reality.

Chapter 11 provides a detailed analysis and recommendations on development of an integrated ocean observing systems for Europe.

[18] http://ec.europa.eu/maritimeaffairs/policy/marine_knowledge_2020

[19] https://webgate.ec.europa.eu/maritimeforum/system/files/

[20] www.eurocean2010.eu/declaration

BOX 2A. The future of European marine stations

Marine Stations were conceived in Europe as large research infrastructures located in direct proximity to the systems they were designed to study. Research in marine stations has largely focused on:

- Biodiversity inventories;
- Experimental laboratory work on model animals collected near the station;
- Evaluations of the state of the environment, often including collection of long-term time-series data;
- Capacity building with summer courses; and
- Experimental field work on nearby ecosystems, with or without manipulations.

Marine stations combine a narrow spatial coverage with a long-term perspective and are of crucial importance for marine biology and ecology in shallow coastal environments. In recent years, the viability of many marine stations in Europe has been subject to scrutiny and some have been closed or are running the risk of being closed. Others are mutating into large research infrastructures that perform excellent science that is, however, not directly linked to the nearby environment. If the activities of marine stations are not directly linked to their local marine environment, then this often raises the questions the value of retaining them if they are performing research that might be carried out at more centrally located research facilities (e.g. on a main university campus).

It is becoming increasingly important to consider the strategic role of European Marine Stations. In particular, it is arguable that marine stations have a critical role to play as marine observatories, keeping our coastal waters under continuous check, especially in the context of rapid environmental change. A shift from monitoring (i.e. the routine measurement of the values of a predefined set of variables) to observation (i.e. an adaptive way to assess the conditions of the environment, coupling monitoring with a more open attitude to perceived change) must be emphasized. Marine stations are ideal infrastructures for observation systems (Wiltshire *et al.,* 2010).

Credit: M. Guichou, Station Biologique de Roscoff (CNRS/UPMC)

Credit: F. Boero

Credit: F. Boero

Marine Stations at Roscoff, France (top), Portaferry, Northern Ireland (bottom left), and Naples, Italy (bottom right)

3

Changing oceans in a changing Earth system

Credit: IFREMER

3.1 Introduction

The oceans are an integral part of the Earth system and are intimately linked to the atmosphere and geosphere. Oceans supply almost all of the water that falls on land and they store and transport heat from the sun. The surface ocean takes up about one third of all human-generated carbon from the atmosphere and ocean ecosystems in turn absorb and export carbon to the deep ocean. The structure and health of this biological pump is a critical component of the carbon cycle and plays an important role in the regulation of global climate and in mitigating long-term climate change. Unravelling the links and feedbacks between the different components of the Earth's system, both in the past and in the present, is therefore not only scientifically challenging; it is also essential to understand the future of our planet.

It is now commonly accepted that human-induced climate change poses one of the main challenges faced by society in the coming decades. Global warming and high CO_2 levels are driving changes in, for example, sea-level, patterns of air temperature, precipitation and extreme weather events. In addition, changes in sea temperatures, ocean circulation and ocean chemistry (e.g. acidification) are expected to affect the species composition in the open ocean and, in turn, the removal of atmospheric CO_2 by the ocean, with unknown consequences. The impacts of climate change and ocean acidification may also affect commercial fishing as a result of changes in the size and distribution of fish stocks.

Although large climate changes occurred during the geological past and even the last century was characterized by climate fluctuations, the present *rates* of change are, in terms of geological time-scales, unprecedented. Moreover, there is no certainty regarding the precise nature and rate of future climate change. However, even the more moderate of the predicted scenarios is expected to result in major changes in the marine environment, with potentially enormous environmental, economic and social consequences.

Fundamental marine scientific research has significantly contributed to an improved understanding of the underlying processes, and analyses of current and future potential impacts of climate change on the marine environment. But science is still a long way from being able to predict future changes accurately; this is a necessity for reducing uncertainty and facilitating the planning of appropriate adaptation and mitigation responses to expected changes. Research is also critical to unlock some of the potential opportunities and benefits which may be presented by changes in the marine environment. This chapter takes a look at some of the major known climate change trends and impacts on the marine environment, the associated scientific questions and potential societal implications. It concludes with a list of high-level research priorities, presented according to the categories of change identified (e.g. sea-level rise, melting Arctic ice, etc.). The chapter and its recommendations build upon the work of the EU FP7 CLAMER[1] project and, in particular, the Marine Board Special Report (Heip *et al.*, 2011).

[1] www.clamer.eu

3.2 Major climate change trends and impacts on the marine environment

The marine climate change research agenda is driven by clear trends in observed environmental change in the seas and oceans. The following is a synopsis of some of the key trends, cumulative impacts and particular areas of concern, which provides the context for the future research priorities detailed later in this chapter.

3.2.1 Physical properties and motions of the seas

Sea-level rise

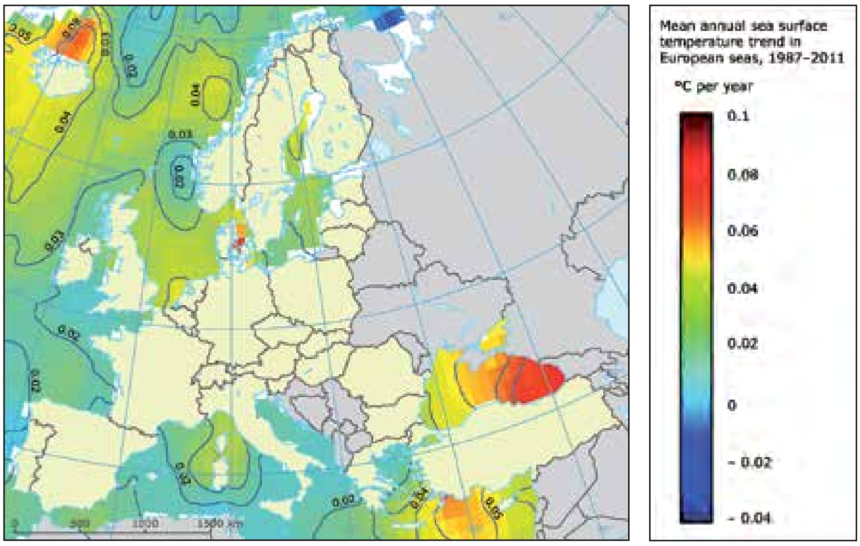
Sea-level rise is one of the most direct manifestations of the warming climate. The addition of mass from melting land ice (e.g. Greenland ice sheets) coupled with the addition of heat to the seas - which increases seawater volume - are the main causes of the observed global rise in mean sea level. For the past century, global estimates for annual sea-level rise were around 1.7±0.3mm y^{-1} (Church and White, 2006). Since the early 1990s, high precision satellite altimetry has recorded a global sea-level rise of 3.3 ± 0.4 mm y^{-1} which suggests that sea-level rise is accelerating (Ablain *et al.*, 2009). Observed sea-level trends show strongly differing regional spatial patterns, most probably owing to local circumstances in the gravity field, non-uniform ocean warming, the vertical movement of land masses and/or prevailing winds. On average, sea levels are predicted to increase but there is much uncertainty about the role of mass addition resulting from melting icesheets and glaciers. Present estimates for 2100 (excluding non-linear ice-sheet breaking processes) range between 300mm and 1,800mm (Rahmstorf, 2007; Vermeersen *et al.*, 2009; Grinsted *et al.*, 2009). If the major ice sheets on Greenland and the West-Antarctic do collapse, then it is conceivable that by the end of this century, the rise in sea level could locally be in the order of 10m, depending on regional circumstances and distance from the melting ice-sheets.

Credit: ESA

Traditionally, sea levels have been measured by tide gauges. Since the early '90s, sea levels are also measured and recorded using altimeters on satellites, such as EnviSat

Sea Surface Temperature (SST)

In the period from 1986 to 2006, the increases in Sea Surface Temperature (SST) in European waters, including the Atlantic Ocean, were three to six times higher than those of the global sea surface temperature (Coppini *et al*., 2010). Notably, enclosed seas such as the North Sea, the Mediterranean Sea and the Baltic Sea have, during this period, provided a preview of conditions of future global warming. Scenario simulations suggest that by the end of the 21st century, the temperature of sea basins such as the Baltic Sea and the North Sea could increase by between 1.5˚C and 5˚C. Changes in seawater temperatures in European Seas have also shown complex spatio-temporal patterns, such as differences between winter and summer trends in SST at various latitudes, the occurrence of warming in sub surface layers, and the interruption of warming trends by cool periods.



Credit: Instituto Nazionale de Geofisica e Vulcanologia (INGV)

Credit: IFREMER

↑ Coral is sensitive to seawater temperature

← Spatial distribution of sea surface temperature trend over the past 25 years (1987-2011) for the European seas as calculated from the HADISST1 dataset

The Thermohaline Circulation (THC)

The sinking of cold dense water in the northern North Atlantic is a major component of the so-called Thermohaline Circulation (THC), that part of the large-scale ocean circulation which is driven by global density gradients. Changes in water temperatures and salinity gradients due to global warming and supply of meltwater may result in a reduction of the THC. This would influence the Atlantic Meridional Overturning Circulation (AMOC) and the associated northward heat transport in the North Atlantic. In general, on short time scales, a reduction of the THC is not expected to stop the global ocean temperature and sea-level increases, but locally some areas such as the western margin of Europe, could experience reduced warming.

Stratification

Most seas and oceans are characterized by a vertical gradient in water density corresponding to gradients in temperature and salinity, often in the upper 50m to 100m of the water column. The stronger the degree of this stratification, the more difficult it is for deep and surface waters to mix.

The degree of stratification is expected to increase globally as the result of enhanced warming of the sea surface, to increase locally at high latitudes as the result of melting sea ice, and to change locally as the result of changes in precipitation patterns. Crucially, in open waters, increased stratification could reduce the upward supply of nutrients and trace elements from the sea bottom to the euphotic zone near the surface, with consequences for primary production there. Changes in the stratification patterns, for example, may have been responsible for recent mass mortalities of marine organisms in the Mediterranean.

3.2.2 Melting Arctic sea ice

The record low Arctic sea ice extent which was measured on 16 September 2012 represents the lowest level of Arctic summer sea ice cover since instrumental records began (Haugan, 2013). In addition, the average thickness of the sea-ice at the end of the melting season has decreased by more than half during the past 40 years (Kwok and Rothrock, 2009).

The shrinking of the Arctic sea ice affects Arctic marine life with consequences for the biodiversity and functioning of the Arctic ecosystem. The reduction of the ice is expected to reduce the growth and condition of ice-bound, ice-associated and ice-borne organisms (Wassmann *et al.,* 2011). Model experiments indicate that primary production could triple in a warming Arctic Ocean (Slagstad *et al.,* 2011). The warming of the Arctic waters has also been accompanied by an increasing advance of relatively species-rich Atlantic waters to high latitudes by way of the prevailing North Atlantic current. The subsequent increase in the number of trophic levels in the Arctic food web has resulted in an increase in biodiversity and a decrease in the food availability for top predators such as seabirds, seals and whales. Because the Arctic ice is expected to reduce further during the next 100 years, increasing incidences of trans-Arctic migrations of marine plants and animals are also expected.


Credit: IOPAN

3.2.3 Movements of marine taxa to higher latitudes

Global warming is expected to drive many marine species towards the poles, a phenomenon that has been shown to occur under similar warming conditions approximately two million years ago (Fields *et al.*, 1993). Burrows *et al.* (2011) have shown that northern hemisphere marine species need to move on average 37km northwards each decade to remain at the same mean water temperature. This is borne out by multiple observations of northward movements of marine taxa coinciding with recent warming. At high latitudes, for example, fish such as cod, haddock and herring have expanded northward and eastward, blue whiting has extended northward as far as the south-western Barents Sea, and blue mussels (*Mytilus edulis*) have appeared in Svalbard after a 1000 year absence. Further south in the Mediterranean, species richness is increasing mainly as the result of introduction and colonization of species with a (sub)tropical affinity, favoured by climate warming (Zeneto, 2008 and 2010). Because not all species have migrated at the same speed and direction, species movements generally result in local changes in community composition and species richness.

Bioclimatic models of the ranges of marine organisms in 2050 suggest further poleward shifts because of climate change. Projected shifts for pelagic species are foreseen to be more rapid than demersal species. Rates of shift can be more than double in a high-range climate change scenario compared to a low-range scenario, suggesting that limiting greenhouse gas emissions will allow more time for species to adapt to the new circumstances.

3.2.4 Shifts in timing of critical biotic life cycles

Global warming has affected the timing of life-cycle events of many marine organisms. Areas such as the North Sea have seen particular change with spring temperatures arriving 5-10 days earlier each decade. In the North Sea, meroplankton has advanced its appearance by 27 days, dinoflagellates and diatoms peak 23 days earlier and copepods about 10 days earlier than 45 years ago (Edwards and Richardson, 2004). In another example, warming of the Black Sea has resulted in a shift from seasonal immigration for spawning and feeding to overwintering of two fish species, the dorado (*Sparatus aurata*) and the salema (*Sarpa salpa*).

If the phenology (the seasonal patterns of biological life-cycle stages) of organisms in one trophic level is more or less sensitive to temperature changes than for the organisms at the next trophic level, climate change may lead to a decoupling of trophic interactions. In a classic example affecting a commercial species, the warming of the North Sea has affected cod recruitment via changes at the base of the food web. The copepods upon which the juvenile cod prey, have reduced in abundance but are also developing at different times in the season than previously, leaving the cod with no access to their preferred prey size (Beaugrand *et al.*, 2003). Such climate-induced mismatches in trophic transfer has been observed between many taxa at different levels of the food web.

3.2.5 Other trends and multiple stressors

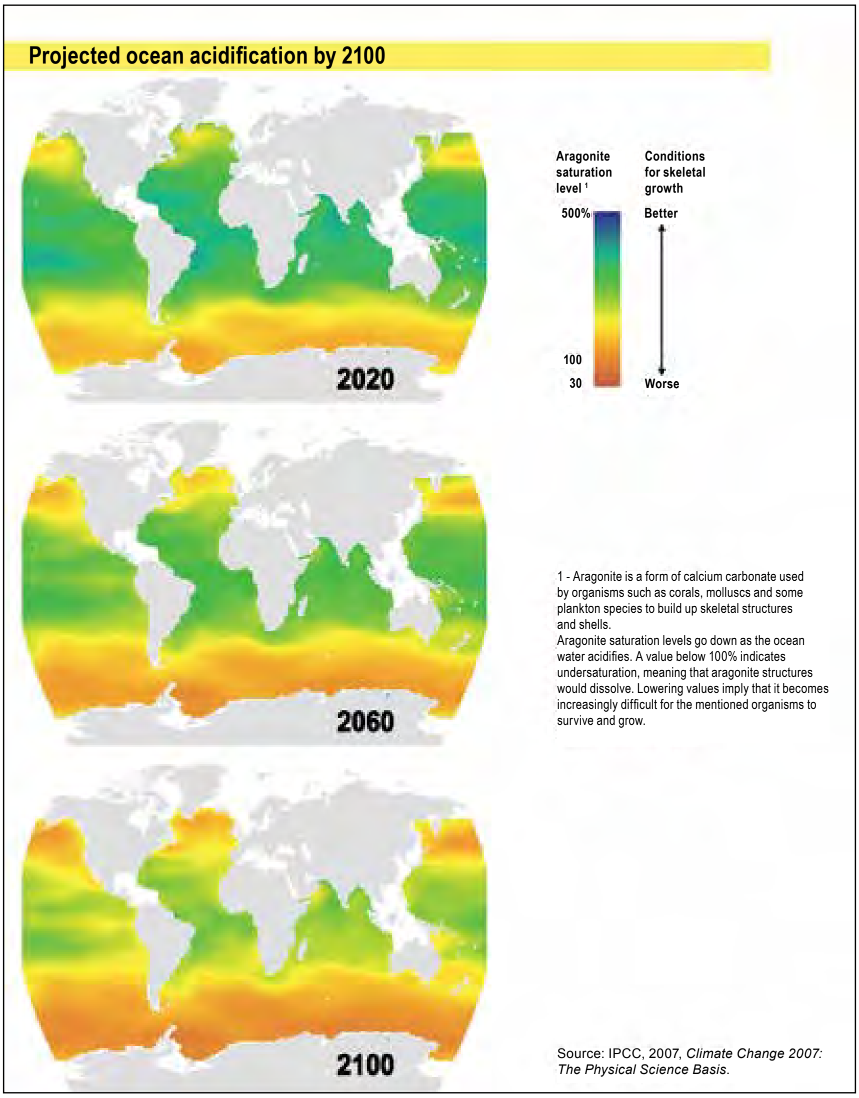
Humans impact upon natural systems in a multitude of ways, yet the cumulative effects of multiple stressors on ecological communities remain largely unknown. Multiple human impacts on marine systems are thought to be cumulative to the direct impacts of global warming.

Ocean acidification

Ocean acidification is caused by the same elevated CO_2 levels that are the primary factor in human-induced physical climate change and is being recognized as an integral part of climate change sometimes known as the “second CO_2 problem”. Since the beginning of industrialisation, the ocean has taken up approximately one third of the total anthropogenic CO_2 emitted to the atmosphere. As the result of the weak acidity of CO_2, the mean pH of the ocean surface waters is already 0.1 pH unit lower than it was in pre-industrial times, and expected to decrease by a further 0.4 units by 2100 (Caldeira and Wickett, 2003). This acidification of the ocean is likely to have profound consequences for marine biota, because it limits the capacity for marine organisms to synthesize skeletal materials and enhances photosynthesis in some phytoplankton species.

Credit: Karen Rappé

↑ Ocean acidification hampers the early development of sea urchins.



Credit: European Environmental Agency (EEA)

→ The maps show projected ocean acidification and related impacts on corals by 2020, 2060 and 2100: from better (blue) to worse (orange) conditions for coral skeletal growth.

De-oxygenation

The open ocean is losing oxygen as a result of a decrease in oxygen solubility, increased stratification, weakened ventilation and an increase in biological respiration. This de-oxygenation affects marine organisms if seawater oxygen levels drop below species-specific thresholds. Climate simulations over the next few centuries predict an overall decline in oxygen concentrations and an expansion of the mid-depth oxygen minimum zones (Keeling *et al.*, 2010). The combination of sustained coastal hypoxia, caused by eutrophication, and climate change could enlarge the 'dead zones' in coastal seas which are characterized by the absence of benthic fauna and fish.

Coastal eutrophication

Coastal eutrophication has also become a widespread phenomenon during the past decades. Nutrient-enrichment of coastal seas, which is the primary cause of increased eutrophication, generally results in an increase of primary production, which may counteract the impacts of acidification and enhance the impacts of de-oxygenation. Changes in primary production may further affect the biomass and species composition of estuarine communities and, in turn, fisheries yields.

Fisheries impacts

Marine fisheries have impacted on targeted and non-targeted fish and invertebrates by reducing their abundance, spawning potential and, possibly, population parameters such as growth and maturation. In the Northern Hemisphere, global landings have shifted from large piscivorous fishes to smaller invertebrates and planktivorous fishes during the past decades, indicating a shift in community structure at sea.

Non-indigenous species

Many seas in Europe have experienced the introduction and establishment of non-indigenous species as the result of migration, discharge of ballast water, and aquaculture. The impact of invasions on the functioning and resilience of ecosystems towards climate change depends on the abundance and the role of the new species within the existing communities. Some new-comers have had significant effects such as the North American comb jelly *Mnemiopsis leidyi* in the Black Sea.

↑ The Common Fishery Policy (CFP) reform aims to improve the sustainability European fisheries

Credit: Tom Ohman

←The non-indigenous colonial sea squirt (*Didemnum sp.*) fouling other organisms, including the commercially important blue mussel, *Mytilus edulis*, in the Irish Sea

Credit:GEOMAR

→The Comb jelly, *Mnemiopsis leidyi*

3.3 Connecting changing oceans to human wellbeing

The likely consequences of sustained global warming and rapid change in marine environments are expected to have major social and economic implications (Heip *et al.*, 2011). Achieving a more accurate estimation of economic and social costs will first require a major improvement in our understanding of fundamental processes and (cumulative) impacts in already changing environments. Mechanisms to achieve a proper valuation of marine ecosystem goods and services will also be vital to quantify social and economic impacts, a topic currently being addressed by a European Marine Board expert Working Group on Valuing Marine Ecosystems[1].

Credit:VLIZ

The BBC Radio Journalist, Quentin Cooper, talks about getting climate change research to chime with the public at EU FP7 CLAMER Conference.

Scientists have already provided compelling evidence that climate change and other anthropogenic pressures are leading to wide-ranging impacts on the marine environment; locally, regionally and globally. While this view is broadly accepted within the scientific community, impacts on the marine environment are not always well known or understood by the general public. To prepare society for the mitigation and adaptation measures which may be necessary, the awareness of citizens to science-based knowledge and advice in this specific area should be raised. However, to date, the communication of this knowledge beyond the scientific community has been largely inadequate and, as a result, the environmental impacts are not well known or understood by politicians, policy makers and the general public (see Box 3A for an example of a science policy advisory mechanism). The EU FP7 CLAMER project addressed this very specific issue and proposed practical mechanisms to close the gap between scientific knowledge and public awareness and understanding.

The effects of climate change in the marine and coastal environment will also create important potential for innovation and opportunities for industry. The EU Blue Growth strategy (EC COM 2012 (494) final) is designed to stimulate innovation, growth and expansion in key areas of Europe's maritime economy including maritime transport and ports, the seafood industry, marine tourism, high-technology marine knowledge-based products and services (including marine biotechnology), the development and expansion of marine renewable energy and new developments in mining for minerals and high-value metals. For Europe to sustainably expand its maritime sectors, more accuracy will be needed in future predictions of change and more clarity will be needed on the socio-economic challenges and opportunities associated with the likely future changes in European seas.

BOX 3A. The UK Marine Climate Change Impacts Partnership

A member state initiative to translate scientific knowledge to advice for policymakers and information for the public.

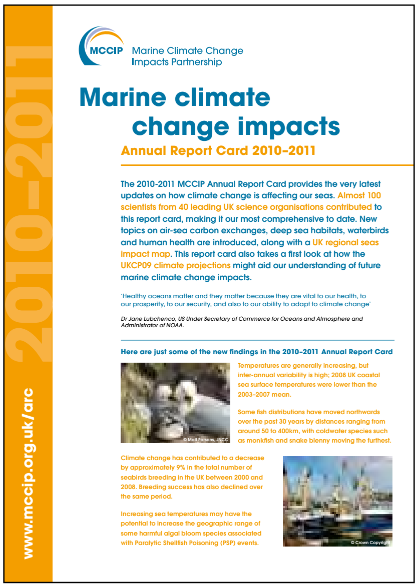
In the UK, the Marine Climate Change Impacts Partnership (MCCIP) plays a key role in translating scientific evidence for a wide audience. MCCIP produces annual report cards which provide up-to-date information on more than 30 marine climate change topics (air and sea temperature, sea-level rise, ocean acidification, etc.).

Short summary report cards provide simple headline statements on ‘what is already happening’ and ‘what could happen in the future’ for all 30 topics, along with confidence ratings. Over 100 scientists from across 40 institutes contribute on a voluntary basis to these reports with a further 30 scientists providing independent peer review.

An MCCIP working group, made up of scientists and decision makers, acts as the intermediary, translating complex scientific messages into clear English. While the report cards are primarily targeted at policy makers, they are also intended to be accessible to the wider public and have enjoyed high levels of media coverage, not only in the UK, but as far away as India, Australia and the United States.

For the scientists, the report card process provides a direct ‘pathway to impact’, with ministerial launch events and extensive media coverage. Feedback from the scientists also suggests that they particularly value the role the working group plays in acting as a “translator” of the evidence for a lay audience, a role they often feel ill-equipped to perform. Having a standardized reporting mechanism, providing very high level, unambiguous, ‘bulleted’ points in clear English would still appear to be the exception rather than the norm. The use of major scientific synthesis reports - which are often long and overly technical - still predominates. The MCCIP model has been adopted by other organizations both in the UK (a terrestrial version is now being produced) and further afield (e.g. Australia).

Further information at: www.mccip.org.uk



The Annual Report Card, produced by the UK Marine Climate Change Impacts Partnership (MCCIP), provides simple headline statements on ‘what is already happening’ and ‘what could happen in the future’ over 30 marine climate change topics.

3.4 Research priorities and recommendations

While there has been significant progress in the past 15 years in marine climate-related science, there remains a definitive need to fundamentally improve our understanding of the complex processes underlying climate change, and ultimately to more accurately predict future changes at the appropriate scales. Europe has a strong track record in climate change research and its expert community must be supported to take the next step in advancing our understanding of climate change, its likely impacts on the seas and oceans, and proposing solutions in terms our societal responses. Given Europe's extensive coastline and the importance of coastal maritime sectors, there is a particular need for further research in coastal zones, because they are the most productive and also the most sensitive parts of the seas.

The future research recommendations are presented in two categories. Against the major categories of marine environmental change described earlier in this chapter, the key research priorities are presented in summary form in Table 3.1 below. To complement this longer list, four high-level strategic recommendations are presented in the following section.

3.4.1 Strategic research recommendations

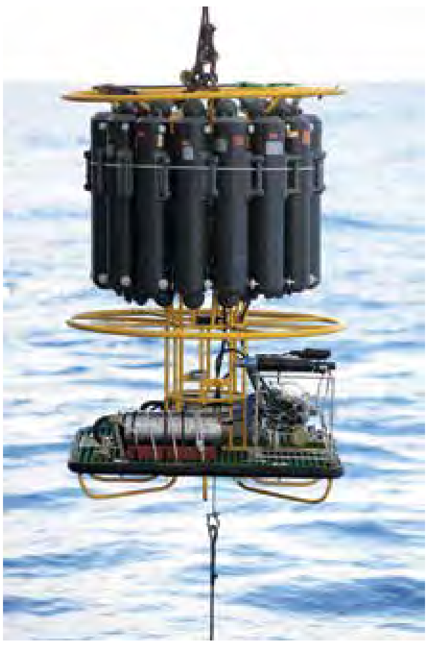
1. **Improved methods to reduce the uncertainty of climate change projections**
   It is of urgent importance to reduce uncertainties associated with:

   - the Antarctic and Greenland meltwater run-off;
   - the strength of the Atlantic Meridional Overturning Circulation; and
   - the efficiency of ocean carbon uptake including the biological pump.

   In addition to the enhancement of the resolution in ocean climate models, and the inclusion of processes important in coastal and shelf seas, there is a clear need for coupling of models which describe different processes (e.g., river basin models, ecosystem models) with the aim of testing interacting effects, the synergy between simultaneous changes, the role of multiple stressors, and possible feedbacks (Thieu *et al.*, 2010). Thus, future ocean modelling will need to integrate marine life and biogeochemistry and arrive at better predictions for CO_2 uptake in the ocean and the effects of future climate changes. It will also be important to improve the mechanistic understanding of possible responses of the hydrological, geological, chemical and ecological properties of the sea to climate change, for example, through paleostudies.

2. **Taking account of the full range of spatial and temporal scales**
   Attribution and projection of climate impacts require that the dominant processes across all spatial and temporal scales should be identified and considered. Currently, however, most studies only focus on a limited part of the full spatio-temporal range, i.e. are limited to a particular scale in space or time. Full cascading chains generally require the attention of all the main disciplines of marine research (e.g. meteorology, physical and paleo-oceanography, biogeochemistry, microbiology and ecology). To improve the accuracy of projections of the impacts of climate change on marine systems, pressures over the full spatio-temporal range should be associated to the interacting scales in time and space of socio-economic systems which govern the response of society. It is therefore recommended to dedicate a major effort, using a multi-discipli-

A CTD-rosette for seawater sampling at different water depths



Credit:IFREMER

nary approach, and considering the most appropriate range in spatio-temporal scales, to further understand, project and validate the hypotheses on the inevitable impacts of climate change on marine environments.

3. **Integrated, robust and efficient observing network**
   A further integration and improvement of oceanic, atmospheric, geochemical and biological observational techniques and monitoring networks would contribute to a better understanding of the various components of climate change. The major gaps in the monitoring efforts should be identified and filled. Such gaps in systematic observations are found in areas such as the Arctic, the deep sea, and the riparian countries of the Black Sea. Gaps also exist in relation to the observation of properties of marine systems, which currently target mainly physical and geochemical properties of the seas such as temperature, salinity, currents, sea level, pH and oxygen concentration. In order to understand the impacts of climate change on marine life, and the possible feed-backs, similar emphasis should be put on biological observation, including variables such as pelagic primary production, trophic transfer rates, migratory behaviour and physiological stress (for further information see Chapter 11 on European Ocean Observing System).

4. **Adaptation and mitigation**
   A most basic societal need is the opportunity and the capacity to cope with climate change and its likely impacts on the marine environment; by providing for some mitigation measures where possible, by adapting to inevitable changes, and, where appropriate, by benefiting from those changes. Scientific research and the provision of usable scientific advice will be of the highest importance in meeting this need. Many of the observed changes in the marine environment are likely to impact or have already impacted on the social and economic fabric of our societies (e.g. sea-level rise, changes in commercial fish stocks, etc.), but there is an urgent need to achieve a better understanding of how future changes will further impact on the marine environment to inform appropriate mitigation and adaptation measures.

   There is also potential to achieve some level of mitigation by using the oceans for carbon sequestration and food production in a sustainable way. Already several innovative mitigation mechanisms have been proposed including ocean productivity stimulation, offshore aquaculture, biomass production (seaweed) which can help to transfer CO_2 into the long-term geospheric reservoir. Understanding the processes which are driving change is important, but so too will be the need to deliver proactive and innovative research-based solutions.

Credit: AeroLinPhoto

The Maeskantkering is a storm surge barrier in the Netherlands, which automatically closes when needed for protection.

3.4.2 Research priorities according to the major categories of climate change effects and impacts

TABLE 3.1: Summary of the key categories of marine environmental changes and impacts in coasts, seas and oceans with their corresponding research priorities
(Note: not all of the categories presented are directly linked to human-induced climate change. There are also significant links and interactions between many of the categories)

Sea-level Changes	• Improve understanding of ice sheet break-up processes, past and present; • Integrate modelling of ice sheet changes into global climate models; • Improve understanding of coastal sea-level forcing mechanisms and integrate it in climate models to account for regional variability; • Develop a robust and efficient monitoring system for mass changes in Greenland and Antarctica; • Develop reliable techniques to forecast regional / local sea-level rise.
Coastal Erosion	• Increase research into relative sea-level trends in relation to future storm tracks; • Develop and undertake a detailed assessment of the extent of coastal erosion in the EU at appropriate temporal and spatial scales; • Improve the societal understanding of coastal erosion and of the difference between coastal protection (defending property) and protection of the coastal ecosystem (which may involve sacrificing coastal property).
Temperature and Salinity Changes	• Improve the ability to detect temperature and salinity changes in the long-term, especially in deep layers; • Identify and reduce the sea surface temperature (SST) and sea-ice-related uncertainty in climate modelling systems, also using analyses of past natural changes; • Increase the resolution and number of coupled regional atmosphere - ocean circulation models; • Improve the parameterization of dominant processes for accurate SST simulation in coupled climate models, both at global and regional scales, past and present; • Study the patterns of climate change of the Northern Hemisphere influencing Mediterranean water temperature and salinity changes.
Ice Melting	• Improve understanding of the properties of snow cover on sea-ice; • Improve the assimilation of observation data in models of the Arctic sea-ice cover, in particular by relating ice physical parameters to electromagnetic properties (observed by satellites) in the development of forward models; • Improve the understanding of the interaction between the ocean and ice melt in order to quantify the role of changing oceanographic conditions to sea-ice melting.
Storm Frequency and Intensity	• Develop and use wind data sets which describe intensity and frequency of storms in a consistent manner; • Increase efforts to analyse regional sea-level patterns in relation to changing storm surges.
Changing Stratification	• Investigate the boundary conditions of the system in terms of increasing atmospheric supply of nutrients and oceanic vertical supply; • Improve the ability to predict the knock-on effects of altered productivity throughout marine ecosystems, including in complex ecosystems with many trophic levels; • Consider the effects of altered stratification in the broader context of how other ocean properties are altered – in particular, seasonality, the depth of the mixed layer, ocean-shelf transport and light climate – as part of a holistic assessment of the cumulative climate change effects on the ocean, also employing past natural examples.
Thermohaline Circulation (THC) Changes	• Increase understanding of the key factors determining thermohaline circulation changes and determine changes in freshwater input to the North Atlantic resulting from global warming; • Determine how predictable the THC system is using today's generation of climate models and how these predictions can refine climate forecasts (particularly on the decadal scale); • Investigate changes in freshwater input to the North Atlantic resulting from global warming and corresponding impacts on the Mediterranean Sea; • Investigate the relationship between the intensity of the Mediterranean overturning circulation and deep mixing rates.

Riverine Discharge and Nutrient Loads	• Improve the understanding of the interactive effects of floods, global temperature increases and coastal biogeochemistry, past and present; • Couple regional climate change scenarios with river basin, nutrient transfer and coastal ecosystem models, to test the interacting effects of global climate change with scenarios of regional socio-economic change; • Create a better understanding of the possible responses of coastal ecosystems to changing riverine nutrient loads, both quantitatively and qualitatively.
Ocean Acidification	• Significantly improve the understanding of the impacts of ocean acidification on marine taxa and underlying processes, past and present; • Increase attention towards acclimation and adaptation, both at the level of the individual organism, and at the community level; • Address the synergy between simultaneous changes of temperature, oxygen and pH; • Improve the representation of biological responses to climate change and ocean acidification in regional and global models. • Improve the knowledge of distributions, controls and temporal variability of natural and anthropogenic carbon in the interior of the Sea (key areas for CO_2 sequestration, role of water formation areas, role of shelf events); • Promote the creation of a Mediterranean – Black Sea component of the Global Ocean Ship-based Hydrographic Investigations Programme (GO-SHIP), to improve the understanding of carbon fluxes and processes, to observe trends and to demonstrate the crucial role the carbon cycle plays in climate regulation and feedbacks.
Ocean Deoxygenation and Coastal Hypoxia	• Characterize the spatial and temporal dynamics of oxygen in both open ocean and coastal environments, past and present; • Identify the drivers of oxygen depletion and distinguish natural variability from anthropogenic impacts; • Establish a global observation system that continuously monitors oxygen concentrations at high resolutions, which is linked to other physical and biogeochemical parameters as well as to climate observations; • Develop an improved understanding of the process towards the formation of dead zones resulting from oxygen depletion; • Improve existing models to better predict the frequency, intensity and duration of future hypoxia events.
Impacts of Climate Change on Marine Eutrophication	• Increase the amount of consistent measurements of pelagic primary production; • Address the lack of data on benthic primary production in shallow seas; • Improve the knowledge to differentiate between the many factors which simultaneously affect rates of both growth and loss of microalgae; • Improve understanding of nutrient load impacts on primary production, and identify and quantify trophic transfers between primary and secondary producers to support the development of realistic and ecologically sound management strategies for sustainable use of coastal seas in a changing environment.
Biological Impacts	• Link biodiversity with ecosystem modelling and ecology with biogeochemistry to improve prediction and risk analysis of climate change impacts on biological communities and ecosystems, past and present. • Further develop the application of individual based models (IBMs) in climate change predictions; • Tackle the lack of knowledge about the ability of marine organisms to adapt and evolve to climate change on relevant timescales; • Drastically improve the level of detail in our understanding of the impacts of fishing on the abilities of marine populations and ecosystems to respond to climate change; • Ensure systematic and sustained observation on long-term and large-scale changes in distribution of key organisms and biodiversity to keep track of change, understand risk, and allow adequate mitigation.

4

Safe and sustainable use of marine and coastal space

Balancing use and conservation

4.1 Introduction

Until recent times, marine space was largely a commons wherein human activities such as fisheries had access to all available coastal and sea areas. With the expansion in use and industrialization of the sea for oil, gas and aggregate extraction, shipping, fisheries, aquaculture, marine renewable energy, subsea mining developments, and recreation, ocean space has become the subject of a sometimes intense competition. Various human uses and conservation needs compete for access or vie for exclusive use (or non-use in the case of conservation). This competition for space, together with evidence that we are potentially reaching the limits of the capacity of the oceans to absorb human pressures, has shown that our marine ecosystems need to be managed holistically. It was this understanding that led to the development of the ecosystem approach to the management of the marine environment (Browman and Stergiou, 2004).

The term 'Ecosystem Approach' (EA) was not widely used in a policy context until the Earth Summit in Rio de Janeiro in 1992. It was subsequently established as a United Nations CBD term at the Conference of Parties 2 (Secretariat of the Convention on Biological Diversity, 2004). Another term which has become interchangeable with EA is "Ecosystem Based Management" (EBM), defined by Grumbine (1994) as *"the integration of scientific knowledge of ecological relationships within a complex socio-political and values framework toward the general goal of protecting native ecosystem integrity over the long-term".* Twenty years later, the ecosystem approach is applied as a fundamental principle in many maritime policy decisions and legal instruments (e.g. Garcia *et al.*, 2003; Smith and Maltby, 2003; Shepherd, 2004; EC COM 2007 (575) final; Ehler and Douvere, 2009). However, while the theoretical basis is largely agreed and accepted, many questions remain regarding its successful implementation:

- Are the knowledge, data and tools necessary to achieve a safe and sustainable use of marine and coastal space available?
- How is the EBM applied in practice in decisions surrounding human activities in the marine environment (e.g. the planning and building of offshore wind parks)?
- What is the role of the European marine science community in supporting the practical implementation of EBM principles in marine management in European waters?

This NFIV chapter focuses on these questions and makes recommendations on the high-level science needs and priorities for the achievement of a safe and sustainable use of marine and coastal space in Europe.

4.2 Societal and policy context

The ecosystem approach requires that the ecological, economic and social aspects of any activity or decision are taken into account simultaneously in a process that integrates all relevant sectors and stakeholders. Thus, to ensure that decision-making supports a sustainable use of ecosystem services, marine areas and resources in an efficient and equitable way, it is fundamental that all social, economic and environmental impacts of a development or activity, both short- and long-term, are identified and quantified (Daily *et al.*, 2000, Beaumont *et al.,* 2007). This is reflected in the EU Integrated Maritime Policy[1] where the provision of comprehensive and accessible sources of maritime data and information is one of the three identified planning tools that cut across sea-related sectoral policies and facilitate integrated management. The other two are maritime surveillance, which is critical for the safe and secure use of marine space, and maritime spatial planning (MSP) which is a key planning tool for sustainable decision-making.

Het Zwin Nature Reserve, Belgium.

Credit: Graffilus voor MDK-Afdeling Kust

The use of "space" as a basis for managing human activities in an integrated manner has proven an effective and practical way of implementing the ecosystem approach, as all activities and ecosystem needs can be defined and managed in a spatial context. Spatial management in the marine environment has developed rapidly and is referred to as marine/maritime spatial planning (MSP). MSP focuses on managing human activities to achieve societal goals for both human developments and the health of the ecosystem. Sound and comprehensive scientific knowledge of the state of the ecosystem, the effects of human impacts and the vulnerabilities of ecosystem components and habitats are essential prerequisites for successful spatial planning (Douvere and Ehler, 2009; Ehler and Douvere, 2009). Furthermore, it is paramount that the collection of coherent datasets transcends national borders. This is where the EU has a clear role to play and where the Marine Strategy Framework Directive (MSFD) is providing an important coordinating mechanism. The initial assessments required from Member States by 2012 under Article 5 of MSFD, may be also used for collecting the scientific knowledge which is necessary for MSP purposes. In this context it should be noted that for every plan or programme, such as a maritime spatial plan, a strategic environmental assessment (SEA) is compulsory in EU Member States under the SEA Directive (European Parliament and Council, 2001, Directive 2001/42/EC).

[1] EC COM 2007/575 final

In Europe, the EU has spearheaded the development of a common approach to MSP by publishing in 2008 its "Roadmap for Maritime Spatial Planning: Achieving Common Principles in the EU" (EC COM(2008) 791 final). This roadmap included ten common principles for MSP (Box 4A) and incorporates the ecosystem-based approach as an overarching principle. The ten principles are broad, since they need to "fit" all Member States. An attempt to explain these in more detail has been provided by Schaefer and Barale (2011). However, further clarifications are still required and the regional seas conventions have an important role to play in this process.

Up to now, marine management has been almost entirely national and sectoral. Moving towards an integrated approach has been a slow process, even at national scale, as integration of management means giving up some sectoral control. However, there has been a slow but steady progress on this issue as the need for EAM has increased the need for more cross-cutting instruments like MSP and regional implementation to handle cross-border conservation and vulnerability issues. Some regional initiatives are already underway such as the HELCOM VASAB[2] initiative in the Baltic Sea, but actual trans-boundary plans have yet to be delivered. The present chapter includes a brief introduction to the present state of marine spatial planning and management before focusing on the likely future scenarios and the key science priorities that need to be addressed in order to progress MSP implementation.

BOX 4A. The European Union's 10 common principles for MSP
As adopted by the Commission in 2008 in "Communication on a Roadmap for Maritime Spatial Planning: Achieving Common Principles in the EU"

1. Using MSP according to area and type of activity;
2. Defining objectives to guide MSP;
3. Developing MSP in a transparent manner;
4. Stakeholder participation;
5. Coordination within Member States — simplifying decision processes;
6. Ensuring the legal effect of national MSP;
7. Cross-border cooperation and consultation;
8. Incorporating monitoring and evaluation in the planning process;
9. Achieving coherence between terrestrial and maritime spatial planning in relation with ICZM;
10. A strong data and knowledge base.

[2] Vision and strategies around the Baltic Sea 2010 - www.vasab.org

4.3 Major scientific developments and achievements in the past decade

4.3.1 MSP and ICZM – a process for better management of EU Coasts and Seas

Depending on the preference of the user, MSP refers to either *"Marine spatial planning"* or *"Maritime spatial planning"*. Both names refer to the same concept. *Maritime* should not be misunderstood as placing more emphasis on the human activities (the economic dimension), and *Marine* should not be interpreted as placing the health of the ecosystem and conservation needs as the sole focus.

There are also several definitions of MSP. The EU defines MSP as:

"a process for public authorities of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic and social objectives"

(EC COM(2007) 771 final)

While UNESCO defines MSP as:

"a public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that are usually specified through a political process."

(Ehler and Douvere 2009)


Credit: University of Aberdeen

Thus the main aim of MSP is to move beyond single-sector management towards a more integrated approach to utilizing and managing marine space, whilst simultaneously applying the ecosystem based approach to human activities and safeguarding sustainability. In practice, this involves distributing and coordinating, in space and time, human activities in the marine environment, allowing for a variety of activities and, where appropriate, stimulating synergies between them. As a forward-looking tool, MSP can anticipate and solve potential spatial conflicts before they actually occur. Such long-term planning gives security to stakeholders and investors. While marine spatial planning needs to be underpinned by sound data and knowledge, it can also provide the additional benefit of an integrated and comprehensive overview of human activities in the seas and oceans.

MSP is distinguished from Integrated Coastal Zone Management (ICZM) by not covering the land part of the coastal zone (usually defined as the land-sea interface, where processes in one area are directly affected by the other). In the US, a combined concept called Coastal and Marine Spatial Planning (CMSP) has been introduced and is used in the planning process. CMSP as a concept is more holistic and ecosystem-based as it covers the whole sea area from seashore to the deep oceanic waters. Biologically, such a holistic approach is more sensible than excluding the coastal zone as many marine organisms, including commercial fish stocks, migrate between the coastal zone and deeper waters during their life-history. In addition, many human activities in the coastal zone have direct impacts on the adjacent sea areas and vice-versa.

Including the coastal zone in a marine planning process increases complexity both in terms of knowledge requirements and governance. The separate planning rules and legislation for land and sea areas must be harmonized, thereby involving a greater number of government institutions and legal instruments. For pragmatic reasons, some countries (such as Norway) have chosen to make their marine planning processes strictly marine, thereby avoiding the added scientific and governance complexity of involving the coastal zone. The best approach may depend upon the flexibility and adaptability of the existing structures governing land and sea areas in different countries and work towards a more common approach between neighbouring countries in the different European sea basins. For the remainder of this chapter, for convenience, the term MSP will be used, as it has become embedded in the European policy vocabulary. However, CMSP is recognised as a valid and indeed more holistic alternative.

Credit: IMARES

Sand nourishment near the island of Texel, the Netherlands

4.3.2 Progress towards MSP/ICZM implementation in Europe

A number of national and international research and development projects and initiatives have been funded in the past ten years with the aim to both improve the knowledge base and lay the foundations for MSP plans in specific areas. Important support has come from the EU through the Framework (research) and INTERREG (regional development and cooperation) programmes. Several projects have aimed at developing the science base and methods for MSP through analyses of specific case studies (e.g. the FP7 projects, MESMA[3] and ODEMM[4]), while others have taken a more practical approach to develop the foundations for MSP in a particular maritime area (e.g. BaltSeaPlan[5], Plan Bothnia[6], MASPNOSE[7]) or to develop MSP to achieve harmonization between different maritime activities (COEXIST[8]).

[3] www.mesma.org
[4] www.liv.ac.uk/odemm
[5] www.baltseaplan.eu
[6] http://planbothnia.org
[7] www.wageningenur.nl/en/show/Maspnose-Maritime-spatial-planning-in-the-North-Sea.htm
[8] www.coexistproject.eu

In addition to the research and development efforts through funded projects, several inter-governmental and non-governmental organizations have focused their attention on the development of ICZM and MSP and the links between them. ICES (the International Council for the Exploration of the Sea) has spearheaded the scientific development of ICZM through a specific expert group on coastal zone management. In 2010, ICES set up a strategic initiative on area-based science and management which brought together scientists and planners from across the North Atlantic to share experiences, best practices and to highlight the most important science needs to support MSP. This process has ultimately led to a shift of focus within ICES to a more holistic approach to marine and coastal zone management (CMSP).

Similar activities have been advanced in European regional seas. OSPAR, the convention for the protection of the marine environment of the North-East Atlantic, has established an intersessional working group on MSP with the aim of improving cooperation on transboundary issues which arise from marine spatial planning. In 2012, HELCOM[9] and VASAB established a joint working group on MSP in the Baltic Sea. VASAB, or "Visions and Strategies around the Baltic Sea," is an intergovernmental multilateral organization promoting cooperation between the ten countries of the Baltic Sea Region with a primary focus on spatial planning and development. These two organizations have agreed on a set of MSP principles which provide valuable guidance for achieving better coherence in the developments of MSP systems in the Baltic Sea Region (HELCOM/VASAB Working Group on MSP 2010). These principles to a large extent build upon the European Union's MSP principles (EC COM(2008)791 final) whilst addressing specific needs of the Baltic.

4.3.3 Development of tools - current status, lessons learned and identified research challenges

At the core of EBM and MSP is the synthesis of knowledge of different ecosystem components and human activities to achieve an integrated and holistic management plan. To analyze this vast array of knowledge, new and often complex analytical methods are required. MSP ultimately comes down to allocating space to different uses and non-uses. Traditional marine science has been poorly equipped to deal with such integrated issues as it has been geared towards supporting single species and single-sector management.

A critical requirement for all MSP processes is a sufficient baseline knowledge the ecosystem, its components, its interactions and all human pressures on the system. This information must be available in a spatial format (e.g. a GIS-based system) to be usable in the analysis and planning process. Once the system baseline is in place, information on ecological values (preferably quantitative), and the vulnerability of the ecosystem and its components to the different human activities are needed.

These first two steps are achievable, based on the existing level of knowledge and methods available to scientists and planners in Europe today (although there is still much progress required on developing agreed value systems for marine ecosystem goods and services). Adequate data on the ecosystem and on human pressures and impacts (with some exceptions) are usually available.

[9] Helsinki Commission: Baltic Marine Environment Protection Programme www.helcom.fi

The challenge is sometimes to extract the spatially relevant information that is needed for MSP. In developing countries there is often a data-deficiency, making the task of establishing a baseline more challenging.

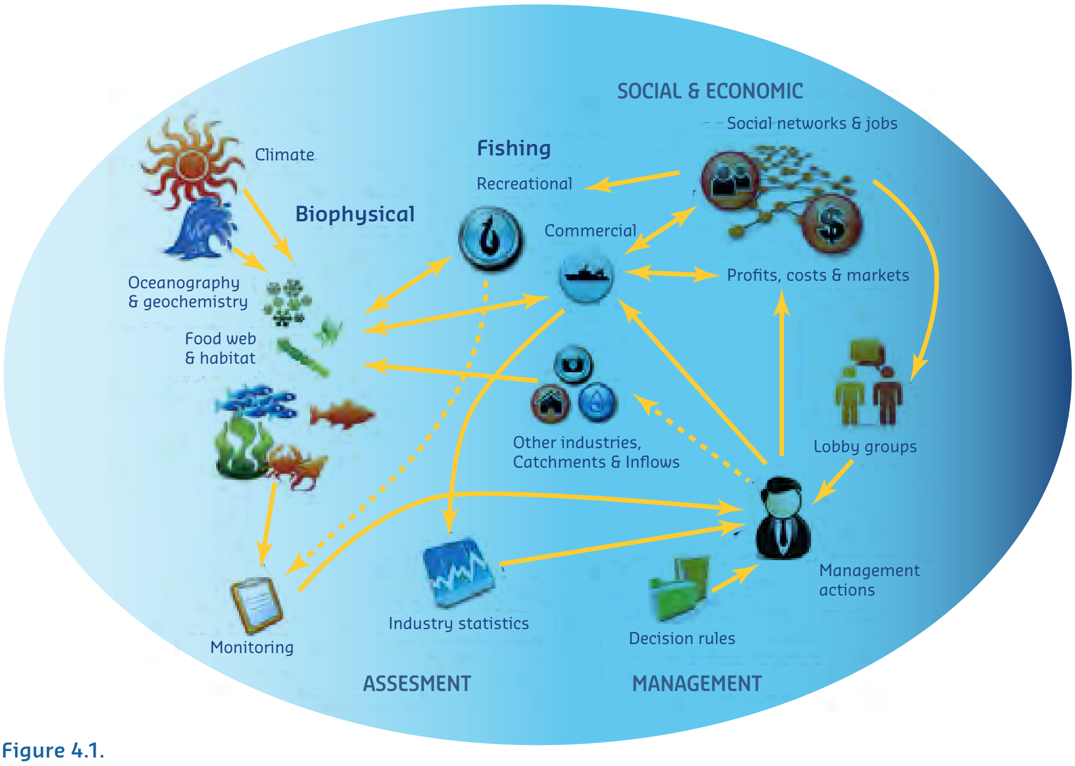


Figure 4.1.

Schematic diagram of the connections, components and major processes included in the Atlantis modelling framework. The major components of the approach are the biophysical system (including the environment, habitat and foodweb), the human users of the system (industry and recreational users), the three major components of an adaptive management strategy (monitoring, assessment and management decision processes) and the socioeconomic drivers of human use and behaviour. Credit: Beth Fulton, CSIRO, Australia

The greatest scientific challenge of MSP is to try to integrate the available knowledge about ecological value and vulnerability across ecosystem components and activities to make an assessment of total or cumulative value and vulnerability. Simply put, this is the equivalent of adding apples and pears. Value and vulnerability are assessed using different methods and scales for each ecosystem component and impact. Finding one common currency for value and vulnerability has been a major challenge in all MSP implementations to date. So far, integrated assessments have been, to a large degree, based on expert-judgement, typically in a cross-sectoral setting where experts from different sectors discuss and analyze together to come up with a common subjective assessment on value and vulnerability. In addition, it is not clear to what extent different impacts work in synergy and create cumulative effects far exceeding the simple sum of their impacts. This issue must be the focus of future research and development efforts.

One way of circumventing the problem of cumulative value and impacts is to use ecosystem models to test management scenarios where different human impacts are combined to evaluate the effects on the ecosystem. Such end-to-end ecosystem models have been under rapid development over the last decades. Australia is currently using the ATLANTIS ecosystem model to support development and management decisions in its MSP planning (Fulton, 2011; see Figure 4.1). The Canadian ECOPATH/ECOSIM models are another example. End-to-end ecosystem models have limited capacity to predict specific future conditions such as stock sizes of fish or future climate, but can be used in a scenario context to analyze the outcomes and ecological impacts of predefined future scenarios. In addition, they are useful to generate data and test the applicability of indicators or other measures of success or goal-achievement which are typically included in MSP plans (Smith *et al.*, 2007). Furthermore, ecosystem models can help to close data gaps discovered in a MSP process when the likely significant impacts of MSP designations on the marine environment must be analysed in the accompanying strategic environmental assessment (Mohn *et al.*, 2011).

Ecosystem models can also be used to test different possible spatial zoning measures. It is possible to design scenarios where areas are allocated to different uses and protection measures (MPAs) to see how the ecosystem responds over time. Such scenarios will allow comparisons of the effects of different management options, allowing planners and scientists to assess the effects of a large number of zoning options without placing the health of the ecosystem, the livelihoods of local communities, or economic progress of commercial maritime activities at risk.

Credit: Dirk Neyts

Europe has some of the busiest shipping lanes in the world; maritime transport is a major user of marine space.

Specialized GIS tools have been developed to assist with the zoning process of spatial planning. Two major systems currently in use are Marxan[10] and Zonation[11]. Both systems were developed as conservation planning tools, designed to support decision-making by identifying areas important to maintain habitat quality. However, conservation needs are only one part of EBM and MSP, and further development of spatial tools that integrate both conservation needs with human uses are needed.

[10] www.uq.edu.au/marxan/

[11] www.helsinki.fi/bioscience/consplan/software/Zonation/index.html

4.4 Developing and implementing a multidisciplinary approach to MSP and EBM

4.4.1 A Generic vision

Marine Spatial Planning (MSP) is a practical way of implementing ecosystem based management (although EBM is more than just spatial planning). This close link between MSP and EBM makes development and implementation of MSP central to achieving EBM. MSP has been taken up by many nations and is in various stages of implementation around Europe. However, the fact that its implementation is still in the early stages represents a great opportunity to link the development of the various national and regional MSP processes around Europe so that they are, to the furthest possible degree, supportive of EBM.

The shortcomings of some existing MSP schemes include (F. Douvere, EurOCEAN 2010):

- They lack scientific baselines;
- They are often treated as one-off acts or documents, rather than as part of a continuous, adaptive and iterative management processes;
- They often consider monitoring and evaluation in terms of environmental quality, rather than in terms of the performance of management measures;
- They include general sets of principles and goals (e.g. establishing sustainable economic development and protecting the marine environment), but do not include measurable objectives and indicators to document changes over time.

Credit: Marine Institute, Ireland

Mussel farming in Killary Harbour, Ireland

Without addressing these valid concerns, there is a real risk that MSP will fail to deliver the management solutions expected of it. Of particular importance is the understanding that MSP are continuous and not one-off acts or documents. Establishing MSP means changing the marine management processes for a sea area into a new and continuous integrated and ecosystem-based approach. Without establishing broad acceptance that MSP involves actual change in how management is carried out in practice, there is little value in mapping conservation needs, human uses or developing ambitious objectives.

4.4.2 Better linking science and policy needs

Marine ecosystem-based management is inherently complicated by the fact that the sea is a 3-dimensional environment. It is also inherently more difficult and expensive to implement environmental observing programmes in the sea than it is on land. Science plays a central role in providing methods and knowledge to observe, monitor and understand the marine ecosystem. Marine management systems should, therefore, have science as a central pillar of their establishment and implementation. The science-driven, bottom-up approach should not be limited to the natural sciences, or solely to conservation needs. Understanding human uses and the potential for economic and societal development is equally important in an integrated management system such as MSP or CMSP. The supporting science should, therefore, be multi-disciplinary - where possible communicating across fields of natural, economic and social sciences - to find common ground for describing effects, possibilities and vulnerabilities. The “ecosystem goods and services” concept is currently being developed to serve as a common currency for understanding both human uses and conservation needs.

A bottom-up science approach provides the best objective understanding of the system we want to manage, but the approach to managing it is very much a question of societal and political choice. Many of these choices have already been made through international agreements like the Johannesburg declaration (United Nations, 2002), and through a long list of EU directives (eg. Water Framework Directive, Birds Directive, Habitats Directive, Common Fisheries Policy, Marine Strategy Framework Directive, Renewable Energy Directive). The Marine Strategy Framework Directive (MSFD), with its target of Good Environmental Status (GES) of European marine waters by 2020, has particular relevance for MSP. However, the contribution of MSP towards achieving GES within the programme of measures of the MSFD needs further attention as MSP by its very nature can only address spatially relevant aspects. Thus MSP can contribute towards achieving GES for some but not all the 11 qualitative descriptors for determining Good Environmental Status (Zaucha and Matczak, 2011).

At national level, there is still room to customize the goals and objectives of marine management. Setting societal goals is a top-down approach led by government, although the goals and objectives may well be developed through bottom-up processes. Integrated and ecosystem-based management such as MSP is, therefore, usually a hybrid of bottom-up and top-down approaches. A hybrid approach also affords an automatic balance between policy and ecosystem constraints. Neither a top-down nor a bottom-up approach is truly holistic on its own. Further discussion on science policy interactions can be found in Chapter 13.

4.5 Key priorities for future research

Integrated ecosystem-based management is not a new concept theoretically, but is still in its infancy when it comes to practical implementation. The move from single-species and single-sector management is a big shift both in policy and management and requires a more integrated and ecological science base. A sectoral approach tends to deal only with the science base relevant for this activity, which means that the complexity of the ecosystem and cumulative impacts of different activities are not taken into account. An integrated science base, which addresses cumulative impacts, would provide decision makers with the necessary information platform for taking integrated decisions consistent with an ecosystem approach to management in order to avoid unlimited exploitation.

Credit: Jan van de Kam

Red Knot feeding in the intertidal zone

Taking into account the recent progress in both practical MSP implementation and MSP-related science, several key research priorities have been identified:

1. **Bioeconomics (including socio-economics in marine management)**
   Most questions concerning EBM and MSP have mainly been driven from a natural science perspective. Less attention has been focused on the socio-economic aspects or how to link ecological value with economic value. Criticism that these processes have been conservation-oriented rather than being oriented on possibilities for co-use, have been raised along with suspicions around whether or not MSP can really be a neutral process. There is, therefore, a need for research on developing bioeconomic tools (for example, the game-theory tools presented in Beattie *et al.,* (2002) for setting values for ecosystem components, vulnerabilities, goods and services as well as the human uses. In other words, the development of a "common currency" to evaluate impacts and benefits is urgently needed. An additional challenge is to achieve this without compromising the ecological approach. It is only possible to manage human activities, not nature itself.

2. **Ecological knowledge and impact analysis**
   Although natural science has driven many of the MSP processes, there is still a lack of basic ecological knowledge to support EBM and MSP. One of the main problems is the lack of comprehensive ecological data sets with a good coverage. There is still a lot of discrepancy between the methods for habitat, community or species mapping carried out by European countries and the mapping does not necessarily cover all of the national waters, or the regional seas. The MSFD obliges EU Member States to collect extensive and detailed data on the marine environmental conditions in their territorial waters as well as potential pressures. If Europe succeeds in developing a common application of the ecosystem approach, will this then be sufficient for achieving and maintaining a good environmental status of Europe's seas, while also ensuring that our approach is compatible with similar systems elsewhere in the world? Better understanding of ecological interactions and vulnerability of the ecosystem to human activities is fundamental for successful MSP. Better mapping of ecosystem goods and services and setting values to each component is also essential. Together with mapping of all human activities, this provides the basic foundations for other more complicated analyses such as vulnerability assessment, assessment of total/cumulative impacts as well as assessing the bioeconomic consequences of different management decisions.

Ecosystems are dynamic, especially towards higher latitudes where there is a greater fluctuation in seasonal climate. Seasonal and inter-seasonal dynamics are currently being further affected by climate change and ocean acidification. External pressures will have large impacts on how ecosystems will develop, and how we can manage them. Understanding the implications on the ecosystem and their associated bioeconomic impacts are essential for long-term management.

3. **MSP tool box : planning and management tools**
MSP is still, to some extent, data driven. European regional seas lack the full range of spatial data sets needed for applying the ecosystem approach when carrying out marine spatial planning and management. Attempts to provide easily applicable GIS "recipes" by which to generate some of the ecological, economic and social data layers needed for MSP have been provided by Snickars and Pitkänen (2007). If European countries could agree to share the same protocols for data collection and handing, this could minimize the need for data harmonisation and all practitioners would be familiar with the degree of accuracy (and error) behind each data set.

Further work is needed to establish a regional sea data exchange infrastructure for MSP purposes. An agreed way forward is needed for a process, including minimum requirements and performance criteria, which will be necessary to ensure that MSP data sets are technically inter-operable, complete, up-to-date and in line with the INSPIRE Directive. Development of technical tools to assist in spatial management is well under way and many zoning tools (e.g. Marxan and Zonation) are already being used internationally. However, few tools have considered socio-economic issues or include human activities along with their possible impact on the marine biota in a way that would be widely agreed, e.g. for an entire regional sea area. Further development is also needed for creating end-to-end ecosystem models and process-oriented tools like the MSP Challenge 2011 game played at the Workshop on Multi-Disciplinary Case Studies of MSP meeting in November 2011 (HELCOM/VASAB, OSPAR and ICES, 2011). Such tools will not remove the need for expert advice and assessments, but can act as a support and guide for management processes.

Aerial view of Zeebrugge Harbour, Belgium

Credit: Dirk Neyts

4. New governance systems (co-management) to combine the role of states, markets and people

EBM and MSP require integrated management, implying a deviation from single-sector and single-species management. Such a change does not come easily as new systems of governance must be established. To achieve this, it must be proven that new ways of governance are more effective e.g. in terms of time saved, lower governance costs, simpler governance structures or fewer conflicts, than the traditional sectoral approach. Research that can illuminate and analyze various governance approaches to EBM and MSP is, therefore, urgently required at national and international level. The more diverse data sets are used for MSP, the more demanding it will be for non-experts to understand the relationships between different planning modules and alternative scenarios. It is essential to improve the ways by which stakeholder groups and private citizens express their rights, and voice their opinions, in a way that ensures stakeholder inclusiveness.

5. New technological innovations to support MSP

In the last decade, automatic identification systems (AIS) and Vessel Monitoring Systems (VMS) have become popular for tracking large maritime vessel traffic and fishing vessels. Today, AIS tracking data is used by marine and coastal planners to assess the spatial needs and potential impact of maritime traffic. Google Maps are frequently used as a basis for displaying spatial data e.g. of recreation, nature conservation and tourism facilities and activities in a way that 20 years ago would have been no more than fantasy. Will, for example, augmented reality (AR) provide the kind of technological leap in marine and coastal planning, surveillance or management that AIS or VMS did? Which solutions, still unknown, will dramatically change the way we carry out MSP in the future? Technological innovations will become a reality only through research and development (and marketing) to develop the prototypes into widely used devices or software applications or to see the new "MSP potential" in devices that have already been developed for purposes other than MSP.

Credit: INCDM, Romania

5 Sustainable harvest from the sea

Credit: Ferdinando Boero

5.1 Introduction

Seafood, supplied by both capture fisheries and aquaculture, is a crucial component in the goal of achieving global food security. Fish and shellfish (molluscs and crustaceans) accounted for 15.7% of the global population's intake of animal protein in 2007 and 6.1% of all protein consumed. The Food and Agriculture Organization (FAO) estimates that seafood production needs to increase by 8-10% annually to meet the requirements of a rapidly rising global population (FAO, 2009 and 2010).

In Europe, the seafood industry is economically and socially important, especially in coastal and peripheral regions. In EU countries alone, the fisheries and aquaculture sectors generate an annual harvest of circa. 6.5 million tonnes of seafood, resulting in an overall value output of €33 billion and supporting approximately 400,000 jobs (data from 2007). The EU imports in the region of 5.7 million tonnes of seafood each year, corresponding to a value of €16.5 billion and making it one of the top three importers of seafood in the world (the US and Japan are the others). The corresponding export of seafood from the EU amounts to 1.8 million tonnes worth €2.9 billion. The EU seafood market is currently supplied by 25% from EU fisheries, 65% from imports and 10% from EU aquaculture, with a total seafood consumption of 13.2 million tones (EC COM(2013) 229 final). For other European countries such as Norway and Iceland, fisheries and aquaculture production are of even higher economic importance, with a total production of 3.3 and 1.3 million tonnes in 2008, respectively.


Credit: J. Steufer, NWO

5.1.1 Policy context

Advancing Europe's bioeconomy is an important element of the Europe 2020 Strategy. This has been reflected in the 2012 European Commission DG Research and Innovation strategy, "Innovating for sustainable growth: a bioeconomy for Europe" (EC COM(2012) 60 final). The strategy encompasses the sustainable production of renewable resources from the land and sea and their conversion into food, bio-based products, biofuels and bioenergy. With respect to fisheries, aquaculture and seafood, the following high-level objectives are stated:

- Bring the exploitation of fisheries stocks to sustainable levels;
- Promote sustainable and competitive aquaculture;
- Reduce the heavy EU dependency on seafood imports.

To achieve these objectives, the following actions were identified:

1. Enhance scientific knowledge and innovation, reinforcing advice on fisheries management, supporting decision-making and strengthening an ecosystem-based fisheries management as a central principle of the revised Common Fisheries Policy;
2. Implement the EU Strategy for the Sustainable Development of Aquaculture (EC COM(2002) 511 final) through development of strategic guidelines[1] and implementation of national strategic aquaculture plans;
3. Promote consumption of safe, nutritious and healthy European seafood and ensure traceability of seafood from net and cage to plate.

These action points are consistent with the Europe 2020 Flagship Initiatives, "Innovation Union" and "Resource-Efficient Growth".

The primary policy instrument for fisheries and aquaculture management in the European Union is the Common Fisheries Policy (CFP), presently under revision, with its fundamental pillars being ecosystem-based management (EBM) and the Precautionary Approach. The objective of the CFP is *'to provide for sustainable exploitation of living aquatic resources in the context of sustainable development, taking account of the environmental, economic and social aspects in a balanced manner'* (Council Regulation (EC) N° 2371/2002). The CFP does not set priorities for these objectives and while direct references are made to adopting a precautionary and an ecosystem-based approach, it is not clear how this relates to economic and social conditions (EC COM (2009)163). However, this is not perceived as an obstacle: *'the economic and social viability of fisheries can only result from restoring the productivity of fish stocks. Therefore, no conflict exists between ecological, economic and social objectives in the long term'* (EC COM (2009)163). Whether this expectation is realistic has not been established, although fisheries management evaluation frameworks necessary for testing environmental, economic and partly also social (e.g. employment) trade-offs have been developed and should be deployed in this context (Sissenwine and Symes, 2007).

[1] Published on 29 April 2013: COM (2013) 229, http://ec.europa.eu/fisheries/cfp/aquaculture/index_en.htm

The revised CFP also requires integration with the EU Marine Strategy Framework Directive (MSFD), a requirement in fact for all maritime activities. The MSFD is a far-reaching commitment for EU Member States to assess, monitor and improve the environmental quality status of Europe's marine waters. It requires ecosystem-based management (EBM, see chapter 4) of the oceans and has fundamental implications for fisheries and other maritime human activities. Provision of a solid scientific basis for MSFD implementation is one of the most demanding tasks for the next decades and is addressed in a series of EU FP7 projects. Within the MSFD, the state of commercially exploited fish and shellfish stocks is directly addressed by MSFD Good Environmental Status (GES) descriptor 3 (population of commercial fish / shellfish), but is also a central component in GES descriptors 1 (biological diversity) and 4 (marine food webs). Moreover, fisheries are major driver of relevance to descriptors 5 (eutrophication) and 6 (seafloor integrity) and hence of central importance to achieving GES.

Credit: J. Steufer, NWO

credit - IMR

An integrated approach to the management of living resources is also a requirement of the EU Integrated Maritime Policy (EC COM(2007) 575 final) and should be underpinned by cross-sectoral science following the approach outlined in the European Strategy for Marine and Maritime Research (EC COM(2008) 534 final) and the EU communication on Maritime Spatial Planning (EC COM(2010) 771 final). Central to all of the above policies is the achievement of a sound scientific and a practical basis for the implementation of EBM. From a purely fisheries perspective, EBM requires implementation of the Maximum Sustainable Yield (MSY) concept, which emerged from the 2002 World Summit on Sustainable Development in Johannesburg. Exploitation levels should aim at restoring and maintaining fish and shellfish resources at levels which can produce the MSY not later than 2015 (EC SEC, 2011/891 & 892 final). This is an ambitious but not unrealistic goal for European fisheries management, as a comparison of present against target fishing mortality rates for the Baltic demonstrates (Fig. 5.1).

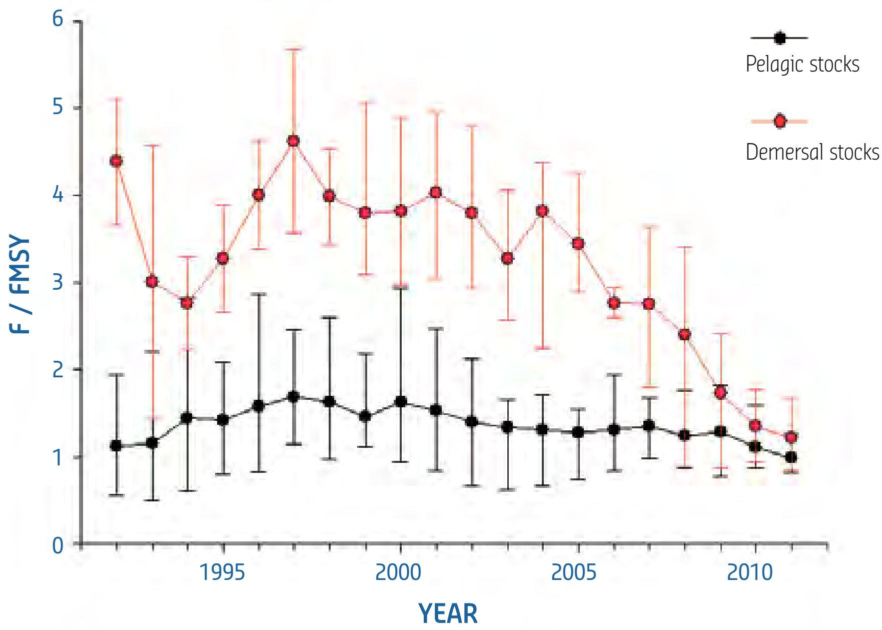


Figure 5.1.
Average ratio between actual fishing mortality (F) and fishing mortality that will result in a stock size that produces the maximum sustainable yield (FMSY) in Baltic demersal and pelagic stocks; bars represent ranges of data (Zimmermann and Barz, 2012[2]).

[2] www.fischbestaende-online.de

Although aquaculture has been an integral part of the CFP since its revision in 2002, it is a not yet a fully developed sector and policy development for aquaculture in Europe is still at an early stage. However, aquaculture presents significant potential for expansion in Europe (EC COM(2009) 162 final) and is the fastest growing food production sector world-wide, already representing half of global seafood protein production. The value of EU aquaculture output in 2010 was €3.1 billion, corresponding to 1.26 billion tonnes of production (EC COM(2013) 229 final). The EU Strategy for the Sustainable Development of European Aquaculture (EC COM(2002) 511 final) and the more recent Commission Communication on Aquaculture (EC COM(2009) 162 final), identify a number of challenges in building an economic and environmentally sustainable European aquaculture industry. The most recent EC Communication, *Strategic Guidelines for the sustainable development of EU aquaculture* (EC COM(2013) 229 final), estimates that each percentage point increase of current EU consumption produced internally through aquaculture could help to create 3,000-4,000 new full-time jobs in the sector. This also explains why aquaculture is one of the pillars of the EU Blue Growth strategy (EC COM(2012) 494 final). Research and innovation will continue to be at the core of EU efforts to provide a basis for sustainable expansion of the sector, but also to make EU aquaculture production the most technologically advanced in the world, producing the highest quality seafood products with the highest safety standards for premium markets.

The EU has developed a comprehensive framework of policies in support of sustainable seafood production in European marine waters. EU policies are also well in line with global commitments, including those of the Convention on Biological Diversity[3] which target a sustainable harvest of fish, invertebrates and aquatic plants by 2020 through application of ecosystem-based approaches, avoiding overfishing, putting in place recovery plans and measures for all depleted species, and avoiding significant adverse impacts on threatened species and vulnerable ecosystems. The achievement of these EU and international policy objectives requires critical knowledge gaps to be addressed, and will only be possible with the support of coordinated and interdisciplinary research. Some of the most urgent and significant research priorities for achieving a sustainable harvest from the seas are outlined in this chapter.

Credit: IMR, Norway

Salmon farming in a Norwegian fjord

[3] UN Nagoya Protocol
http://www.cbd.int/abs/text/

5.2 Major gaps and opportunities for the next decade

One issue that will increasingly come on the horizon in the near future is that of rights and access to fisheries stocks which are changing or moving owing to climate change and human pressures. European fisheries have existed for such a long time and the current policy of relative stability (Morin, 2000) will cause problems as our ecosystems change. These can be environmental changes, as fish and shellfish populations change their geographical range in response, for example, to warming, but may also be a consequence of our improved stewardship (the recent conflict between EU member states and Iceland over the management of Northeast Atlantic mackerel stocks is a good example). Predicting and monitoring changes in commercial fisheries stocks according to natural and human impacts, while also developing novel and effective multi-lateral governance tools to address issues over rights and access to changing fish and shellfish stocks, will be an important goal for multi-disciplinary research in the next decade.

The magnitude and scope of the new policy priorities in the context of constrained public finances will require greater regional co-operation to avoid duplication and overlap and to realize the benefits of scale. There is also a need to align expertise with the changing disciplinary requirements of the ecosystem-based approach to management (EBM). Thus it will be important to:

- Strengthen regional co-operation to share infrastructure and make the best use of human expertise;
- Invest in technology to develop remote sensing and autonomous data collection systems;
- Invest in socio-economic expertise to develop integrated tools for management.

Also in the next decade, EBM must be fully integrated and implemented into the principles, objectives and operational framework of the Common Fisheries Policy, the Marine Strategy Framework Directive, and the overarching European Maritime Policy, under which research and scientific advice play a key role in the management of marine bio-resources. To underpin the future viability of European fisheries and aquaculture, there is a critical need to support multi-disciplinary research taking account of environmental, economic and social factors (EFARO, 2009). Research should be far-sighted, responsive and adaptive in anticipating the future potential challenges facing European fisheries and aquaculture.

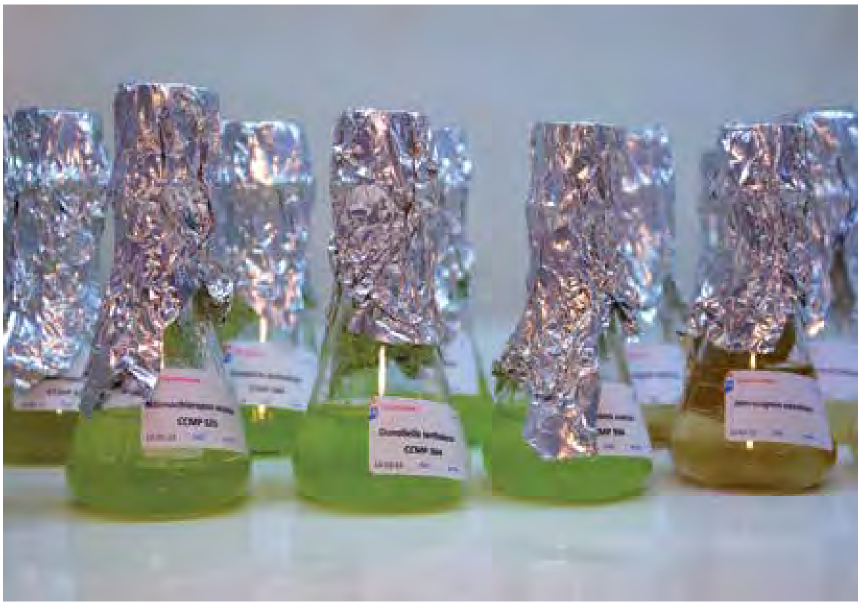
Credit: Ferdinando Boero

The research agenda crucial for meeting emerging and future challenges facing European fisheries and aquaculture comprises four main research areas:

1. Fisheries in the full ecosystem context;
2. Aquaculture in the full ecosystem context;
3. Consumer preference, market development and animal welfare;
4. Socio-economic and governances research;

Of these research areas, numbers 3 and 4 cover issues common to both fisheries and aquaculture. Additionally, three cross-cutting themes can be highlighted as being of major importance in providing a foundation for the priority research areas:

5. Data collection and analysis;
6. Risk assessment and management;
7. Outreach and education;



Credit: NIOZ

Starter cultures in a microalgal cultivation facility

The key priorities under these research areas are outlined in further detail below. Addressing these research questions will be critical to maximize Europe's potential to achieve a sustainable seafood harvest, supporting the industries which produce it, process it, package it and market it, whilst maintaining the sustainability of fishery stocks in a European context. Contributing to Europe's food security by increasing aquaculture output and providing a healthy source of protein is also key to achieving future food security and advancing the blue economy in Europe. In short, Europe must support the next phase of multi-national, cross-sectoral and integrated research on "food from the sea", which addresses these high-level challenges in a holistic way. A trans-disciplinary and inter-disciplinary approach will be essential, requiring expertise from, among others, fisheries and aquaculture science, oceanography, marine ecology, socio-economics and governance, nutritional science and public health.

5.3 Key research questions and priorities

Key research priorities for meeting emerging and future challenges facing European fisheries and aquaculture include:

5.3.1 Fisheries in a full ecosystem context

1. **Improved prediction and modeling capabilities**
   Advance the multiannual (i.e. medium to long-term), multi-species (e.g. multi-stock, predator-prey), multi-fleet (e.g. fleet size, fishing gear and operations), and ecosystem-health approach to scientific advice underpinning management. This includes improvement of observation, modelling and prediction capabilities, allowing the future projection of fish and shellfish stock dynamics and the impact of fisheries on trophic-level dynamics and nutrient cycling, using end-to-end and whole ecosystem modelling approaches.

   Prediction scenarios should cover longer timescales than currently possible. Future scenarios of stock development depending upon climate change and fisheries scenarios can provide decision-making options for managers and should include applications of bio-economic models to project not only the biological production, but also economic drivers of exploitation.

2. **Population dynamics of living marine resources**
   Advance the knowledge of life cycles, distributions and environmental interactions (including responses and adaptation to natural and human-driven environmental change), of biota which play a key role in food webs and which impact on fisheries resources.

   Investigate the effects of climate change (e.g. changes in temperature and primary production) and ocean acidification on the phenologies of fisheries species and their prey, which may result in trophic mismatches affecting the stability of commercial stocks. Also, investigate the impacts of environmental changes on growth, fecundity, recruitment, sensory responses and behaviour (e.g. altered auditory preferences or impaired olfactory function) of commercial species.

3. **Gear and operational technology**
   Investigate ways to make fishing gears and practices more efficient and able to reduce by-catch and discards, limiting habitat and ecosystem impacts, improving selectivity, while also improving fuel consumption when fishing.

4. **Valorization of currently underused components of the catch**
   Develop measures to optimally use all the current catch waste for human benefit, not only for direct human consumption, but also for utilization in the production of meal, pharmaceuticals and medications, or other applications.

5.3.2 Aquaculture in a full ecosystem context

1. **Diversified and healthy seafood for consumers**
   Investigate new, diverse aquaculture species and implement breeding programmes that utilize the latest developments in genetics and genomics to enhance management, performance, disease and parasite resistance, flesh and nutrient quality and welfare traits of farmed species under changing environmental conditions.

   Focus also on the improving the technical and economic feasibility for the cultivation of a range of marine algae species with commercial potential (food and biotechnology applications).

2. **Decreasing the environmental impact of aquaculture**
   Minimize the use and release of various pollutants and veterinary medicines (e.g. through development of improved vaccines for endemic diseases), and the loss of 'escapee' organisms.

   Advance the development of innovative feeds and dietary ingredients that further reduce reliance of the finfish farming sector on marine fish-meal, fish-oil and feedstuffs that can be directly consumed by humans.

   Develop improved management tools based on the ecosystem approach to minimize the impact of aquaculture activity on water quality, ecosystem health and other coastal zone users.

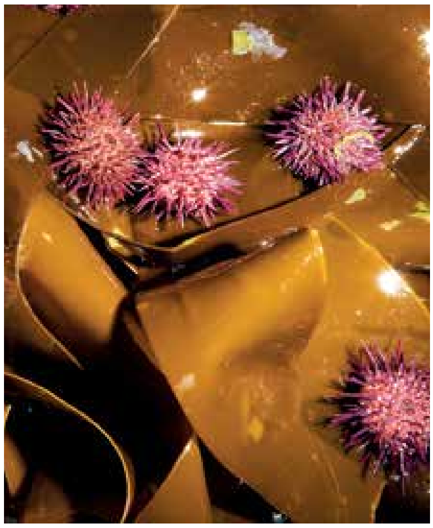
3. **Combatting pathogens and diseases**
   Promote further research on the prevention, eradication and control of infectious aquatic pathogens and diseases, not only affecting currently cultivated species/biota but also to foresee and address emerging and prospective disease challenges involving the cultivation of new species/biota.

   Research is needed to better understand the relationship between immune gene genomic and proteomic expression.

   Develop better vaccine and drug delivery methods, particularly oral delivery systems.

   (See Chapter 6 on the links between marine-borne pathogens and human health)

4. **Development of non-food products and related production lines**
   Add value to aquaculture products and by-products through development of non-food uses, including better separation of bio-products, efficient waste transformation and improved biomass conversion. Also, advance the use of new/unexploited species for novel non-food products and services.



Credit: Marine Institute, Ireland

↑ Sea urchins (shown here *Paracentrotus lividus*) may have potential as a new aquaculture species.

Credit: Parc Marin de la Côte Bleue

5. **Improvement of rearing system technologies**
   Improve the technical and economic viability of systemsfor production in onshore recirculation systems, seafood detoxification, offshore (deep water) aquaculture and integrated multi-trophic aquaculture. Advances in these technologies will be crucial to allow aquaculture to grow in the context of ever-increasing spatial competition in coastal areas (see Chapter 4).

5.3.3 Consumer preference, market development and animal welfare

1. **New seafood products from fish, shellfish, algae and other bio-resources**
   Develop new and diverse products from fishery and other bio-resources for food (e.g. novel or functional foods and ingredients) and non-food (e.g. pharmaceuticals and nutraceuticals) uses, securing the growth and competitiveness of the fisheries and aquaculture industries.nomic models to project not only the biological production, but also economic drivers of exploitation.

A researcher measures kelp as part of a seaweed research programme.

Credit: Marine Institute, Ireland

2. **Consumer health**
   Further investigate and document the human health benefits of eating safe seafood, advancing knowledge on contamination and infection in seafood (e.g. chemical pollution and biological agents), and providing risk-benefit analyses for seafood consumption (see Chapter 6). Develop advanced control measures (e.g. assays for toxins and contaminants) and strategies to support the provision of healthy seafood products at all price ranges to meet a broad range of consumer demands.

3. **Traceability**
   Address the scientific challenges necessary to allow for complete traceability of seafood. This is essential for underpinning consumer confidence that seafood is safe and is supplied from known and approved sources and harvesting/processing methods, and to facilitate full control throughout the supply chain. Numerous research and technology problems must be solved concerning methodology, practical implementation and validation.

4. **Certification and branding (labelling)**
   Support research required to permit establishment and verification of certification schemes (e.g. eco-labelling, organic production) and standards to attain sustainable practices for fisheries and aquaculture. Such schemes can offer market information to show that products are, for example, harvested from sustainable sources, are healthy, safe and of high quality, and promote good animal health and welfare standards.

5. **Animal welfare**
   There is growing evidence that fish and shellfish can experience "pain", although the definition of pain in this context is contentious. Further research on this issue is required from an animal welfare perspective to inform on whether improvements are needed in how animals are handled in the fisheries, recreational fisheries, aquaculture and in fisheries research.

5.3.4 Socio-economic and governance research

1. **Socio-economic analyses and impact assessments of fisheries and aquaculture**
   Conduct impact assessments of management regulations, market development and technological advancement, based on analyses of social, economic and ecological forcing functions of fisheries and aquaculture. The analyses should recognize and predict how the development of bio-resources and the regulations governing harvesting and production can impact on the fishing and aquaculture sectors (e.g. behavior, employment, income, overall wealth and health, community identity, etc.).

   Provide multi-disciplinary scientific support towards operationalizing ecosystem-based management (EBM) and the sustainable use of natural (renewable) resources, including the development of an effective trans-boundary marine spatial planning framework (see also Chapter 4).

   Investigate how policies, regulations and incentives affecting fisheries and aquaculture are developed and agreed, and the factors responsible for governance success or failure, allowing for the application evidence-based and adaptive policy making.

Develop a better comprehension of the socio-economics of fishing communities and of the behavior of marine stakeholders, and find ways to involve fishers in addressing obstacles blocking the successful development and implementation of policies and governance measures. This can include educational programmes (see Chapter 14 on ocean literacy) and innovative and efficient solutions to data collection, processing and analysis.

Credit: Jean-Joseph Renucci, iStock

5.3.5 Data collection and analysis

Support collection of (and access to) more and better data on the socio-economic aspects of fisheries, aquaculture, recreational fisheries and marine ecosystem goods and services. Besides collection/access to data, there is a critical need to build a 'knowledge base', spanning basic and applied research, to improve understanding of how 'systems' work. These systems range from individuals to populations and ecosystems, and from economic agents to socio-economic communities. This knowledge base should be extensive, inclusive and multidisciplinary. The data should be of good quality and accessible to both researchers and stakeholders.

Given the significant impacts that fisheries and aquaculture may be having on species which are not or cannot be currently assessed, it is also imperative to improve knowledge and methods for dealing with data poor and data-deficient species.

5.3.6 Risk assessment and management

The meaningful incorporation of uncertainty and risk into ecosystem management is in its infancy. Risks and uncertainties relating to fisheries and aquaculture systems are the product of numerous pressures and impacts including climate change, invasive species, pathogens, parasites and harmful algal blooms, through to uncertainties in stock assessments, industry compliance and policy impacts. Risk analysis should be a basic component of impact assessment of policies and the basis for developing new or improved policies and/or management actions. A framework should be developed to enable the inclusion of uncertainty and risk in policy development and the assessment thereof throughout fisheries, aquaculture and the related ecosystem.

5.3.7 Outreach and education

Develop a multi-sectoral approach to improving the knowledge of seafood consumers and stakeholders on the origin, ecological importance, stock status and health, nutritional quality and socio-economic importance of different seafood products. Simple information on these issues can allow consumers and those involved in the seafood industry to understand and appreciate the environmental value and cost of fisheries and aquaculture, improving their perspective towards good governance measures. This will require improved support for dissemination, publicity and engagement with the public and with seafood professionals (see Chapter 14 on ocean literacy).

Credit: Parc Marin de la Côte Bleue.

6

The oceans and human health

Risks and remedies from the sea

Credit: N. McDonough

6.1 Introduction

The marine environment contributes significantly to human health through the provision and quality of the air we breathe, the food we eat, the water we drink and in offering health-enhancing economic and recreational opportunities. At the same time, the marine environment is threatened by human commercial and recreational activities and pollution. Although we remain dependent upon marine ecosystems, humans have altered, and will continue to alter, the marine environment. Evaluation and management of the resultant impacts, on both marine ecosystems themselves, and on human health, have largely been undertaken as separate activities, under the auspices of different disciplines with no obvious interaction. Hence, many of our perceptions of the relationships between the marine environment and human health are limited and still relatively unexplored, leaving critical knowledge gaps for those seeking to develop effective policies for sustainable use of marine resources and environmental and human health protection.

Credit: Ferdinando Boero

The rapid growth of coastal populations is placing increasing pressures on marine ecosystems which, in turn, has implications for public health.

6.2 Societal challenges

For millennia humans have been dependant on the seas and oceans as a source of food and a means of transport and cultural expansion. However, the oceans and coastal seas are like a double-edged sword when it comes to interactions with human health. Natural events such as hurricanes, severe storms and tsunamis can have devastating impacts on coastal populations, while pollution of the seas by pathogens and toxic waste can cause illness and death. An estimated 250 million cases of gastroenteritis occur worldwide each year as a result of bathing in contaminated water, and 50,000-100,000 people die annually from infectious hepatitis (UNEP – Targeting Sanitation[1]). The overall global burden of human disease caused by sewage pollution of coastal waters has been estimated at 4 million lost person-years annually.

On the positive side, the oceans provide humans with many benefits including food for around a third of the global population, the air that we breathe and our climate system which enables habitation of much of the planet. The marine environment can also be the source of potential health benefits through the provision of healthy food, novel pharmaceuticals and related products derived from marine organisms, and through a contribution to general well-being from a close association with the coastal environment (i.e. recreational and psychological benefits, or the "Blue Gym" effect) (Depledge and Bird, 2009; Fleming *et al.*, 2006; White *et al.*, 2010).

Since the industrial revolution, the influence of humans on the global environment has been arguably greater than that of any other species. Human impact on our environment is shaped by our social actions, governance, economic forces, international trade, land use and industrial and urban development (Roodman, 1998; Torres and Monteiro, 2002). In many cases we are not even aware of how actions in one place affect other parts of the ecosystem.

[1] http://www.ourplanet.com/imgversn/144/vandeweerd.html

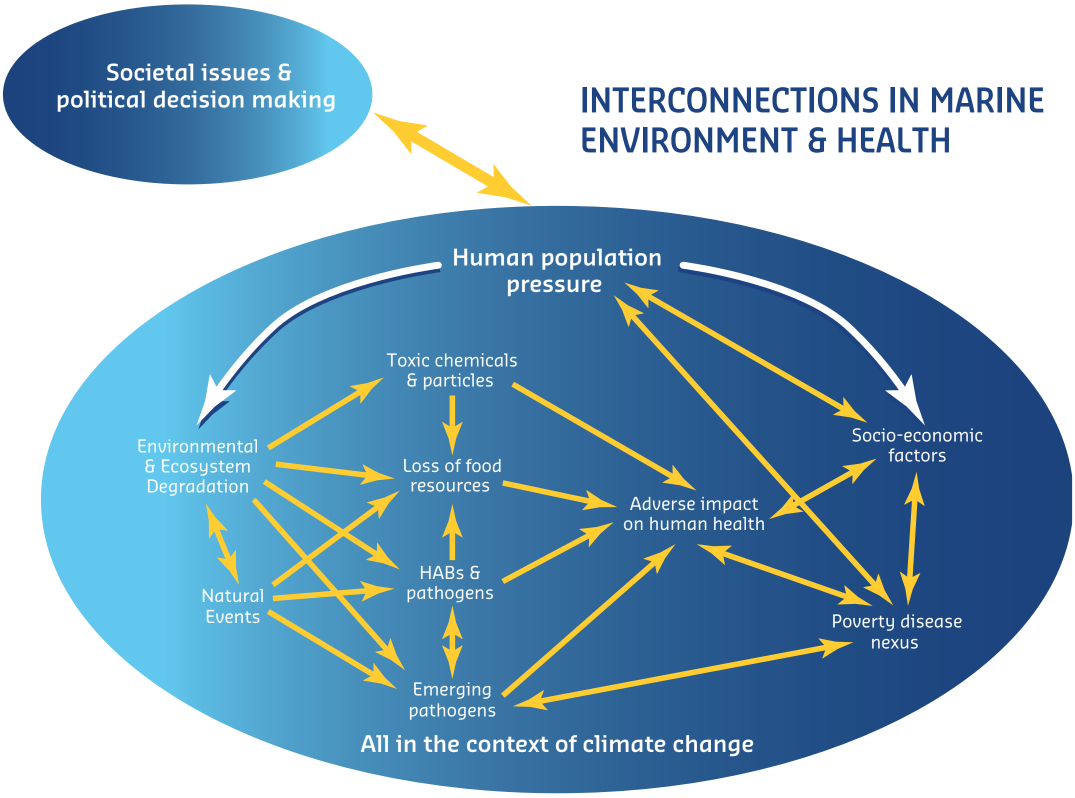


Figure 6.1.
A summary of the interconnectivity between the key processes linking public health and the marine environment (Adapted from Moore *et al.*, 2011)

Factors that may have a negative influence on ecosystem function and ecological integrity, may also adversely affect human health or well-being but the link between these elements is not usually clear (Figure 6.1.; Moore *et al.*, 2011). Environmental changes are often regarded as unavoidable or as the unforeseen consequences of economic and cultural changes. However, there is much that we can do through policy interventions to manage human impacts on the marine environment. Likewise, appropriate policies and management actions are required to maximise the benefits of marine resources and environments for human health and well-being.

From a societal perspective, the main challenge is to improve our capacity to manage the human health risks posed by the seas and oceans while maximising the benefits they offer for our health and well-being at a time of major global changes. This will require a better understanding of the complex relationship between the oceans and human health, and of the opportunities to protect public health through holistic maritime policies and management actions.

6.3 Research questions and priorities

Research in Oceans and Human Health must be directed at understanding and elucidating key environmental processes, and providing a predictive capability for both biotic and abiotic environmental influences on human disease and well-being. The way forward requires the mobilization of interdisciplinary competencies across Europe and ensuring that the necessary scientific and technical capabilities are available. A coherent and coordinated approach to European Oceans and Human Health research should thus be developed and supported to ensure the scale of investment and interdisciplinary collaboration necessary to address the major challenges of understanding and dealing with the immense complexity of marine environment and human health interactions.

The key interdisciplinary research goals include:

1. An understanding of the direct and indirect causal relationships between the marine environment (especially in coastal regions) and adverse and beneficial effects on the well-being of the human population;

2. Innovative monitoring and surveillance techniques which allow much greater provision of relevant and accurate datasets. This includes, for example, remote observation systems for coastal and marine ecosystems, detection of chemical and material pollutants, biogenic and microbial toxins and human pathogens, and improved testing for seafood and water safety.

3. Improved understanding of the physical, chemical and biological processes involved in the transport and transmission of toxic chemicals and pathogenic organisms through the marine environment to humans.

4. Improved environmental models to determine the extent of natural dispersion of sewage, agricultural effluents and industrial waste.

5. Expert systems to link existing models with our experience and knowledge of the connectivity between the marine environment and human health

6. Appropriate indicators, to show the effectiveness of moving towards sustainable development where environmental, social and economic measures are linked. Indicators should be linked to those developed in support of implantation of the EU Marine Strategy Framework Directive

7. Methods and mechanisms which demonstrate the value (economic, cultural, aesthetic, etc.) to human well-being of marine environments at local, regional and global scale.

Public notice warning against the consumption of shellfish from areas where biotoxin contamination is present (Florida, USA)

Credit: Lora Fleming / European Institute for Environment and HumanHealth, UK

Red tide caused by a toxic harmful algal bloom (HAB)


Credit: Ocean Champions

In order to comprehensively address the above research goals, it will be necessary to develop or improve a range of research support functions and capacities. Capacity building will be crucial to increase European competence in this area and is urgently required to overcome the fragmented nature of current research effort in Europe. Initial investments at European level should aim to fast-track the development of key structural elements including research infrastructures (including observation and monitoring platforms), the building of interdisciplinary networking and partnerships, improved training programmes (for PhDs and early stage researchers), and more effective knowledge management protocols and science-policy interfaces to ensure rapid uptake of policy-relevant knowledge.

Specific strategic recommendations to maximize the efficiency and impact of an OHH science programme include:

- Support for research and training of young investigators in OHH;
- Links with business, e.g. co-funded PhDs and Research Fellowships;
- Interdisciplinarity and capacity building (focus on modelling to design early warning systems, etc.), linking experts in oceanography, marine ecology, eco-toxicology, epidemiology, public health, etc.;
- Knowledge management and horizon scanning for emerging problems, benefits and technologies;
- Bridge building between relevant stakeholders (including early involvement of stakeholders in project formulation);
- Capacity building both within Europe, but also beyond the EU where Europe can develop global leadership;
- Opportunity to explore alternatives to standard risk assessment procedures;
- Communication to, and participation by, the wider public; and
- Ocean literacy – outreach to the public on understanding the role that the oceans play (e.g. citizen science, public participation, beach watches, etc.) and specifically about risks and benefits of human interactions with the marine environment (see Chapter 14 on ocean literacy).

It is clear that there is a complex but important relationship between the marine environment and human health which raises many questions and challenges both for scientists and for policy makers. Moreover, policy makers will rely on scientific research and advice to develop a deeper knowledge and understanding of the cause-and-effect relationships between marine environmental health and public health in order to frame appropriate and effective policy responses. This will ultimately allow us to:

- Better understand the potential health benefits from marine and coastal ecosystems;
- Reduce the burden of human disease linked with marine environmental causes; and
- Anticipate new threats to public health before they become serious.

This is not a national or even a regional problem, but is in fact a major global issue that will require trans-national solutions if the marine environment is to remain ecologically functional and economically sustainable (Bowen and Depledge, 2006; Fleming *et al.*, 2006; Moore and Csizer, 2001; Todd, 2006).

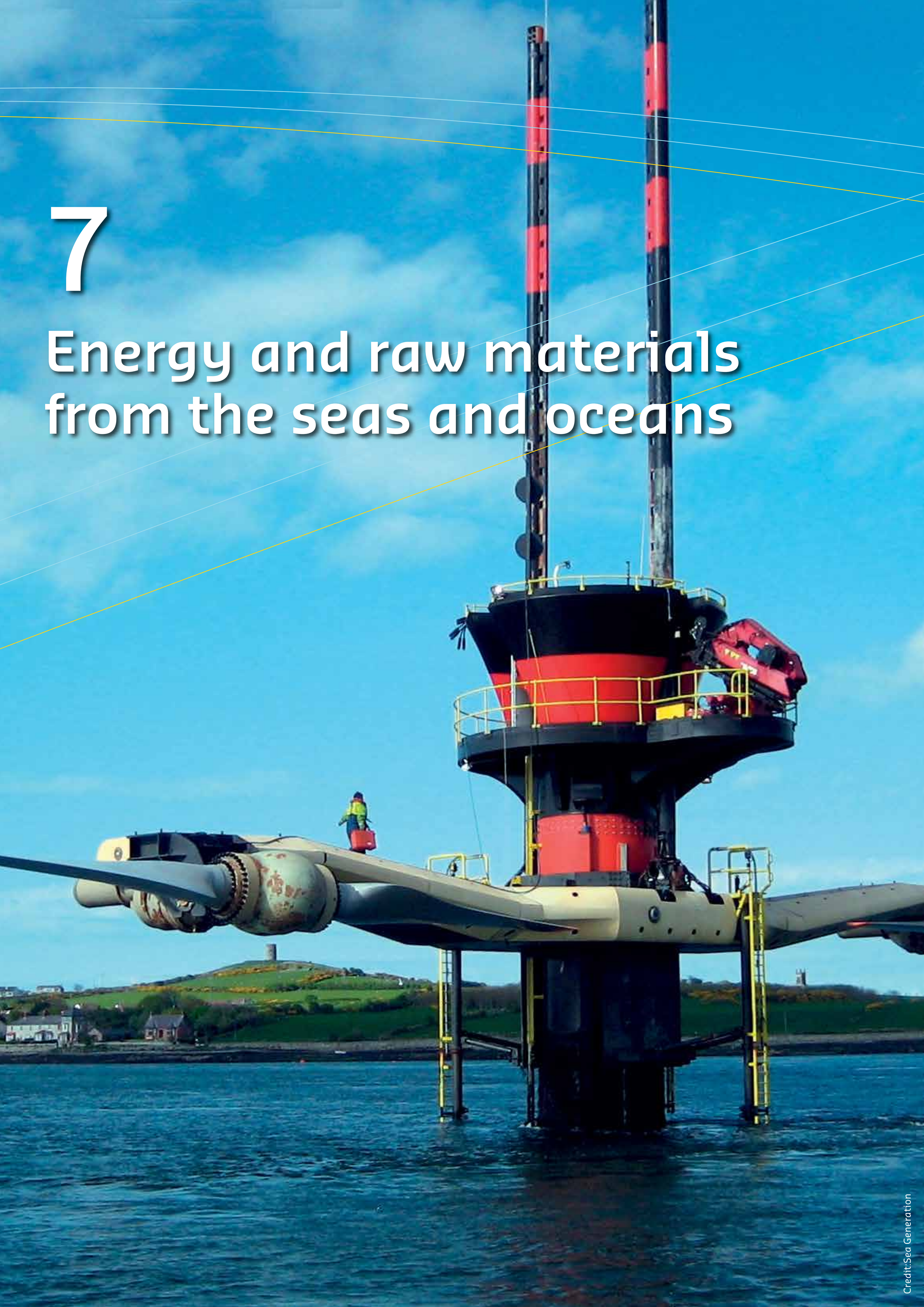
Credit: Ocean Champions

Living and spending recreation time in close proximity to the marine environment can have beneficial psychological and therapeutic effects, termed the "Blue Gym" effect

This chapter is drawn from:
Moore, M., *et al.* (2013) Linking Oceans and Human Health: A Strategic Research Priority for Europe. European Marine Board Position Paper 19. McDonough N., Evrard M., Calewaert J-B. (Eds.). European Marine Board, Ostend, Belgium.

7

Energy and raw materials from the seas and oceans



Credit:Sea Generation

7.1 Introduction

The sustainable use of marine renewable energy resources and the responsible exploitation of marine mineral and hydrocarbon resources are essential components of Europe's Blue Growth strategy (EC COM(2012) 494 final). Both are the subject of major commercial interest and a substantial R&D investment. However, there are significant questions and challenges surrounding the technical and economic feasibility of many aspects of ocean energy generation, marine mineral resource exploitation, new approaches to hydrocarbon exploration and production, and the environmental impacts of all of these activities. Multi-disciplinary research will be central to dealing with these challenges and for providing Europe with an opportunity to source a proportion of its energy needs and a valuable supply of raw materials from the seas and oceans. The opportunity also exists for Europe to be a global leader in the next generation of technologies required to sustainably exploit non-living ocean resources. The research challenges for blue energy and raw materials present some commonalities and both are highly strategic and competitive fields for Europe's maritime economy (Figure 7.1). They are addressed together in this chapter.

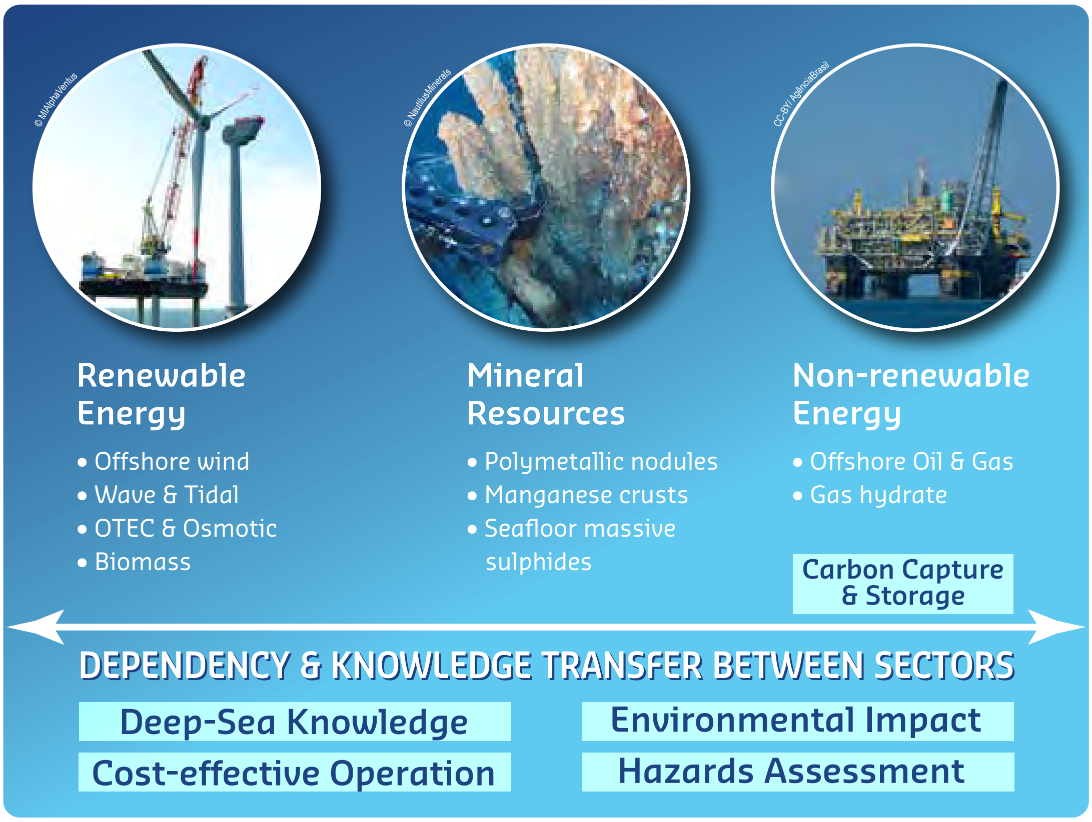
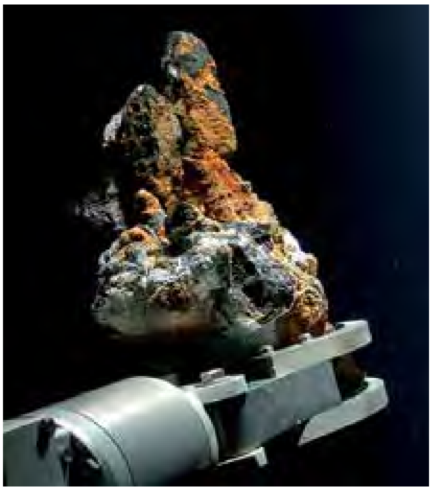


Figure 7.1.
The exploitation of energy and mineral resources presents overlapping challenges and, in some cases, interdependencies. The scientific and governance needs must keep pace with commercial development, allowing these sectors to develop following an ecosystem-based approach and according to coherent and agreed marine spatial planning (MSP) frameworks. Coordination between these sectors will also have added value in environmental monitoring, research project integration, multi-purpose platform development and development of human capacities (training and careers).

7.2 Key societal challenges



Credit: MARUM

Collecting samples from a deep sea vent chimney using an ROV robotic arm

Notwithstanding the major technical and engineering challenges which are addressed in the following section, the exploitation of marine energy and mineral resources presents a number of interlinked societal challenges:

1. **Environmental impact:** Research on the environmental effects of both blue energy exploitation and marine mining is increasingly lagging behind the developing technology and is urgently needed (Inger *et al.*, 2009). Environmental stressors related to marine renewable energies include the physical presence and the dynamic effects of energy devices, energy removal effects, and acoustic and electromagnetic fields. These effects can result in single or multiple impacts on ecosystems in the vicinity of energy devices over different timescales (Boehlert and Gill, 2010). There is also a very limited knowledge of the potential environmental impacts of deep sea mining because the sector is still in the early stages of development. An opportunity exists to put in place appropriate conservation measures which will facilitate a low-impact commercial exploitation of marine minerals in potentially vulnerable deep sea ecosystems (Van Dover, 2012).

2. **Use of marine space:** Infrastructures for energy and mineral resource exploitation require marine space. A comprehensive and consistent marine spatial planning (MSP) framework is necessary to avoid potential conflicts with other maritime activities such as fisheries, transport, and tourism. One option to reduce the requirements for the use of marine space is development of multi-purpose offshore platforms designed to integrate e.g. offshore wind farms with open ocean aquaculture and environmental monitoring[1]. A more efficient and sustainable use of space will require both technical and governance innovations (see Chapter 4 for further discussion of sustainable use of marine space).

3. **Appropriate governance:** While blue energy developments are likely to remain within exclusive economic zones (EEZ), there is significant interest in mining for marine minerals and deep sea resources in areas beyond national jurisdiction (ABNJ). There are concerns over the capacity of the present system of governance to deliver sustainable management of deep sea non-living resources in these areas. Much of the discussion on these issues at international level is dominated by legal and policy experts. The voice and contribution of science is essential to guide effective decision making in support of safe and environmentally sound exploitation of marine mineral resources. Developing appropriate legal and policy frameworks for the exploitation of deep sea resources must take account of the unsynchronised progress among relevant stakeholders: i.e. those who wish to exploit deep sea resources usually move more quickly than scientists, managers and legislators (Ramirez-Llodra *et al.*, 2011). An effective stewardship of deep-sea resources is therefore necessary and requires continued exploration, research, monitoring and conservation measures, working in tandem with one another.

4. **Dealing with safety and hazards:** As commercial interest grows, concerns about environmental hazards related to offshore energy and raw material exploitation have been raised. Hazards, such as oil spills, gas leaks and landslides, could occur during exploration or extraction of resources with potential to cause human casualties, damage to infrastructure and environmental impacts. For a sustainable exploitation of non-living marine resources, strategies are urgently required to predict, mitigate and respond to potential hazards and disasters which could be triggered by human activities.

[1] 3rd European Marine Board Forum, *New Technologies For A Blue Future* (April 2012), http://www.marineboard.eu/fora/3rd-marine-board-forum

7.3 Recent developments, policy drivers and research recommendations

7.3.1 Blue energy

By 2030 the global population is set to exceed 8 billion people. The increasing industrialisation of developing nations and a projected doubling of global GDP will demand immense energy resources. In the same timeframe, a significant global reduction in the dependence on non-renewable hydrocarbon energy will be essential in order to reduce greenhouse gas emissions and to prepare for an eventual depletion of finite fossil energy supplies. The question of how to develop and maintain a viable supply of energy is, therefore, one of the greatest societal challenges of the 21st century.

Currently, more than 80% of European oil and natural gas is produced offshore. However, primary production of non-renewable energy in the EU is likely to decrease significantly in the next decades. By 2030, European oil production is projected to decline to 30% of current levels (onshore and offshore), while production of natural gas will decrease to less than half of current production levels. In a business-as-usual scenario, Europe's energy security will become increasingly tenuous, forcing ever increasing reliance on imported energy. Exploitation of methane hydrate, an unconventional fuel source, offers some interesting potential, but a viable means of exploiting this volatile energy resource is some way in the future. The development of marine renewable energy is, therefore, a strategic priority and already the subject of major commercial interest.

Marine renewable energy is defined here as renewable energy production that makes use of marine resources (wave or biomass) or marine space (offshore wind). Among various types of marine renewable energies, offshore wind, tide and current are the three with the greatest short-term production potential in Europe (Le Boulluec *et al.*, 2010). The highest offshore wind and ocean energy resources exist off the coasts of Portugal, north of Spain, along the Atlantic coasts of France, the UK, and Ireland, and in the North Sea basin and along the coasts of Denmark and Sweden and Norway[2]. Given that the most favorable sites for offshore wind and ocean energy are often located far from the main population centres, development of these energy resources will require a major investment in grid capacity both offshore and on-shore to bring the energy from the production site to the consumer.

It has been projected that offshore wind energy could meet between 12.8% and 16.7% of the entire EU electricity demand by 2030[3]; while renewable ocean energy (wave, tide and currents) could meet 15% of EU energy demand by 2050[4]. The renewable energy goal is a headline target of the Europe 2020 strategy for smart, sustainable and inclusive growth (EC COM(2012) 271 final). Europe 2020 targets a 20% increase in renewable energy production, and a corresponding 20% reduction in CO_2 emissions. To achieve these targets, there is a strong need for energy diversification and for a transition towards alternative energy sources.

[2] http://www.aquaret.com/

[3] http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/Offshore_Report_2009.pdf

[4] http://www.eu-oea.com/wp-content/uploads/2012/02/EUOEA-Roadmap.pdf

Credit: IFREMER

Enormous amounts of energy are available at the sea surface. The challenge is to develop technology which can harness wave energy and withstand the harsh conditions it generates.

7.3.2 Marine hydrocarbon resources (oil, gas, and methane hydrate)

IFREMER ROV (Remotely Operated Vehicle) Victor 6000 taking samples of gas hydrates at 3,200m water depth off the Congo margin, Gulf of Guinea.

Credit: IFREMER.

Credit:IFREMER

The presence of free gas alveoli isolated in massive gas hydrates in a marine seawater environment can be explained by a fast gas flow into a favourable temerature and pressure conditions for gas hydrate formation.

According to the International Energy Agency World Outlook Report (2012)[5], the world energy map is changing rapidly. Among the main reasons for this significant change are the rapid resurgence of oil and gas production in the United States, the global development of unconventional hydrocarbon production, and the possibility of a (partial) retreat from nuclear power in some countries. Despite the pressure to reduce CO_2 emissions, hydrocarbons will continue to provide a significant part of the global energy mix in the decades to come. The fate of marine non-renewable energy resource exploitation will surely be impacted by these major changes, but also by the growing environmental concerns as offshore oil and gas exploitation moves into deeper waters and more hostile environments.

Europe must adapt to the decline of the North Sea oil and gas reserves and production from more mature fields. Enhanced recovery from existing fields and discoveries of new reserves could mitigate this trend. The current price of hydrocarbons favours increased efforts towards the development of cost-effective technologies for both exploration and production, with an increasing focus on marginal fields, the deep sea, and harsh environments such as the Arctic.

Vast amounts of carbon are stored in methane hydrates deposited in marine sediments along the continental margins. The ever-growing demand for natural gas could be met by gas production from these unconventional deposits. At the molecular level, these ice-like solids are composed of methane trapped in water cages. They are only stable under certain high pressure and low temperature conditions and occur typically at water depths of between 300m and 4,000m, in sediments several hundreds of meters below the seafloor. Methane hydrates outcropping at the seabed are found at cold seeps and mud volcanoes where methane from deeper sources ascends towards the surface. Warming may induce large-scale dissociation of these near-surface hydrates.

Methane released from dissociating gas hydrates is typically oxidized by microorganisms in the surface sediments and in the overlying water column. Dissolved oxygen is consumed by these organisms while methane is ultimately converted into carbon dioxide (CO_2).

The on-going de-oxygenation and acidification of seawater may thus be amplified by gas hydrate dissociation with harmful consequences for marine ecosystems. At shallow water depths, a significant portion of the methane released escapes into the atmosphere to amplify global warming in a positive feedback loop. Methane hydrates thus represent a potential threat and opportunity; they may strongly affect the long-term evolution of the marine environment and the climate system but could also secure the supply of natural gas far into the future.

The technology to deliver a viable supply of natural gas from methane hydrate deposits is still in its infancy. Successful tests have been completed in onshore permafrost areas, such as at Malik[6], Canada (in 2002 and 2007/2008) and Alaska[7], USA (in 2012). The gas was released at depth by the injection of hot water to de-pressurize the reservoir (Malik) or by the injection of gaseous CO_2, which is trapped in the water cages of the hydrate structure releasing methane gas. CO_2 can be obtained from coal power plants and industrial sources and can potentially be sequestered safely underground as an ice-like solid.

[5] http://www.worldenergyoutlook.org/publications/weo-2012/

[6] http://soundwaves.usgs.gov/2002/04/

[7] NETL, The National Methane Hydrate R&D Program http://www.netl.doe.gov/technologies/oil-gas/FutureSupply MethaneHydrates/projects/DOEProjects/MH_06553HydrateProdTrial.html

It is estimated that the entire Japanese gas demand could be met over a period of at least one hundred years by the production of methane gas from its indigenous hydrate resources. Long-term offshore production tests financed by the Japanese national gas hydrate programme at the Eastern Nankai Trough[8] will begin in 2014. These offshore tests aim to produce gas via depressurization of the reservoir located at the Japanese continental margin. China, India, South Korea, Taiwan and Brazil have also initiated large-scale national programmes to develop marine gas hydrates as a new energy resource. Cutting-edge technologies for gas production via CO_2 injection are also under development within the German SUGAR initiative coordinated by the Helmholtz Centre for Ocean Research, Kiel (GEOMAR[9]).

While the security of the European gas supply could be greatly enhanced by the development of indigenous gas hydrate deposits, gas production via CO_2 injection would also complement European carbon capture and storage (CCS) objectives, providing important incentives for the large-scale implementation of CCS. There is thus an urgent need for a well-defined research strategy on gas hydrates and large-scale coordinated programmes at EU level.

Offshore hazards can be triggered both by human activities and natural geological events, which are an important economic issue for the hydrocarbon industry. Environmental pressures for the offshore hydrocarbon sector include impacts related to exploration, drilling, operation and decommissioning. Routine operations at production platforms can lead to the release of oil, chemicals and naturally occurring radioactive materials into the sea, especially through discharges of produced water and from drill cuttings (Roose *et al.*, 2011). The 2010 Deepwater Horizon explosion and oil spill in the Gulf of Mexico highlighted the need for updated standards and regulations for hydrocarbon exploration and production in the deep sea. To introduce stringent measures from prevention to response, and to address liability issues, will be necessary to guarantee the highest level of protection throughout the EU and the rest of the world[10].

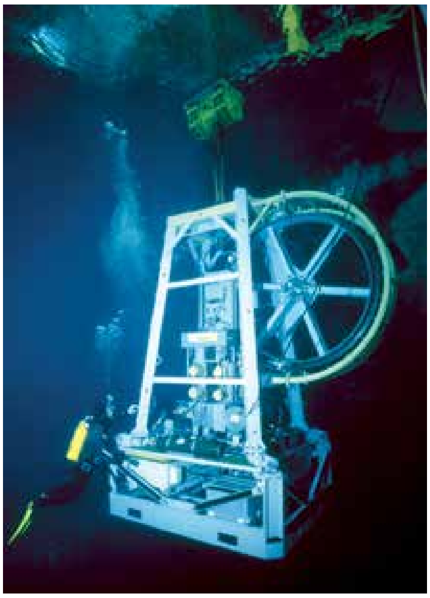
The research challenges facing the offshore hydrocarbon (oil and gas and unconventional fossil fuel such as methane hydrate) may be categorised under (1) Knowledge, monitoring and prediction; (2) Technology and engineering; and (3) Hazard monitoring and mitigation.

1. **Knowledge, monitoring and prediction**
   Research to improve the theoretical understanding of methane gas hydrate processes, including investigation of the mechanical behaviour of gas hydrate-bearing sediment, will provide important fundamental knowledge for safe and viable exploitation. Efforts to monitor, in the long-term, hydrate dissociation, microbial methane consumption and methane fluxes into the atmosphere at high northern latitudes will also be beneficial as part of the environmental and climate change research agenda. This will require improved numerical models to facilitate prediction of long-term impacts of future gas hydrate dissociation on marine ecosystems and climate change. Models may also be used to analyse and predict the potential environmental impact of gas hydrate exploitation actions. It will also be strategically beneficial to conduct an in-depth survey of the European continental margin to quantify the reserve capacity and distribution of near-surface gas hydrates and exploitable gas hydrate deposits.

[8] Fire in the Ice, 2012:12(2), Methane Hydrate Newsletter, The Energy Lab, NETL. http://www.netl.doe.gov/technologies/oil-gas/publications/Hydrates/Newsletter/MHNews_2012_June.pdf

[9] http://www.geomar.de/en/research/fb2/fb2-mg/projects/sugar-2-phase/

[10] COM(2010) 639 final: Energy 2020 A strategy for competitive, sustainable and secure energy, European Commission.



Credit: IFREMER

A piezocone "Penfeld" seabed penetromoter is used to characterize the geological and physical properties of the sediments up to 30m below the seabed

2. **Technology and engineering**

During the last decades, floating production platforms, sub-sea umbilical riser and flow lines, and sub-sea production equipment have been successfully developed by the oil and gas industry. However, new innovations are still required in order to ensure safer operations, especially in new frontiers such as the deep sea and the Arctic. Sub-sea processing and intervention also require further improvements, including managing the supply of electrical power from land.

From a technological perspective, new geophysical tools are needed, including improved sub-salt/sub-basalt imaging; very high resolution 3D seismic imaging systems; electromagnetic seabed logging technologies; seafloor monitoring systems; and exploration systems with reduced impact on marine life (marine mammals, fish, benthic communities, etc.). Research and development should also focus on the delivery of technological advances in the following areas:

- Developing safer deep sea drilling technologies with reduced environmental impact.
- Improving methods for enhanced oil recovery (EOR) by polymer injection and a better understanding of its environmental impacts.
- Developing innovative techniques for the exploration and production of natural gas from hydrate-bearing sediments (CO_2 injection, thermal activation or depressurisation), accompanied by an economic evaluation of each method.
- Developing associated carbon capture and storage (CCS) techniques; e.g. CO_2 injection to enhance oil recovery and to store carbon in depleted offshore fields or saline aquifers.

3. **Hazard monitoring and mitigation**

With energy exploration moving further offshore into deeper water and harsher environments, it will be essential to improve the tools and knowledge for identifying risks and hazards. Key activities will be field characterization and *in situ* monitoring. An improved understanding of fundamental processes and reliable models to detect and interpret hazard precursors will also be necessary to prevent and react to hazards and threats.

Credit: U.S.Navy

Dark clouds of smoke and fire emerge as oil burns during a controlled fire in the Gulf of Mexico to help prevent the spread of oil following the explosion on Deepwater Horizon in 2010

For natural gas hydrate exploitation, it will be essential to assess the evolution of hydrate dissociation during the production phase, to monitor methane fluxes into the atmosphere at high northern latitudes, and ocean acidification in the region of the activity. Determining how sediment partially saturated with gas hydrates will behave once the gas hydrates begin to dissociate will be critical. For example, it will be necessary to assess the potential for, and consequences of, sediment deformations and submarine landslides. Interpretation and understanding of different failure and geohazard scenarios (from causes to consequences) can be achieved with numerical modelling, based on well identified and understood processes. Efficient mechanisms and approaches to achieve these monitoring and modelling needs should be the focus of research and development activities in the short-term.

7.3.3 Marine renewable energy

7.3.3.1 Offshore wind

The most notable recent development in offshore wind is the move from very shallow nearshore wind parks to deeper offshore wind arrays and the development and implementation of floating windmill installations. Deepwater wind parks using prototype installations have been developed in Portugal (2011, Principal Power[11]) and Norway (2009, Hywind[12]); in both cases electricity generation is in the megawatt (MW) range. Compared to onshore wind turbines, there is also a gradual shift towards gigantism in offshore turbines, which brings engineering and maintenance challenges associated with large components such as blades, support structures and foundations.

Credit: Errichtung, RePower

A major expansion in wind energy is underway in many inshore areas around Europe. Wind farming is set to move further offshore.

[11] http://www.principlepowerinc.com/news/press_PPI_WF_inauguration.html

[12] http://www.statoil.com/en/TechnologyInnovation/NewEnergy/RenewablePowerProduction/Offshore/Hywind/Pages/HywindPuttingWindPowerToTheTest.aspx

A prime objective in the EU Strategic Energy Technology Plan's[13] European industrial initiative on wind energy is to facilitate the expansion in offshore wind energy production by reducing the cost of installation and operation. As the number of devices to be installed around European coasts increases, there is a need for a more cost effective and dedicated installation fleet. Production, operation and maintenance of the large number of devices and arrays will inevitably result in the development of a service industry much like that servicing the North Sea offshore oil and gas sector. Increased service life and reduced maintenance requirements will also be critical and will depend in large part on the types of materials used in the devices. Hence materials science will be a very important focus area within the sector. Specific technical research challenges will include development of:

- Innovative turbine designs to facilitate installation (e.g. reduced weight) and to reduce maintenance requirements further offshore;
- Larger floating offshore wind turbines (from current 2MW to more than 3-5MW) in larger arrays;
- Improved understanding of the interaction between waves and structures (floating or moored), and the optimum positioning of wind turbines within an array;
- A substantial grid structure as envisaged by Friends of the Supergrid[14], a proposed pan-European transmission network facilitating the integration of large-scale renewable energy and the balancing and transmission of electricity, with the aim of delivering efficiencies for the European market.

Underwater tidal turbines convert the energy of marine tidal streams into electricity, in the same way as wind turbines do with the wind. Picture shows a tidal turbine being tested at the port of Brest

Credit: OpenHydro, DCNS

7.3.3.2 Tidal and wave energy

Tidal power converts the energy of tidal flows into electricity. Despite high installation costs, tidal energy is attractive and more reliable than wind because of its predictability. Two types of generators are used to extract tidal energy:

1. **Barrage:** Installing a dam structure across the river that uses the ebb and flow of the tides to create the height difference essential for generating energy (e.g. La Rance in Brittany, which has been in operation since 1966). Tidal range structures are generally characterized by high investment costs and a high environmental impact.

[13] SET-Plan; COM (2007) 723 and COM(2009) 519

[14] http://www.friendsofthesupergrid.eu/

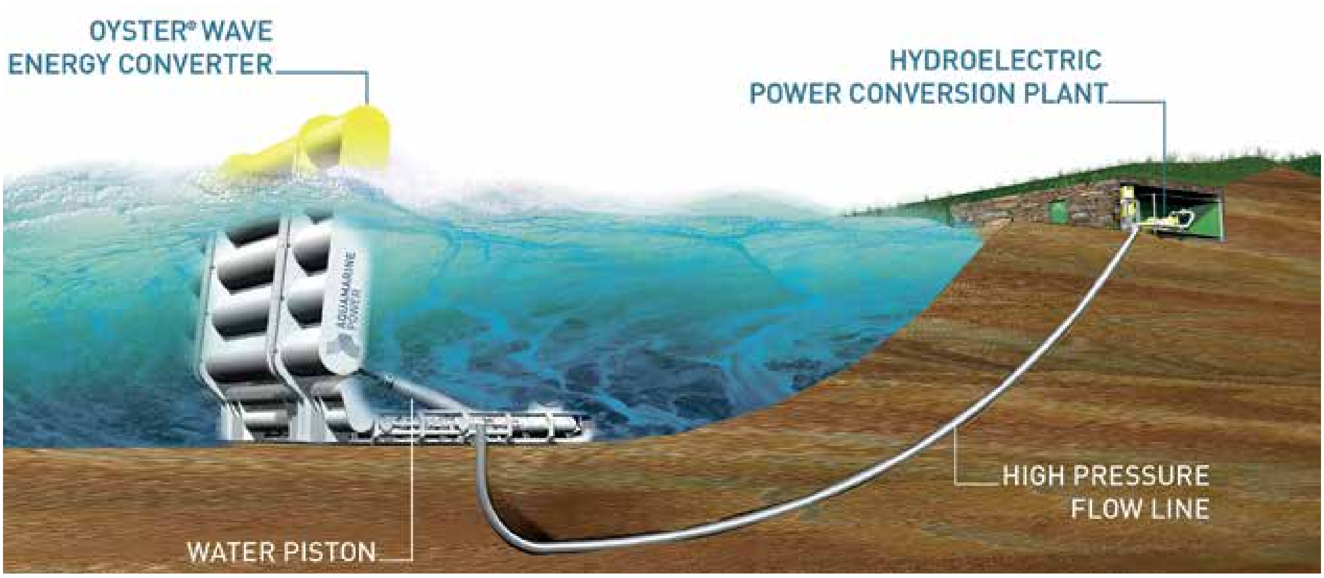
2. **Tidal current (stream) generators:** This approach involves installing turbines underwater in fast flowing tidal streams. Examples of already installed systems include SeaGen[15] in Northern Ireland while prototype tidal power turbines (e.g. Hammerfest Storm 1000) are being demonstrated at the EMEC (European Marine Energy Centre) tidal test site in the Scottish Orkney Isles[16]. It has been suggested that the progress in tidal energy to multi-megawatt arrays could advance much faster than that achieved for wind energy development (Bahaj, 2013).

There is further potential for the development of tidal energy but this will be restricted by the availability and access to suitable marine sites. On the basis of current technology, a minimum flow of 2.5m per second is required for economically viable energy generation, a criterion that limits potential site options.

Wave energy, the harnessing and conversion to electricity of energy from ocean surface waves, is still less mature. As a nascent technology, many different concepts and prototypes have been developed resulting in strong competition in a technology race to deliver the first commercially viable system. Examples of systems in development include 'Wave Dragon'[17], and Oyster[18]. Another potentially innovative design is the S3, a flexible floating wave tube which can harvest wave energy via an electro-active polymer ring generator. (see Chapter 10 on blue technolgies)

The technology race to develop a commercially viable prototype wave energy converter will continue in the coming years. Design, construction materials and control systems are crucial issues in the development of devices that can endure and operate cost-effectively in the harshest sea states. For wave energy converters, it will be particularly important also to reduce weight and to reduce production and operating costs.

The Oyster hydro-electric wave converter is a buoyant, hinged flap designed to attach to the seabed. Wave energy causes the flap to rise and fall, an action which drives water into a shore-based hydro-electric power conversion plant.



Credit: Aquamarine Power

[15] http://www.marineturbines.com/

[16] http://www.emec.org.uk/facilities/tidal-test-site/

[17] http://www.wavedragon.net

[18] http://www.aquamarinepower.com/

Research priorities common to development of both wave and tidal energy resources include:

- Improve the understanding of the nature of the total flow environment and methods to holistically assess the energy delivery potential at sites of interest. Develop enhanced modelling of wave and current coupling and its impact on performance and component design.
- Improve computational tools to better understand and manage the large motions and strongly non-linear behaviour of wave energy absorbers. Improve device responses to wave grouping and multi-directionality.
- Develop models to facilitate better wave climate forecasting (short-, medium- and long-term).
- Develop tidal energy converters able to exploit low flows for economically viable tidal energy generation.

7.3.3.3 Osmotic energy (salinity gradient power)

It is possible to generate energy from the difference in the salt concentration - and hence osmotic potential - between seawater and river (brackish or fresh) water. Two osmotic methods are under investigation: pressure-retarded osmosis (PRO) and reverse electro-dialysis (RED). The former technique has been in use since 2009 at the first osmotic energy plant in Tofte, Norway (Statkraft[19]). The RED method is being developed and tested by Wetsus[20] in the Netherlands. Both technologies have been demonstrated to produce electrical energy in the kW range. A major focus will be on up-scaling to megawatt-level production and developing commercially viable systems as the infrastructure for the process is currently very expensive. It is estimated from the Statkraft experience, that to supply power for 30,000 homes would require a plant the size of a sports stadium with 5 million m² of the membrane.

Credit: StatKraft HR.

In an osmotic power plant, the pressure created from the membranes is utilised through a turbine to generate electricity.

The advantage of osmotic energy is that the plants are located at river exits which are often close to both grid infrastructure and populated areas. However, the technology is still in the early R&D phase. The semi-permeable membrane that separates two solutions of different concentration is the most essential component in the osmotic power system and hence is a key focus for further research and development. A particular challenge is to alleviate the problem of bio-fouling of the membrane with silt and algae.

7.3.3.4 Ocean Thermal Energy Conversion (OTEC)

OTEC uses the temperature differences between cooler deep and warmer shallow ocean waters to run a heat engine and produce electricity. This technique is largely restricted to use in tropical regions and may therefore have applications in some of Europe's outermost regions (a prototype has been developed and installed in the French Reunion Islands in the Indian Ocean). However, as it combines the potential for production of electrical energy with the ability to both produce fresh water and potentially fertilize the sea by bringing water from the deep sea to the surface, it represents a very attractive technology where Europe can play a major role in further development and implementation[21].

[19] http://www.statkraft.com/energy-sources/osmotic-power/

[20] http://www.wetsus.nl/research/research-themes/blue-energy

[21] http://www.otecnews.org/

Addressing engineering issues related to the deployment, survival and maintenance of OTEC equipment in the harsh marine environment is a key research challenge. It will also be beneficial to develop a production control in OTEC devices for regulating electricity generation, fresh water production and fertilization capacity.

7.3.3.5 Marine biomass

Marine biomass in the context of renewable energy refers to the use of microalgae and macro-algae for biofuel production. This energy resource can potentially be grown and harvested all along the European coasts. It has been estimated that a marine biomass farm the size of Luxembourg could produce 12.6 TWh of energy[22]. Hence, farming and harvesting of marine biomass, and its conversion to fuel, has the potential to be a substantial source of energy for Europe, avoiding the inherent conflicts of producing biomass energy from land based crops where it competes for space with food production.

The productivity of algal biomass is higher than for terrestrial crops, and microalgae in particular, can be grown in highly-efficient closed systems with close to complete cycling of nutrients and water. Several marine biomass projects are in progress in Europe including, Seaweed Energy Solutions AS (SAS) operating in both Norway and Portugal[23] and AlgaePARC[24], a pilot plant in the Netherlands designed to develop knowledge, technology and process strategies for the sustainable production of microalgae as feedstock for fuel, chemicals and feed at industrial scale.

The challenges for developing viable marine biomass production are manifold because of the enormous up-scaling which will be needed for commercial production (Querellou *et al.*, 2010). Research priorities include:

- Improving knowledge and understanding of the biodiversity of microalgae at the molecular level and on a global scale;
- Exploitation of the physiological potential of microalgae to produce commercially viable biofuels using bioengineering;
- Developing selected microalgal strains and cultivating at a scale of production to deliver an optimal mix of bio-energy and bioproducts;
- Achievement of a net energy gain along the whole production chain necessary to convert microalgal biomass into biofuels;
- Achievement of full sustainability of the whole production chain in terms of regional and global impact.

Credit: AlgaePARC, Wageningen UR, Netherlands

AlgaeParc is a high-technology algal biomass production facility designed to test production methods for a range of end products including fuel, chemicals and animal feed.

[22] http://wavec.org/client/files/9_-_Pal Bakken.pdf

[23] http://www.seaweedenergysolutions.com/

[24] http://www.marineboard.eu/fora/3rd-marine-board-forum/2-uncategorised/113-3rd-marine-board-forum-presentations http://www.algae.wur.nl/UK/projects/AlgaePARC/

7.4 Marine mineral resources

Exploitation of marine mineral resources is identified as a priority area in the EU Blue Growth strategy. Europe has traditionally relied heavily on the import of such raw materials. Hence, while deep sea mining is a potentially profitable commercial enterprise in its own right, it is also strategically important to sustain and support the increasing demands of green and emerging technologies. The surge in the price of non-energy raw materials and the pressure on supplies of strategic metals and rare earth elements (REE), have driven the search for new deposits, especially in the marine environment. There is a notable increase in exploration activities in the international part of the seabed, access to which is regulated by the UN International Seabed Authority (Table 7.1).

Credit: IFREMER

The yellow elasipod holothuroid on a dense bed of polymetallic nodules in the Clarion-Clipperton Fracture Zone.

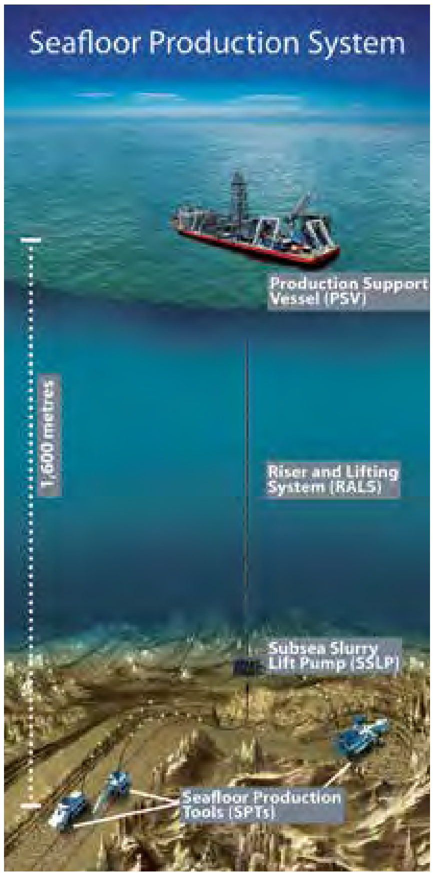
There are three types of deep-sea deposits with commercial potential as mineral resources: seafloor massive sulphides or SMS (which can contain high concentrations of copper, zinc, gold, silver, cobalt and lead), polymetallic nodules, and cobalt-rich manganese crusts (Hein *et al.*, 2013). The scientific exploration of the oceans, carried out over the past three decades, has identified several geological and geochemical processes leading to the concentration of marine mineral deposits. Submarine hydrothermal activity is a consequence of the motion of tectonic plates and the associated volcanic activity. The presence of heat and faults facilitates the circulation of fluids within the oceanic crust and leads to the concentration of minerals in hydrothermal vent sulphide deposits.

The physical properties of polymetallic nodules and manganese crust have allowed them to accumulate and concentrate metals from the surrounding seawater. Polymetallic nodules are found in all oceans, at depths exceeding 4,000m and in areas characterised by slow sedimentation rates. Cobalt-rich ferromanganese (Fe-Mn) crusts occur throughout the global ocean on seamounts, ridges and plateaus where ocean currents and slow sedimentation rates have prevented sediment deposition for millions of years. Deposits have precipitated from ambient seawater onto rock substrate forming a crust with thicknesses varying from several to tens of centimetres, at depths between 400m and 4,000m. Developments in remote operated vehicles (ROVs) and manned and autonomous submersibles have greatly advanced the potential to discover new reserves of these high-value materials.

To obtain a better estimation of the potential of all the reserves, it will be essential to increase our understanding of the physical, chemical and biological processes that have led to their genesis and to their location. Key research challenges include:

- Understanding the geological, geochemical and biological processes leading to the formation of potential mineral resources;
- Mapping the mineral resources of the deep sea and evaluating their industrial potential. To facilitate high resolution seabed mapping in remote regions, advancing the technology of automated underwater vehicles (AUV) could lead to discoveries of new mineral deposits. New exploration tools should also be developed to access deeper targets and more hostile environments.
- In addition to high resolution seabed mapping, habitat mapping and monitoring should also be employed to characterize the existing ecosystem and provide an ecological reference, prior ro exploitation.

The scientific community has a role to play in the process to establish clear regulations for sustainable exploitation beyond a simple mining code. Europe needs to work with international organizations such as the ISA (International Seabed Authority) and UNCLOS (United Nations Convention on the Law of the Sea) to develop transparent guidelines and rules for deep sea mining in international waters. Conservation policies should become an integral part of international seabed regulation, for example to be initiated by ISA (Van Dover, 2011a). Exploitation proposals should be accompanied by scientifically sound biodiversity and conservation plans in order to mitigate against significant environmental impacts and to restore ecosystems (Van Dover, 2011b).



Credit: Nautilus Minerals Ltd.

Schematic showing deep sea mining system

TABLE 7.1. International and European development in marine mineral resource exploration and exploitation (as of December 2012)

	Country	Leading Organization	Development
International	Canada	Nautilus Minerals Inc.	The government of Papua New Guinea granted a 20-year mining lease for polymetallic sulphide extraction at Solwara 1 in the Manus Basin.
		Deep Green Resources Inc.	Mine deep sea polymetallic nodules in the Pacific: Clarion-Clipperton Cu-Ni project
	China	COMRA (China Ocean Mineral Resources R&D Association)	Application (2012, ISA) for approval of a plan of work for exploration for cobalt-rich ferromanganese crusts in the West Pacific. Approval (2011, ISA) of a plan of work for exploration for polymetallic sulphides located in the Southwest Indian Ridge.
	Kirabati	Marawa Research and Exploration Ltd.	Approval (2012) of plan of work of polymetallic nodules exploration in the Clarion-Clipperton Fracture Zone.
	Japan	JOGMEC (Japan Oil, Gas and Metals National Corporation)	Application (2012, ISA) for approval of a plan of work for exploration for cobalt-rich ferromanganese crusts in the West Pacific Ocean.
	Korea		Approval of a plan of work (2012, ISA) for exploration for polymetallic sulphides in the Central Indian Ocean.
	Nauru	Nauru Ocean Resources	Approval (2011) of a plan of work for exploration for nodules in the Clarion-Clipperton Fractured Zone.
	Tonga	Nauru Ocean Resources Inc. (NORI) Tonga Offshore Mining Limited (TOML)	
	Russia	Ministry of Natural Resources and the Environment of the Russian Federation	Approval of a plan of work (2011, ISA) for exploration at the Mid-Atlantic Ridge.

	Country	Leading Organization	Development
Europan	Belgium	G-TEC Sea Mineral Resources NV	Approval of plan of work for polymetallic nodules exploration in the eastern-central part of the Clarion-Clipperton Fracture Zone in the Pacific Ocean.
	France	IFREMER	A plan of work, operated by IFREMER and approved by ISA, for exploration for polymetallic sulphides situated along the Mid-Atlantic Ridge. At the same time, Ifremer has, since 2002, a 15 year contract with ISA for the exploration of polymetallic nodules in the Pacific Ocean
		Public-private consortium*	Under national strategy on deep-sea mineral resources, the partnership carried out three research cruises (2010, 2011, 2012) in waters off the Wallis and Futuna Islands (French overseas territory in the Western Pacific) for potential sulphides deposits.
	Germany	German Federal Institute for Geosciences and Natural Resources (BGR)	Contract for the exploration of polymetallic nodules in the Central Northeastern Pacific with ISA since 2006 for 15 years.
	UK	UK Seabed Resources Ltd.	Approval of a plan of work by ISA for polymetallic nodules in the eastern part of the Clarion-Clipperton Zone.

* French Ministry of Ecology, Sustainable Development and Energy, the Territory of Wallis and Futuna Islands, public institutions, IFREMER, Marine Protected Areas Agency (AMP), the Geological and Mining Research Office (BRGM), mining (AREVA and ERAMET) and engineering (Technip) company

8
Sustainable use of deep sea resources

Credit: MARUM – Center for Marine Environmental Sciences, University of Bremen

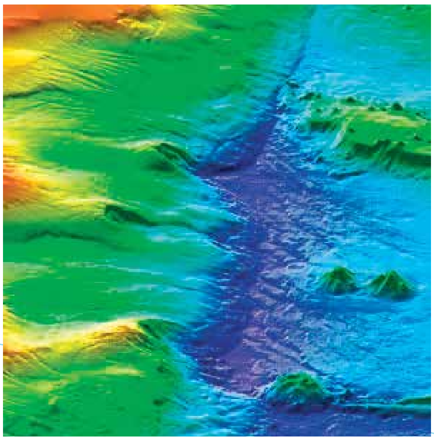
8.1 Introduction

The deep sea provides more than 90% of the total habitable volume of Earth and contains an extensive but largely undiscovered biodiversity. Over the past decade there has been a drive for ocean exploration leading to the discovery of many new species (Box 8A). Despite these efforts, only 0.0001% of the deep-sea has been sampled biologically. Still less is known about the functioning of deep-sea ecosystems, how these systems have evolved or their resilience to human threats and natural pressures. Recent technological advances have revolutionized access to this vast and remote environment, leading to the discovery of a wealth of physical, mineral and biological resources in the deep-sea. This, together with the depletion of land-based resources, is driving a growing commercial interest to exploit the deep-sea.

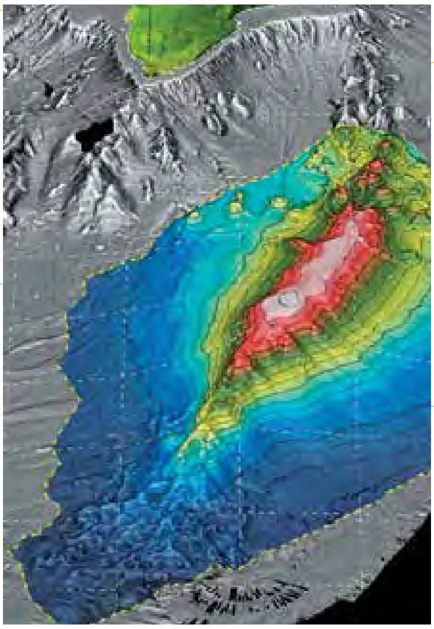
The deep sea

The deep sea is defined as the area of the ocean that is deeper than the continental shelf edge, which lies at variable depths. For ease of simplicity the upper boundary of the deep sea is often placed at 200m depth or in some delineations 400m. Using the 200m definition its global area is >350 million km² or >66% of the global surface.

The full societal value of the deep sea is only just beginning to be revealed (Armstrong *et al.*, 2012). Emerging deep-sea industries include mining for gas hydrates and minerals, bio-prospecting for marine biotechnology and genetic resources, extraction of hydrocarbons in very deep water and CO_2 sequestration. Whilst this offers a real opportunity for providing society with goods and services, the sustainability of the current rate of exploitation from the deep sea is highly questionable. The impact of human activities is evident across the global ocean and yet the vulnerability of deep-sea ecosystems to human threats and natural pressures is not fully known (Armstrong *et al.*, 2012). Responsible and sustainable utilization of the deep sea will require a new era of high quality, integrated deep-sea research delivered in the context of societal challenges and needs to balance socio-economic gain with sustainable management and governance of the deep sea. In recent years, a number of European initiatives have presented scientific recommendations and roadmaps for future deep-sea and sub-seafloor research (e.g. Cochonat *et al.*, 2007; Kappel and Adams, 2011; Kopf *et al.*, 2012). However, there remains a strong need for an interdisciplinary and cross-sectoral approach taking into account expertise in the social, legal and policy domains.



Credit GEOMAR



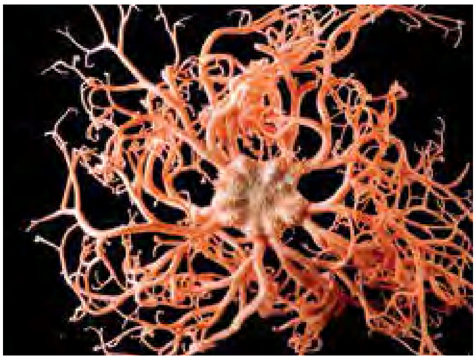
Credit: F. Tempera, ImagDOP. & J. Luis, UAlg-CIMA

Bathymetry map of the deep seafloor. Recent technology developments have facilitated a much greater access to the deep sea and subsea floor. However the deep sea is vast and still mostly unexplored.

The Condor Seamount to the southwest of the Azorean island of Faial, Portugal (vertical exaggeration: 2x). This elongated volcanic ridge extends 39 km in length and rises from more than 1,800m depth to 185m.

BOX 8A deep sea biodiversity: a decade of discovery

The first international Census of Marine Life (2000-2010) transformed our knowledge of deep sea biodiversity, distribution and abundance, identifying over 5,500 new marine species (Ausubel *et al.,* 2010). The European Implementation Committee (EuroCoML) were key contributors to this global effort. For example, the EuroCoML MAR-ECO project revealed new insights into deep-sea biodiversity and ecosystem functioning in the Atlantic Ocean. The field work in 2010 along the Mid-Atlantic Ridge between Iceland and the Azores led to the identification of new species of Acorn worms, believed to be close to the missing evolutionary link between vertebrate (backboned) and invertebrate animals. In parallel, the European science community has been active in numerous deep-sea, sub-seafloor and extreme environment initiatives funded by the EU Framework Programme including the Coordinated Action for Research on Life in Extreme Environments (CAREX) project, Hotspot Ecosystem Research and Man's Impact on European Seas (HERMIONE) project, the CoralFISH project assessing the interaction between cold water corals, fish and fisheries and the Deep Sea and Sub-Seafloor Frontier (DS^3F) project.



Credit: David Shale

Basket star (*Euryalid Ophiuroid*) from the North Atlantic (MAR-ECO CoML expedition)

Credit: David Shale

Acorn worm (*Pink Enteropneust*) from the North Atlantic (MAR-ECO CoML expedition)

Credit: Marcel Jaspars, University of Aberdeen

Researchers sorting specimens from a deep sea haul

Credit: MARUM, University of Bremen

Flytrap anemone (*Actinoscyphia*)

8.2 Deep sea resources: benefits, impacts and emerging areas

8.2.1 Deep sea ecosystem goods and services

Despite their remoteness, deep-sea environments provide us with goods and services that we are often unaware of. These range from direct provisioning services such as fish, chemical compounds for industrial and pharmaceutical use, or mineral resources, to less directly identifiable services such as regulation of the global biogeochemical cycles and supporting services such as nutrient cycling which are crucial to the functioning of our planetary system (Armstrong *et al.*, 2012; Millenium Ecosystem Assessment, 2005[1]). The increase in cost-effective access to the deep sea and knowledge of the resource potential has driven a rise in interest to exploit these areas for biological and mineral resources. As a result, there are a variety of emerging ecosystem goods and services including marine genetic resources and mining of minerals and gas hydrates that are likely to require new governance approaches and careful environmental assessments to ensure socio-economic gain is balanced with sustainable management (Box 8B).

Credit: GEOMAR

The hydrothermal ecosystem at Logatchev vent site (North Atlantic)

[1] www.unep.org/maweb/en/index.aspx

BOX 8B. Emerging deep sea industries

Credit: Nautilus Minerals Ltd.

Deep sea sampling by Nautilus Minerals Ltd. on exploration cruises in the Bismarck Sea off Papua New Guinea

The exploitation of **marine genetic resources** is a growing field, with over 18,000 natural products and 4,900 patents associated with genes of deep-sea marine organisms; the latter growing at 12% per year (Arrieta *et al.,* 2010). Much work needs to be done in determining the ownership rights and entitlements to these resources, many of which are found in areas beyond national jurisdiction and which should be subject to benefit sharing for the common heritage of mankind (Arnaud-Haond *et al.,* 2011; Nagoya Protocol, 2010).

The rise of commercial interest in deep-sea minerals is leading to new industries including mining for polymetallic sulphides, cobalt crusts and manganese nodules and possibly, although less likely, mining for rare earth elements. These deep-sea mining activities are posing a risk to rare, vulnerable ecosystems such as seamounts, which host a fauna rich in endemic species (possibly 50% of their diversity).

The mining of gas hydrates on continental margins has been mooted for several years and feasibility studies are being carried out that would involve extraction of the gas *in situ*, e.g. by replacing the methane hydrate with CO_2 Hydrate. There remain many unresolved questions in this area such as how to quantify the volume of methane hydrate on continental margins; the role of microbes in methane consumption (Boetius *et al.,* 2000), fluid flow within rocks and on the production of hydrate; the stability of sediments during extraction of methane and subsequently; and geosphere/biosphere interactions and their stability under a warming climate regime.

(Deep sea mining and gas hydrate exploitation are further discussed in Chapter 7).

Credit: Nautilus Minerals Ltd.

Credit: Fundacion Medina, Andalucia, Spain

Geologist examining a piece of drill core

Researchers working on marine bacterial cultures

8.2.2 Human impacts

Despite the clear socio-economic gain from deep-sea resources, the current rate of exploitation from the deep-sea environment appears far from sustainable. Halpern *et al.* (2008) showed that no part of the global ocean was devoid of human impact and 40% is already strongly affected. There are no global estimates yet available for change in deep-sea habitats but there is growing evidence that deep-sea ecosystems are being increasingly impacted by anthropogenic activities. At present, bottom trawling has by far the greatest physical impact (Benn *et al.,* 2010), although policies are being discussed to reduce the fishing effort in areas most at risk, both within jurisdictional waters (e.g. the 2013 revision of the EU Common Fisheries Policy) and in international waters by the United Nations (Division for Ocean Affairs and Law of the Sea).

Credit: Pål Buhl-Mortensen, IMR, Norway, HERMIONE project

Left: Norwegian deep-sea coral reef;
Right: Deep-sea corals destroyed by bottom trawling

The hydrocarbon industry has a much lower footprint on the seabed, but oil extractions, particularly in deeper parts of continental margins, will expand notably in the next two decades, and the effects of another oil leak such as that which occurred in the Gulf of Mexico in 2010 could be catastrophic. To reduce the impact of any future oil spill, more research is needed on the impact of hydrocarbons on marine ecosystems, and again on the distribution of different habitats in the vicinity of production platforms and major shipping routes. Deep-sea ecosystem models are quite rare because of the difficulty in collecting the relevant data and the complexity of many of the ecosystems, but they are becoming increasingly necessary. Furthermore, it is recommended to link industrial exploration and exploitation with thorough ecosystem assessments, including long-term observatories to study ocean variables to detect impacts. The continuing production of CO_2 from fossil fuels will necessitate its removal in the future possibly by CO_2 sequestration below the seabed, although the local, regional and longer-term impacts on deep-sea ecosystems is still largely unknown.

One other major pollutant in the deep sea is litter. Despite the long-standing Convention (1972) and Protocol (1996) on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, such activities continue to be problematic with much pollution ending up on the deep seafloor. Litter, and especially plastic, occurs both in the form of macroscopic debris and microscopic particles.

Many pelagic organisms are killed or maimed by ingesting plastic waste, whilst the breakdown products of this waste create microscopic particles that can absorb organic pollutants from seawater, including PCBs, DDT, PAHs, and possibly heavy metals, thus becoming even more problematic (Boumedjout, 2011). The full impact of this is yet to be established, and although early investigations focused on the Pacific, the problem exists in all oceans including the Atlantic and Mediterranean Sea.

Credit: Alex D Rogers, Oxford University

8.2.3 Monitoring climate change impact on deep sea ecosystem functioning

Other impacts on the deep sea include climate change and deep-water warming which are progressing at an unprecedented rate. They will have their greatest impact in the polar regions, and summer ice cover has already reduced significantly in the Arctic in recent years. Abyssal ecosystems and fragile deep-sea habitats are also expected to be impacted, both along EU continental margins (e.g. Fram Strait; Bergmann *et al.,* 2011) and in the land-locked basins (Mediterranean Sea, deep fjords). Long-term monitoring stations have been installed and need to be maintained close to the ice front to monitor these changes and their effect on the deep-sea biota. The arrival of invasive species which may compete with native ones and the displacement of the latter because of the warming of ocean waters is also a matter of concern given its potential to destabilize marine ecosystems. The impact of greater human activity in the deep-sea will also need to be monitored and appropriate policy guidance developed. The impacts of climate change may be felt in other areas of the deep-sea through, for example, changes in productivity of surface waters that feed the deep communities and changes in intensity or frequency of episodic events, such as cold water cascading that may bring oxygen and nutrients to the deep (Canals *et al.* 2006). Ocean acidification may also have an impact on cold-water corals and other organisms with calcareous skeletons and will act synergistically with deep-water warming and deoxygenation of the deep-water masses leading to potentially catastrophic consequences in the deep sea.

8.3 Infrastructure for next generation deep sea research

8.3.1 Deep sea technology driving interdisciplinary, novel research

Research technology has developed rapidly over the last few decades with increasing use of Remotely Operated Vehicles (ROVs) and, more recently, Autonomous Underwater Vehicles (AUVs), or cabled underwater observatories bringing internet and continuous data flow to and from the deep sea. Each advance has enabled more in-depth studies and revealed more and more complex habitats and seafloor features and processes. For example, we can now navigate swath bathymetry systems through deeply incised canyons and investigate individual hydrothermal vent chimneys or map individual coral patches (Huvenne *et al.,* 2012). Sophisticated scientific equipment can be placed in precise positions on the seabed, e.g. to study fluid escape vents on submarine mud volcanoes (Jorgensen and Boetius 2007; Colaço *et al.,* 2011). There is, however, a trade-off between area covered and resolution with detailed studies covering extremely small areas of seabed. Thus, although we are beginning to understand small areas of seabed quite well, we still need to extrapolate to the vast areas in between.

The European Commission and Member states have made significant investments to develop sustained networks of open ocean and seafloor observatories, funding a range of projects (e.g. ESONET, EuroSITES) and identifying the European Multidisciplinary Seafloor Observation (EMSO) initiative as a large-scale European Research Infrastructure by the European Strategy Forum for Research Infrastructures (ESFRI) Roadmap. In 2012, EMSO entered Phase 1 with a five year phased implementation of EMSO sites extension, construction and operation. This parallels international developments such as the Ocean Observatories Initiative (OOI) that installed the Regional Scale Nodes (RSN) cabled network component during summer 2012. The observatory infrastructure ranges from cabled and moored infrastructure to sensors, samplers and satellite connections to enable autonomous monitoring and high speed, high capacity data transfer. Deep-sea observatory infrastructure could revolutionise the ability to conduct real-time, high resolution *in situ* deep-sea research into ecosystem functioning. However, the infrastructure costs are high for both installation and maintenance and priorities will have to be given to areas of high societal relevance, e.g. geohazard monitoring (Ruhl *et al.,* 2011). The Canadian experience with the deep sea cable observatory, NEPTUNE,[2] shows that observatories can be strategically located to stimulate interdisciplinary research, allowing joint studies of earthquakes, plate tectonics, fluid flow in the seabed and marine processes including the effect of climate change in deep-sea ecosystems, while being an opportunity for innovative engineering and data management developments.

Credit: Jago and Hookman. Max-Planck-Institute Seewiesen

Credit: DOP-UAz/EMEPC

Submarine launched for deep-sea research

Collection of deep-sea organisms by ROV Luso on the Condor Seamount (Azores, Portugal)

8.3.2 Multi-use deep-sea platforms

In other areas a more pragmatic approach will be to work with offshore industries and to capitalise on their infrastructure to carry out environmental monitoring. This also applies to research infrastructures initially built for other purposes such as seafloor neutrino telescopes.

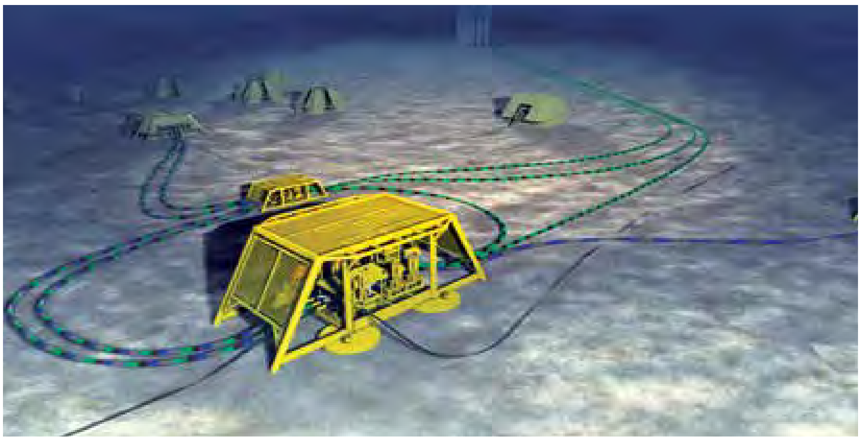
[2] http://www.neptunecanada.ca

This monitoring would not need to be located too close to the industry installations if additional cabling was laid, and/or if dockable AUVs were utilized that could use the docking station to download data as well as recharge their batteries. However, industrial locations tend to cluster on the continental shelves and upper continental slope, leaving most of the world's biosphere practically without coverage. One instrument that could help to fill this gap is a long range AUV that could cross the ocean, or sit for long periods on the seabed waiting to be activated by an event such as a benthic storm or earth tremor. Such vehicles are now being developed in Europe. However, these vehicles do not currently allow sediment sampling or seafloor observations and manipulations, which are needed to reveal the secrets of life and the wealth of resources of the deep ocean interior.

8.3.3 Cross-sector investment and innovation for deep-sea research

The development of technologies for deep sea research need not be done in isolation, there are many fields outside of marine science that have existing technologies that can be adapted for marine use. Progress is being made towards the development of inexpensive, power-efficient and miniaturised sensors for marine monitoring systems. These types of sensors are currently widely used in the medical industry and adaptation for use in the marine environment is making good progress (e.g. at the Hausgarten observatory off Svalbard). In the near future, with continuing investment, a suite of sensors will be available to address important deep sea issues, such as changes in pH, dissolved inorganic carbon, organic carbon export and consumption These sensors will be used on a number of platforms such as deep long-range AUV's and permanent observatories on the seabed. Sensors are required to detect leakage from hydrocarbon reservoirs. These in turn will be adapted for detecting leakage from the carbon capture and storage sites that are currently being proposed to mitigate climate change. These sensors for pH and reduced chemical species are at the near commercial phase of development, while more experimental sensors use *in situ* mass spectrometers for detecting and quantifying hydrocarbons and persistent organic pollutants in the deep sea (Camilli and Duryea, 2009).

Oil and gas seafloor platform



Credit: FMC Konsberg

8.4 Governance approaches for conservation and management of the deep sea

As emerging areas of deep-sea exploitation grow, it will be vital for scientists to work closely with policy makers to ensure that new policy developments are based on the best scientific advice and the precautionary principle (Santos *et al*. 2012), and to establish restoration protocols whenever possible. The creation of Marine Protected Areas (MPAs) together with the identification of Areas of Biological or Ecological Significance (EBSAs) and Vulnerable Marine Ecosystems (VMEs) will all play a role in conservation both within and beyond areas of national jurisdiction (Olsen *et al,* 2013). However, identifying these specific areas is a major task, especially since they need to be planned as a network so that migratory species can be protected in addition to important breeding and feeding grounds. Our knowledge of connections between marine communities is poor due to the impossibility of direct tracking in remote environments, yet modern genetic tools are allowing indirect assessments of connectivity. New deep-sea habitats and their associated life forms are continuously being discovered. Research is therefore needed to comprehensively map and characterize the vulnerable ecosystems in the deep sea, assessing spatial distribution of rare and common organisms as well as the turnover of communities.

The concept of using marine scientific research including habitat mapping for fisheries management is now enshrined in UN Resolution 66/68. It is improbable that the ocean floor will be mapped in sufficient detail in the foreseeable future and therefore mapping efforts need to be focussed on areas that are being, or could be, impacted by exploitation. Physical mapping is just the first step in producing a habitat map and must be followed up by thorough ground-truthing with camera surveys and sampling. For wider areas of the deep-sea floor, where the scale of mapping and follow-up work is impractical, predictive habitat models may be the only mechanism to obtain information. These require detailed knowledge of the physical and biological parameters that sustain the species in question (e.g. water depth, temperature, salinity, currents, food supply, substrate, habitat type etc.). A huge step forward could be achieved if environmental data, including mapping, could be released by maritime industries such as the fishing fleet that spends orders of magnitude more time at sea than the research fleet.

Credit: Project DeepFun, ImagDOP

Sailfin roughshark (*Oxynotus paradoxus*) swimming over sea-whip gorgonians (Menez Gwen Hills, Azores, Northeast Atlantic)

8.5 Recommendations

Europe should position itself as a leader and front-runner in matching economic opportunities with best science and governance associated with the emerging exploitation of biological and mineral resources from the deep ocean. Given the growing expansion of these industrial and economic activities into the deep sea, there is a strong need for a powerful vision based on an ecosystems approach, sustainable development and ocean health coupled with the precautionary approach to support the goal of sustainable development.

Key recommendations for future deep-sea research in the context of societal challenges and policy needs include:

1. **Continue to support research programmes for curiosity-driven, deep-sea research.** This is vital to allow the continued discovery of new deep-sea habitats, to further our understanding of deep-sea processes and environments, and to enhance knowledge of the deep-sea biological diversity and interconnections between marine communities to underpin evidence-based ocean governance and conservation management.

2. **Foster interdisciplinary and cross-sector deep-sea research** between natural and social science, and the industry, legal and policy sectors. This is vital for increasing the impact and relevance to society, assessing the socio-economic value of the human impact on the deep sea, and to further improve existing legal frameworks for the sustainable exploitation of seabed resources both within and beyond areas of national jurisdiction. Given the increasing commercial and stakeholder interest in the deep-sea, funding for some deep-sea research (particularly applied) could be sourced through private (or mixed model) funding mechanisms.

3. **Integrate existing deep-sea observations into a full-depth European Ocean Observing System, including the combined use of *in situ* and remote measurements.** This coordinated approach will allow systematic monitoring of the deep sea in the context of the full oceanic system, providing valuable time-series for the study variability and long-term change. This will also allow further understanding of the effects of human impacts including climate change stressors on deep-sea benthic ecosystems and will enhance the ability to predict the response of deep sea ecosystems to environmental change (see Chapter 11 on ocean observation).

4. Develop **integrated deep-sea habitat models** to understand better and predict the potential impacts of environmental disasters (e.g. oil leaks) or sequestration (e.g. CO_2) events on deep-sea communities.

5. **Encourage multiple stakeholder use of and investment in deep-sea research and research infrastructures,** promoting interaction between academia and off-shore industry to stimulate knowledge transfer and fast-track innovation of novel technology for monitoring the deep seafloor and subseafloor.

6. **Promote open-access to deep-sea environmental data** and encourage data sharing across marine and maritime stakeholders. This should include mapping by maritime industries such as the fishing fleet that will provide crucial data for predictive habitat models.

7. **Develop Frameworks for policymakers regarding environmental protection** measures to ensure ecological impact assessments are carried out before, during, and after commercial exploitation.

8. **Improve the current science-policy interface** to establish platforms or mechanisms for deep-sea scientists to engage with wider stakeholders, ensuring that cutting edge deep-sea research is part of the science advisory process for marine policy and management. This could include developing mechanisms for providing knowledge-based services to maritime activities such as fisheries management (see Chapter 13 on the science policy interface).

9

Polar ocean science

Credit: Jon S. Rønning

9.1 Introduction

The polar regions, i.e. the Arctic and Antarctic, are of enormous importance for the Earth's climatic stability and hold the key understanding fundamental Earth system processes. Both regions are an international heritage of humankind, but are very different in physical nature and political organization. Antarctica is a continent surrounded by an ocean. It is regulated by the Antarctic Treaty to which a number of European nations are signatories. The Arctic region, on the other hand, is an intra-continental ocean surrounded by national territories inhabited by indigenous peoples and subject to national laws. The Arctic Ocean contains Exclusive Economic Zones (EEZ) of the surrounding states, including some European states.

The polar regions are experiencing significant environmental changes affecting both continental areas and oceans. Given their critical role in the Earth system, these changes will have far reaching effects on atmospheric and ocean circulation. The most noticeable environmental changes include sea ice retreat and thawing permafrost, disturbances in the thermohaline circulation (THC) and ocean acidification (which is more rapid in colder polar seas than elsewhere). Related changes to polar ecosystems and biodiversity may be less well observed to date but are no less significant.

In Antarctica, the effects of climate change are not always straightforward or uniform, and despite a general warming trend, the sea ice extent has actually increased in some areas. Nonetheless, the West Antarctic Peninsula is experiencing rapid warming which may eventually lead to the collapse of the West Antarctic ice sheet. Although unlikely in the near future, if this does happen, global ocean levels would rise by a few metres in a very short period of time. In contrast, the Arctic has already been strongly affected by climate change. The most notable manifestation of this is the continuing reduction of the summer sea ice extent, which in September 2012, reached its lowest level since instrumental records began.

Credit: M. Jakobsson © ECORD/IODP

The drillship Vidar Viking in Arctic sea ice during an International Ocean Drilling Programme (IODP) Arctic coring expedition.

Credit: F. Delbart/IPEV

Changes in the polar environment including ocean currents, temperature conditions, ice cover and reduction of permafrost regions will have potentially significant impacts on marine and terrestrial ecosystems and weather patterns, not just at high latitudes but throughout the world. Increasing coastal populations, particularly in northern latitudes, are also creating serious pressure on fragile polar environments. Such changes are likely to have significant, but as yet unquantified, socio-economic consequences. Moreover, because many of these changes are happening much more rapidly than was previously predicted, we are largely unprepared (Haugan, 2013). Investing in research to better understand the changes and their implications is, therefore, a societal imperative.

9.1.1 Changing polar oceans and regions – key societal challenges

The polar regions harbour a wide range of important resources which may be of great economic value for industry sectors such as food, energy, raw materials, transport and biotechnology. It has been suggested that as much as 25% of the global hydrocarbon resources are stored beneath the Arctic Ocean. In addition, methane hydrates, placer deposits (accumulations of valuable minerals), polymetallic nodules and biological resources can be found in abundance in the region. Significant oil and gas fields can also be found on the Antarctic continental margin, as well as manganese nodules, possible placer deposits, sand and gravel. Antarctica is also rich in biological resources including fish, squid, cetaceans and krill and the huge potential for releasing the fresh water reserves locked up in icebergs is also starting to raise interest.

The foreseen expansion in fishing, maritime transport, ocean drilling and seabed mining in the polar regions will have a significant impact on the marine environment, on the living resources they contain, and on the regional social organization. Such developments will result in new demands for marine management, monitoring systems, emergency response systems, search and rescue services and a necessary increase in international cooperation. It will be important, therefore, to gain a better understanding of the opportunities and risks associated with exploring and conducting commercial operations in changing polar regions and to be able to maximize the benefits without jeopardizing fragile polar environments.

Major societal and health issues are induced by global change and particularly by sea ice retreat in the coastal regions, changes in fishery areas and conditions, and changes in traditional food availability and water pollution. Circumpolar health problems such as those associated with changes in diet are expected to increase, especially for those populations in Arctic regions accustomed to traditional foods that may become increasingly scarce. For many Inuit people, the retreating sea ice has resulted in a reduction in hunting opportunities which could have major cultural and health implications (Chapter 6 addresses in more detail the complex relationship between the oceans and human health).

The polar oceans are regulated by two very different legal frameworks. Activities in the Antarctic Ocean are subject to the specific regulatory requirements of the Antarctic Treaty which came into force in 1961. This treaty integrates a Protocol for Environmental Protection and two conventions, respectively, for the protection of seals (CCAS) and living marine resources (CCAMLR). Because of its nature (ice covered water), the Arctic Ocean is governed by the 1982 United Nations Convention on the Law of the Sea (UNCLOS) which does not regulate the exploitation and use of the marine environment but contains a number of general provisions concerning its protection and preservation.

There are still many unresolved issues related to the existing legal frameworks and national claims on continental shelf and sea areas that involve international law. The increasing changes and impacts in polar regions resulting from both natural and human pressures, highlight the need for urgent governmental and institutional actions to safeguard the marine environment by means of new regulations, exclusion zones and stricter standards. The sustainable exploitation of marine living resources, in particular, is a major concern and requires close political attention. Scientific knowledge is crucially important for supporting the development and implementation of effective political agreements and regulatory systems governing exploration, accessibility, exploitation and liability. Dialogue and international agreements based on scientific evidence and foresight will be essential for finding satisfactory solutions.

Credit: Cecilie von Quillfeldt/Norwegian Polar Institute

Credit: Hauke Flores, Alfred Wegener Institute

↑ Polar cod (*Boreogadus saida*) depends on the sea ice as its habitat

← Deployment of an autonomous underwater vehicle used for mapping under the ice

9.2 Research Challenges

Europe has a long tradition in polar research which has contributed significantly to our understanding of the global climate system and its impacts on European populations. Moreover, the polar regions offer an unrivalled opportunity for research at the frontiers of knowledge, both for scientific and strategic reasons. A significant proportion of polar research is focused on climate change owing to the fundamental role of the polar regions in modulating the global climate and the very high sensitivity of these regions to the changing conditions. A number of emerging scientific questions and technological developments, all in the context of climate change and associated impacts, will drive polar ocean research in the coming decade.

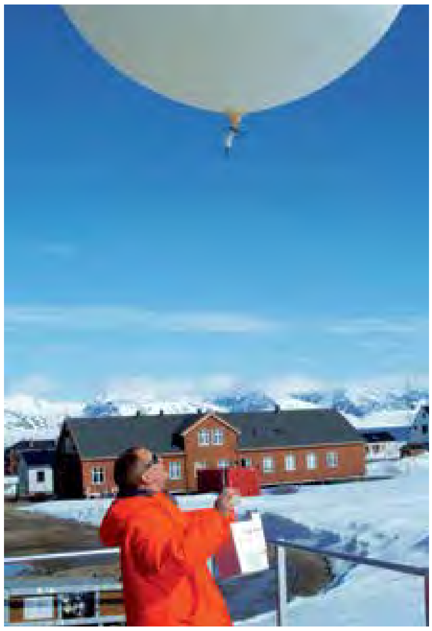
1. **Knowledge and prediction of climate change trends and impacts in polar regions**
   Human-induced climate change is causing the observed reduction in the extent and thickness of Arctic summer sea ice, thawing permafrost, coastal erosion, changes in the seasonal distribution of ice and snow, and changes in the distribution and abundance of marine living resources. In a positive feedback scenario, climate change in the polar regions has the capacity to accelerate global warming and lead to more rapid sea-level rise with major consequences for human settlements and for ecosystems, both in polar regions and lower latitudes.

   It is important to gain a better understanding of the interactions between the polar oceans, ice and atmosphere, how they influence the climate system, and how they are impacted by current climate changes. With declining Arctic sea ice, we are likely to see a continued accumulation of freshwater in the Arctic and in the Beaufort Gyre, which may result in another Great Salinity Anomaly (freshwater pulse), with uncertain impacts. The steady decrease of sea-ice cover in the Arctic changes the energy balance and feedback between the air and the water, prompting the need for investigation of the changing relationship between a thinner and weaker ice cover and wind and precipitation. Processes in the area of contact between ocean and melting glaciers deserve proper attention, despite difficulties in sampling at sea glacier interfaces. These areas may have an important influence on the present balance of heat and mass in the Arctic and may also provide and insight to past climate through marine sediment core analysis.

Researchers taking water samples from pools on the Arctic sea ice

Credit: Christiane Uhlig, Alfred Wegener Institute.

Sea ice is an important habitat for many polar species and its reduction is affecting polar ecosystems in general. Climate change is also affecting the distribution patterns of microorganisms, zooplankton, fish, mammals and seabirds and more knowledge is needed on the nature and pace of such changes. The timing of reproduction at various trophic levels may be affected by climate change causing disruption of predator-prey relationships or patterns of competition amongst species. The increased light penetration resulting from the retreating ice cover will impact both pelagic and benthic foodwebs. The biodiversity and mechanisms of adaptation to the extreme conditions of polar deep sea ecosystems are still poorly understood. Hydrothermal activity has recently been discovered in the Arctic that could support biological communities comparable with those of other deep sea vent ecosystems. There are major research challenges around mapping the physical and biological characteristics of pelagic, benthic and sub-seafloor ecosystems in the polar regions. This will be essential to better predict future changes and impacts and is a prerequisite for the development of appropriate mitigation and adaptation measures.



Credit: Marko Herrmann/AWI

Weekly launch of an ozonesonde from the AWIPEV research base. The ozonesonde is a lightweight, balloon-borne instrument that measures the concentration of ozone and standard meteorological parameters such as pressure, temperature and humidity at various altitudes and broadcasts the data by radio.

2. **Thermohaline circulation**

   One of the main features of both polar regions is their role in the global heat balance that drives atmospheric and oceanic circulation. The cover and the seasonal variation of sea ice plays a crucial role in this balance. The thermohaline circulation (THC) of the oceans is generated by differences in temperature and salinity related to the temperature gradients between high and low latitudes. The THC is a crucial element for global heat transport and deeply influences the atmospheric circulation and climate of the Earth. In the past, huge changes in patterns of atmospheric and oceanic circulation occurred, often in a relatively short time-span. Major research questions concern the prediction of future patterns of stability or change in the THC, and the associated impacts on natural and social systems.

Credit: Christiane Uhlig, Alfred Wegener Institute.

3. **Increasing loads of Chromophoric Dissolved Organic Matter (CDOM) in the Arctic Ocean**

   It is estimated that the Arctic Basin receives 10% of the total fresh water inflow to the global ocean, while its volume accounts for only 1% of the global ocean. Present studies suggest that the hydrological regime along the Arctic coasts has altered in the last decades as a result of climate warming and changes in permafrost conditions. Because of hydrological and permafrost alterations, a significant amount of terrestrially-derived organic matter is now being relocated from land to the Arctic shelf. Arctic riverine discharges contain CDOM from thawing permafrost soils. As this thawing continues and freshwater inflow increases, the already greater load of CDOM in the Arctic may further increase. Recent studies of optical properties in Arctic seas have concluded that CDOM is a significant light absorbing factor, (Stedmon *et al.,* 2011), reducing the light available for primary production, as well as contributing significantly to solar heating of Arctic surface water, thereby inducing accelerated sea-ice melt and increased stratification of the surface layer (Hill, 2008). Research on the role of CDOM in the Arctic Ocean will be essential to reduce uncertainty in climate models or for predicting changes in thermohaline circulation in Arctic waters.

4. **Ocean acidification**
   The capacity of the ocean to absorb CO_2 is an important factor for the future of carbon dioxide concentration in the atmosphere. The cold waters of the polar regions absorb relatively higher levels of atmospheric CO_2 than other warmer regions. When this dense, cold water sinks further after cooling, the CO_2 is rapidly sequestered into the deep ocean. The uptake of CO_2 also causes ocean acidification which in turn affects many biological processes such as the calcification of coral and some marine plankton. It will be important to investigate how this shift in ocean chemistry will affect key polar species.

5. **Maritime transport in the polar regions**
   The melting of Arctic sea ice is leading to the opening of new sea routes and significantly shorter journey times for shipping between, for example, Europe and Asia. Maritime engineers are already engaged in the development of advanced research and commercial vessels designed to operate effectively and efficiently in the harsh polar conditions. An increasing volume of shipping will also result in local pollution, which is expected to have an impact not only on marine organisms, but also on reducing the reflectivity (albedo) of the snow and ice surfaces. Likewise, the breaking of the ice surface due to the growing use of polar routes will lead to increased local melting associated with a reduction in albedo. Thus, research challenges surrounding the foreseen expansion of maritime activities in the polar regions largely concern maritime engineering solutions and measuring and mitigating against the associated environmental impact.

   (Further discussion and research recommendations on climate change and associated impacts on the marine environments can be found in Chapter 3.)

Credit: Catarina Magalhaes, CIIMAR

Credit: Institute of Marine Research, Norway

9.3 Strategic recommendations

Addressing the research questions highlighted in this chapter will be critical to improve our understanding of polar ocean systems and to achieve long-term societal benefits from sustainable use of polar resources. It is also important for Europe to remain a leader in polar research. However, the cost, complexity and interdisciplinary nature of scientific research in polar regions require a significant investment and a targeted and coordinated approach. To achieve these goals will require the following strategic actions:

Credit: R. Mugford, Scott Polar Research Institute, Univ. of Cambridge

1. Improve coordination, structuring and investment in collaborative European research to radically advance our understanding of the ongoing climate and environmental changes in polar regions, and our capacity to predict future impacts. This will require in particular:
   (i) development, integration and investment in long-term monitoring and observation systems and programmes to detect changes in the polar regions and their major drivers;
   (ii) research to understand unerpinning polar environmental change;
   (iii) modelling to predict future changes in polar regions and to reduce uncertainty.

2. Ensure the cost-effective development and operation of polar research infrastructures, improved collaborative or joint use of polar ships and stations, investment in groundbreaking new technologies and development of a number of outstanding scientific networks in polar studies. The operational coordination of European polar research infrastructures should be implemented at a scale which will significantly enhance scientific excellence, researcher mobility, and international cooperation. This includes efforts to improve the harmonisation of data collection, to make those data widely available for other scientists, and to translate scientific knowledge to policy makers and the public.

3. Better align polar research funded through the EU Horizon 2020 programme with the priorities of national funding agencies (and vice-versa) and improvement in the integration of activities funded and organized at various administrative scales. This could be greatly enhanced by:
   (i) the establishment of dynamic partnerships and multinational coordination of polar research programmes, infrastructures and activities;
   (ii) the development of joint funding programmes designed to address grand polar challenges; and
   (iii) resource planning and prioritization of research themes both in the Arctic and Antarctic and encouragement of a higher level of compatibility between national programmes.

4. Strengthen cooperation and links with international partners (i.e. beyond Europe) to ensure cutting-edge science and the long-term availability of reliable research infrastructures and resources.

5. Enhance education, communication and outreach activities related to polar ocean research. This can be achieved by establishing common guidelines for polar education and outreach and by ensuring that education and outreach activities are an essential part of any national and pan-European polar research programme. This goal represents part of the broader ocean literacy agenda discussed in Chapter 14.

10

Blue Technologies: Innovation hotspots for the European marine sector

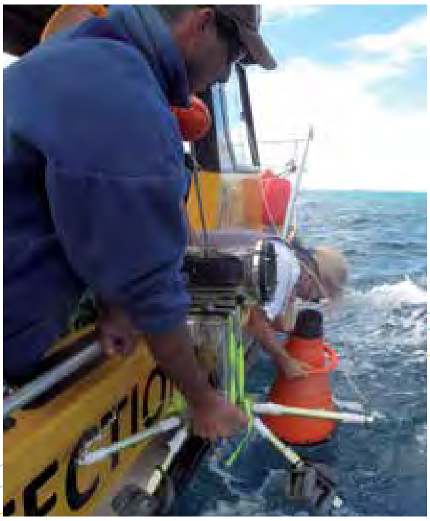
Credit: Liquid Robotics

10.1 Introduction

Today, the latest technology developments are crucial to the way humans interact with the seas and oceans, and have resulted in cost-effective applications for marine sectors including research, environmental monitoring, navigation, defence, security and maritime industries such as fisheries and dredging. Such Blue Technologies are often developed within fields outside marine science including robotics, Information Communication Technology (ICT) and wider engineering research and development. Interdisciplinary collaborations between fields is crucial to develop truly transformative blue technologies that can change the way people and societies undertake fundamental functions (maintain health, communicate, access energy and nutrition, etc.). Given the increasing pressure that human activity is placing on the marine environment, advanced technologies will become increasingly important, if not essential, for a truly sustainable management of our seas and oceans. This chapter provides information on the European context for blue technologies, presenting examples of some key technologies and applications currently under development in Europe. Further information on ocean technologies can be found in related chapters (e.g. Chapter 11 on the European Ocean Observing System).

10.2 European investment in emerging technologies

Historically, European funding for emerging technologies has been implemented through a number of programmes including the NEST (New and Emerging Science and Technology) initiative, implemented during FP6 by DG Research and Innovation (formerly RTD) and the Future and Emerging Technologies (FET) programme, implemented in FP7 by DG INFSO. While much of this funding was targeted at Information and Communication Technologies, there has been a growing recognition of the opportunity and need for multidisciplinary activities and cross-fertilization across disciplines to promote applications in the environmental sector including the marine sciences. The European Commission recognized this and launched the "Ocean of Tomorrow"[1] initiative within the Seventh Framework Programme (FP7). This supported joint calls spanning multiple themes of the Cooperation sub-programme such as Energy, Environment and Climate Change, Transport, Health and Nanotechnologies, fostering cross-sector engagement. A final call under Ocean of Tomorrow in 2013 focused specifically on developing competitive and innovative marine technologies for a wide range of applications in areas such as marine monitoring, transport and deployment and antifouling.



Credit: NOC, Subglacial Lake Ellsworth Consortium, UK

Engineers and technologists, testing a novel sensor probe in 2012 for deployment in Lake Ellsworth, a pristine subglacial lake in Antarctica

The European Marie Curie programme also increased support for Industry-Academia Partnerships and Pathways (IAPP)[2] actions focused on developing cross-border strategic science and technology partnerships between commercial and non-commercial partners to boost the exchange of skills and to stimulate innovation. In preparation for the EU, Horizon 2020 Programme (2014-2020), a number of thematic workshops were also held to consult the scientific community on the role and scope, positioning and modalities for research themes going forward.

[1] http://ec.europa.eu/research/bioeconomy/fish/research/ocean/fp7-ocean-projects_en.htm

[2] http://ec.europa.eu/research/mariecurieactions/about-mca/actions/iapp/index_en.htm

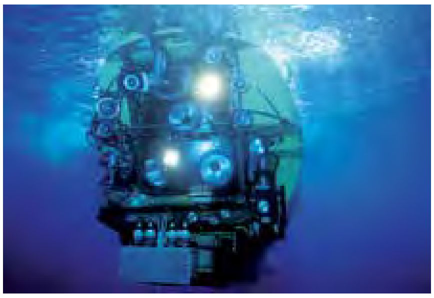
In a consultation workshop on Future and Emerging Technologies (FET) organized by the European Commission in 2011, participants expressed "strong support and persuasive arguments for the continued existence, expansion and broadening of a coherent, integrated FET programme supporting high-risk, multi-disciplinary, pathfinder research in a broad range of novel emerging scientific and technological areas." (European Commission, 2011 workshop report). In addition, the marine science community has hosted events on Blue Technology to create a platform for showcasing emerging technologies and fostering networking between sectors. For example, the 3rd Marine Board Forum, *New Technologies for a Blue Future*, held on 18 April 2012 in Brussels, identified innovation hotspots for the European marine sector and highlighted the continued need for investment in both blue skies ocean research and applied technology development to drive innovation [3].

10.3 Emerging blue technologies: unlocking the potential from the marine environment

The field of blue technology development is fast-paced and cutting-edge. The challenge is to produce technologies that drive smarter, more efficient marine and maritime activities whilst maintaining and empowering responsibility towards nature. This section presents a selection of blue technologies that are set to revolutionize marine research and societal applications into the next decade. This list is not exhaustive but highlights a range of innovations both directly from the marine sector and those from other disciplines which have marine applications.

10.3.1 Robotics and autonomous systems

Innovations in the field of robotics are already having a huge impact on marine research, with autonomous platforms such as Remotely Operated Vehicles (ROVs), Autonomous Underwater Vehicles (AUVs) and gliders all pushing the boundaries of ocean exploration to reach deeper, more remote and hostile regions than ever before. Engineering capability is resulting in record-breaking deployment times with 6-month deployments of gliders and a range of next generation AUVs and increases in pay-load allowing simultaneous sampling of multiple ocean variables. Such technologies already have wider applications, for example in surveillance and monitoring and for commercial sectors such as the offsore oil and gas industry and will be increasingly in demand with the expected surge in interest to exploit deep sea marine resources (see Chapter 10 for more discussion on autonomous *in situ* observation platforms and Chapters 7 and 8 for commercial applications). Interactions between the research and commercial sectors is set to becoming more commonplace and can facilitate the fast-tracking of commercialization opportunities.



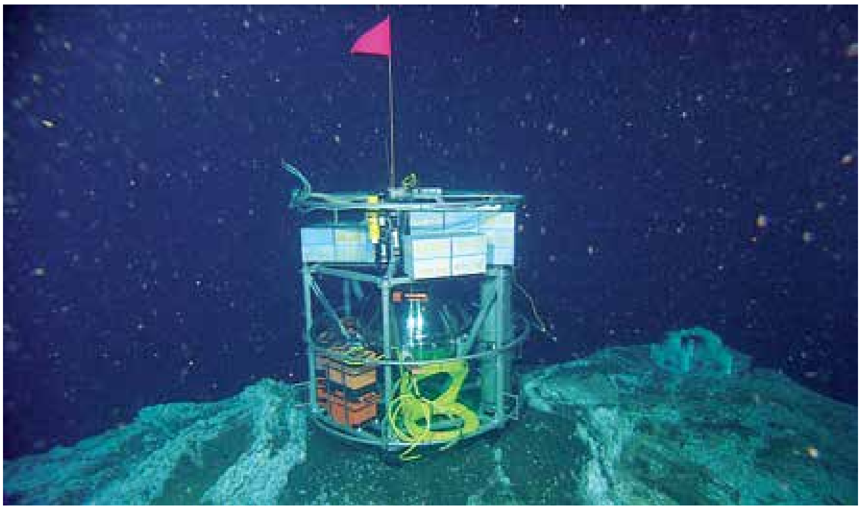
Credit: IFREMR/ Eric Lacoupelle

The French underwater submersible Nautile

[3] http://www.marineboard.eu/fora/3rd-marine-board-forum

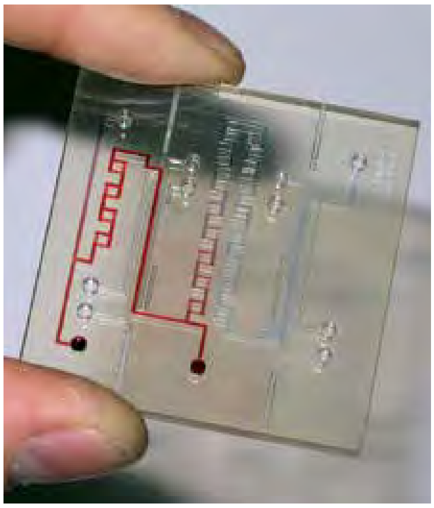
10.3.2 Minaturized solutions to marine monitoring

Environmental micro sensors and observation tools are set to deliver new ways of monitoring complex biological and chemical oceanic processes. Over the past decade, technology has been developed for *in situ* biosensing of the marine environment. Commercially available equipment includes the Environmental Sample Processor (ESP) which can conduct *in situ* ecogenomics, allowing the genetic signature of a water sample to be automatically processed, often in remote locations such as the deep sea. However, such technology is still very expensive (>$250,000) and a major challenge is to miniaturize analytical processes to produce cost-effective sensors that can be marketed for widespread use. Across Europe, scientists and technologists in academia and industry are now working on the miniaturization of biogeochemical sensors. These include lab-on-a-chip solutions for molecular techniques and flow cytometry with far-reaching applications from marine genomics to monitoring contaminants. Such developments rely on effective collaboration between the fields of electronics, computing, biochemical and marine sciences. A particular challenge is making the micro-fluidic detection assays robust and repeatable.



Credit: MBARI (2010)

In July 2010, MBARI's Deep Environmental Sample Processor (d-ESP) was deployed on a ridge of carbonate rock about 800 meters below the sea surface, just seaward of Santa Monica Bay in Southern California. The deep ESP collected water samples and analysed these samples for genetic material from microbes that are associated with the methane gas which bubbles out of the seafloor in this location

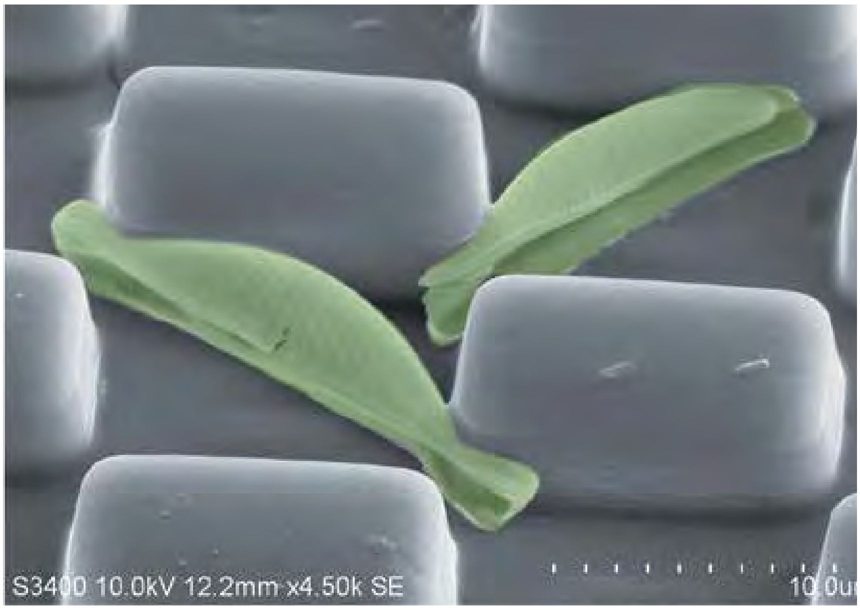


Credit: University of Southampton

The development of a new generation of biogeochemical miniaturised sensors to measure nutrients and pollutants in the world's oceans is the focus of a major research programme at the University of Southampton and the National Oceanography Centre, Southampton. The sensors are capable of operating in harsh environments and are being developed for deployment over months at a time. The development of these sensors will provide a new technology platform for marine scientists, and have applications in the water industry in environmental impact assessment and in monitoring ship ballast water.

10.3.3 Nature-inspired design

Biomimetics is an emerging field taking inspiration from nature to create solutions and applications for marine science and maritime industry. For instance, marine organisms have created elegant solutions such as specialised surfaces to combat biofouling. Learning from nature, technology is allowing artificial replication of such surfaces based on nature's designs which is producing non-toxic antifouling material alternatives e.g. diatom antifouling assays, for application to marine sensing instrumentation, improving the operational lifetime and reducing the cost of ownership and maintenance of marine deployed structures (Chapman *et al.,* 2012; Sullivan and Regan, 2011; Czugala *et al.,* 2011). Such work is multidisciplinary, fostering collaboration between the fields of chemistry, engineering, microbiology and statistics.



Artificially coloured scanning electron micrograph of diatom cells (*Amphora coffeaeformis*) trapped on a textured poly(dimethyl siloxane) elastomer surface. The design principles of this textured surface were derived from study of the antifouling characteristics of the surface topography of Mytilidae shells. While the artificial texture bears little resemblance to that of the original surface, critical dimensions such as height, spacing and aspect ratio can be retained, allowing exploration of the effects of surface texture on settlement of marine microorganisms.

Credit: Timothy Sullivan, MESTECH, Dublin City University

10.3.4 Acoustics to enhance marine ecosystem management

The field of acoustics is fast-developing with ever more abundant data streams and enhanced resolution transforming the possibilities for predictive modelling and species-specific monitoring. Exploiting acoustic technology (band and beam widths) and developing platforms for sensors, ecosystem processes can be observed at appropriate spatial and temporal scales across a range of biophysical parameters, an essential requirement for quantitative ecosystem understanding and modelling. Furthermore, the approach also supports the knowledge and information needed to resolve trophic interactions from individuals to populations and to establish a better basis for an ecosystem-based fisheries management (see Chapter 11 for further discussion on developments in marine acoustics).

10.3.5 Nano-biotechnology

Nano-biotechnology is a key technology of the 21st century which could offer solutions and applications in many fields including medicine and optical fibres. Marine organisms are an important resource for this field and are increasingly in demand as model organisms for such research. For example, marine sponges are one of the most ancient metazoan taxa and studies of their genetic blueprint have already identified key compounds such as cytosine arabinoside (AraC), which has anti-tumor properties and is now used in almost any therapy concept for leukemia. Sponges can also create *de novo* nanostructured biominerals. Novel nano-biotechnology is enabling the artificial replication in the laboratory of the biomineralisation process which may help identify the gene responsible. In addition, large spicules of some sponges use an organic light source (luciferase protein) and inorganic light transducing silica spicules to produce effective light-collecting optical fibres. Understanding this process may have applications for more cost-effective marine cables with applications across the maritime industry and communication sectors.

↓ View of the upper end of the cage-like glass sponge, *Euplectella aspergillum*. The silica skeleton reinforces the 15-25 cm long specimens. The silica glass scaffold is synthesized by an enzyme termed, silicatein. Since this gene has been successfully transferred to bacteria those microorganisms acquired the property to synthesize the sponge protein. In turn this protein can be prepared in ample/sufficient quantity and provides the rational basis for a sustainable application of a sponge protein for biotechnological applications (biomedical materials; optical wire systems).

Credit: W.E.G. Müller

Credit: W.E.G. Müller

↑ A demosponge (*Tethya lyncurium*) after submersion into a solution with a green fluorescence dye. From a related species the anti-tumor compound, used in almost any therapy concept for leukemia, with the name cytosine arabinoside (AraC), has been isolated. This structure has also been used as master/model to synthesize adenine-arabinoside (araA), a powerful anti-herpes compound; in Japan this drug is among the highest-selling anti-herpes compounds (Arasena-A).

BOX 10A Focus on marine biotechnology

Marine biotechnology encompasses those efforts that involve the marine environment and its bioresources, either as source or target of biotechnological products and applications (e.g. new drugs and biomedical applications and novel enzymes of industrial interest).

Interest in marine biotechnology has grown rapidly in the past decade owing to a recognition of the sheer scale of opportunity presented by the largely unexplored and immense biodiversity of our seas and oceans and the need to meet growing demands for food, new drugs and industrial products. This growing interest and activity is also reflected in the growing number of gene patents associated with Marine Genetic Resources (MGR), with more than 90% of claims filed after 2000 (Arnaud-Haond *et al.*, 2011).

The biotechnological potential of marine organisms is largely related to the fact that: (i) life in the oceans is ancient, having evolved over 2.8 billion years; (ii) diversity of life in the oceans is high but still largely unknown; (iii) adaptations to marine environmental conditions are diverse and often unique which has led to a high level of chemical diversity and a wide range of biomaterials and bioactive compounds with unique properties. In addition, the science and policy landscape has also evolved; the genetic basis for adaptations is now increasingly understood and new tools are available for exploring the marine environment (from omics to deep sea Remotely Operated Vehicles or ROVs). As a result, we are in a much better position today to move from discovery to application than ever before.

Credit: Kirsti Helland, MabCent, University of Tromsø, Norway.

Sea anemones produce toxins with interesting properties for various applications including pesticides and drugs

Credit: W.E.G. Müller

Cultivation of marine bacteria on agar plates and selection of bacterial clones.

Over the last 15 years, several science-policy initiatives have highlighted important challenges and barriers that must be addressed to allow for a commercially viable, sustainable and ethical use of available MGRs. For example, the EC Collaborative Working Group on Marine Biotechnology (CWG-MB) and the Marine Board Working Group on Marine Biotechnology [4] (WG BIOTECH), pointed to the high level of fragmentation of research efforts and infrastructures in Europe, the low level of pan-European and regional coordination, and the lack of knowledge about research and development activities in European countries and regions (Querellou *et al.*, 2010). This knowledge is indispensable for a coherent and efficient European approach and international collaboration activities.

In response, the European Commission has facilitated the creation of a range of coordination initiatives which have greatly reduced the level of fragmentation and improved pan-European collaboration at the level of research actors (e.g. the Networks of Excellence in Marine Biodiversity Marbef [5] and Marine Genomics MGE [7] now coming together as Euromarine [6]) and at the level of research infrastructures (e.g. facilitating access to research vessels with EUROFLEETS [8], to marine stations and marine model organisms with ASSEMBLE [9]/EMBRC [10] and to high-throughput screening platforms with EU-OPENSCREEN). At the science policy and research programme level, the EU FP7 Coordination and Support Action in Marine Biotechnology (CSA MarineBiotech), a collaborative network consisting of 11 partners from 9 European countries worked intensively from 2011-2013 to explore the opportunities and needs for European coordination, trans-national cooperation and joint activities in the area of marine biotechnology research which should culminate in a MarineBiotech ERA-NET foreseen to begin in late 2013.

[4] CWG-MB scoping paper available at http://ec.europa.eu/research/bioeconomy/pdf/cwg-mb_to_kbbenet_report_final.pdf

[5] www.marbef.org

[6] www.euromarineconsortium.eu/fp6networks/marinegenomics

[7] www.euromarineconsortium.eu

[8] www.eurofleets.eu

[9] www.assemblemarine.org

[10] www.embrc.eu

BOX 10A Focus on marine biotechnology

The European Commission has also funded an increasing number of large collaborative research projects addressing issues such as marine microbial cultivation challenges, bottlenecks in the marine biodiscovery pipeline, and the development of new marine-based biosensors. However, while a lot of progress has been made in recent years and the profile and visibility of marine biotech has greatly improved, many challenges remain. To address these, it will be essential to:

- Further improve our understanding of the marine biotechnology landscape (in particular industrial activities, main key stakeholders and market trends) and ways to stimulate development from basic science to commercial applications;
- Stimulate the development of strategies and programmes at various levels (local/regional, national, sea basin and pan-European level) and align them with each other and with broader EU bioeconomy goals;
- Secure the development of marine biotechnology activities in a sustainable way, protecting the marine environment and MGRs with particular attention to deep sea resources, developing new management tools and regulations were appropriate;
- Improve technology transfer mechanisms and industry/academic collaborative approaches to develop markets and businesses, making full use of the knowledge and networks of the local and regional blue biotech clusters in Europe;
- Stimulate multidisciplinary education and training (see also Chapter 12).

For more information see www.marinebiotech.eu

Credit:Vivian Hertz/VLIZ

Participants at the CSA MarineBiotech Conference, Marine Biotechnology in the European Research Area: Challenges and Opportunities for Europe (Brussels, 11-12 March 2013). The conference addressed the status and progress of European marine biotechnology research efforts and capacity at various scales and identified critical needs, gaps and challenges to inform future marine biotechnology policy and coordination efforts

Credit: (c) 2013 SBM Offshore

In 2010, SBM proved the concept of the Standing Wave Tube WEC with integrated power take-off using a small scale model at the ACRI-IN wave tank in Sophia Antipolis, France.

10.3.6 Renewable energy harvesting: from wave energy to algae biofuels

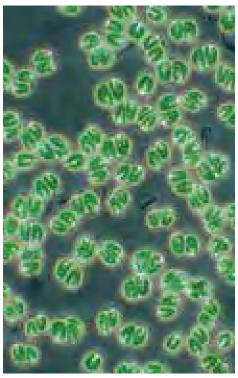
With world petroleum and oil supplies declining fast, European blue technology is offering new, more efficient alternatives including harvesting renewable energy from the marine environment. One example is the field of wave energy. In this area, European researchers have developed a wave energy convertor – the S3 by SBM Offshore - which amplifies pressure waves, efficiently harvesting wave energy from a wide range of wave periods (Andritsch *et al.,* 2012). Its structure is composed of only electro active polymers (elastomers) - a class of materials that change their shape when excited by an electric field, and is extremely flexible, environmentally friendly and silent requiring no maintenance of moving parts. This is just one example of the growing marine renewable energy sector that also includes innovations in tidal energy. Chapter 7 addresses these and other developments in marine renewable energy in greater detail.

Biofuel extracted from algae is another potential energy source which could meet the energy demands of European citizens into the future. With faster growth rates than terrestrial crops, marine plants from seaweed to cultured micro-algae, are seen as viable organisms for producing biofuel, food and feed. Recent European FP7 projects such as MABFUEL[11] have tackled issues from the biomass production to extraction methodologies. Meanwhile, research at Wageningen University, the Netherlands, includes pilot studies for an algae cultivation park that aims to take algae cultivation from the small-scale fundamental research to full-scale production facilities.

↓Raceway pond for algae cultivation

↓Outdoor horizontal tubular photobioreactor

Credit: AlgaePARC, WageningenUR (Netherlands).



Credit: AlgaePARC, WageningenUR (Netherlands).

↑The microalga, *Tetraselmis suecica,* a marine green alga that can be grown as a foodstock in aquaculture and potentially also for obtaining biodiesel as it contains a high lipid content.

[11] FP7 project MABFUEL: Marine Algae as Biomass for Biofuel: http://www.marine.ie/home/research/ProjectsDatabase/CurrentProjects/MABFUEL+-+Marine+Algae+as+Biomass+for+Biofuel.htm

10.3.7 High performance computing and ICT innovations

There is a growing need for large distributed electronic infrastructure that can store and process the ever increasing amounts of marine data, including raw data of environmental variables and derived data, e.g. from genomics research and marine biotechnology. Innovations from the field of Information and Communication Technologies (ICT) such as hybrid data infrastructure and cloud computing are also an important for increasing the accessibility to data and the impact of knowledge applications for marine safety, resource management and conservation. Developments in High Performance Computing are also revolutionizing processing speeds resulting in a range of applications for marine sciences including the potential for modelling oceanographic features e.g. turbulence flows (see Chapter 11 for further information on high performance computing).

Credit: EPCC, University of Edinburgh, HECTOR UK.

Internal picture of the HECTOR Phase 3 machine, UK National Supercomputing Service, http://www.hector.ac.uk

Credit: J. Mai, ESA

ESA's satellite operations Main Control Room in Darmstadt, Germany

10.4 Multi-sector partnerships: fast-tracking innovation

research and industry is key to track market trends, identify potential opportunities for innovative technologies and to fast-track product commercialization and the impact of the emerging technology. Small to Medium Enterprises (SMEs) are crucial to this step and offer an important platform for bridging the gap between research prototype and commercial product. The marine technology and engineering fields are currently increasing, stimulating entrepreneurship across Europe to take advantage of new markets. Horizon 2020 requires a minimum percentage of SME involvement for certain calls, meaning that SMEs, as the drivers of innovation, are likely to play an increasing role in European funded projects.

10.4.1 Training the next generation of marine technologists

In order to maintain a position at the forefront of marine technology development, the European community must ensure attractive and targeted education programmes are in place to train the next generation of ocean engineers, scientists and technologists (see Chapter 12 on training and careers in the marine sector). These should be interdisciplinary but also encourage interaction with industry both to raise awareness within the scientific community of future industrial applications, and to understand consumer and societal needs. The European Commission has funded a number of Marie Curie International Training Networks that have paved the way to enabling early career scientists with a platform for cross-disciplinary technology development. Examples include SENSENET[12] which funds a range of marine sensor developments from optics to chemical microsystems and the project, BIOMINTEC[13], which focuses on the biomineralization process involving multidisciplinary teams from the fields of molecular and cell biology, inorganic chemistry, and physical chemistry, and computational science.

Scientist holding a culture of *Pseudomonas fluorescens* which was used as positive contaminant for establishing sterility of the engineered structures

Credit: British Antarctic Survey, UK

[12] http://www.eu-sensenet.net/

[13] http://www.biomintec.de/

10.5 Recommendations

While there are still significant hurdles moving from research funded technology developments to operational applications and industry based production, fostering innovation will be key to achieving success. There is a real potential for gaining societal and commercial benefits from scientific excellence through horizon scanning such as tracking policy developments and needs, market trends, identifying emerging markets and rapid recognition of potential winners.

10.5.1 Fundamental research

It is critically important to maintain a strong investment in marine knowledge in order to achieve economic growth in the context of responsible environmental management. New technologies are only possible with a sound fundamental science base. Many relevant technology developments actually started out as blue skies research ideas and have taken years to progress to the innovations we see today. Therefore, investments in blue-skies research should remain a key component of any innovation research aiming looking to bring new technologies into the operational stage.

10.5.2 Innovation

In the coming decade, innovation will be essential to underpin scientific discoveries, drive a thriving maritime economy and offer new tools to assess and sustainably manage the marine environment. Hence, there is a particular need for technology innovations that drive smarter, more efficient marine and maritime activities whilst maintaining responsibility towards nature. Pilot studies integrating natural and social sciences and creating an ideal test-bed for trialing technological innovations, could be very beneficial.

10.5.3 Multi³: multi-sector collaboration, multi-disciplinary approach, and multi-stakeholder initiatives

Emerging blue technologies show a trend towards increasing collaboration and integration between different sectors, scientific disciplines and stakeholders. The next generation of integrated coastal and marine monitoring and management is essential to facilitate the transition from a state-funded approach towards beneficial partnerships, e.g. between the private and public sectors. Stakeholder collaboration will become ever more pressing with the growing use of a limited sea space and, as such, is vital for driving multi-use of ocean space towards a smarter, more efficient and environmentally sustainable use of European seas and oceans. This is also likely to fast-track commercial exploitation of the technologies themselves, thus contributing to blue growth.

Credit: Liquid Robotics

A Wave Glider just before the launch bundle is released. The Wave Glider SV Series are the first unmanned autonomous marine robots to use the ocean's endless supply of wave energy for propulsion

10.5.4 Knowledge transfer

We are moving towards a knowledge-driven society. Education and knowledge transfer hold the key to ensuring that innovations are relevant and have a high impact. There is a need to clearly define different types of knowledge, who owns it, its market readiness and, conditions of access. This will maximize the impact and transform the value we gain from marine knowledge.

11

An integrated and sustained European Ocean Observing System (EOOS)

Credit: WHOI and NASBOS project

11.1 Introduction

The global Ocean is facing multiple anthropogenic and natural stressors and consequently marine ecosystems are increasingly vulnerable to exceeding tipping points which may lead to irreversible change (Bundy *et al.*, 2010). But how will society be placed in the coming decades to tackle these threats and turn challenges into opportunities? The Rio Ocean declaration (16 June 2012) called for an "*integrated approach addressing the interlinked issues of oceans, climate change, and security" and for countries to "Establish the scientific capacity for marine environmental assessment, monitoring, and prediction, including the implementation of......the global ocean observing system*". Routine and sustained ocean observations are crucial to further our understanding of the complex and vast oceanic environment and to supply scientific data and analyses sufficient to meet society's needs.

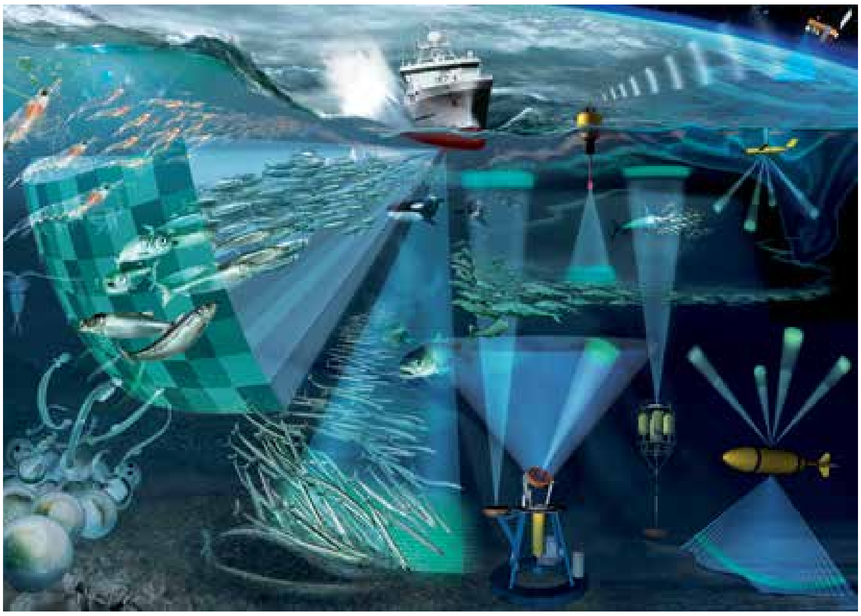
The need for such an integrated ocean observing system is particularly important in Europe because of the complexity and density of human activity in European seas and oceans. This results in a high demand for marine knowledge in the form of data, products and services to support marine and maritime activities. There is also a critical need for basic and applied marine science to inform society, ocean governance and decision-making, supporting a knowledge-based maritime economy that is sustainable into the future. A relatively mature European ocean observing infrastructure capability already exists including resources, hardware, facilities and personnel. However this is largely fragmented and the need and value for coordinated development and utilization of marine research infrastructures has been identified at a European level (MRI expert group report[1]). But how will the European Ocean Observing System (EOOS) evolve to address the needs of multiple stakeholders into the future and what are the research needs and challenges that will drive such a system?

This Navigating the Future IV chapter addresses research frontiers for next generation ocean observation and current and future infrastructure developments and places these in the context of European needs and policy frameworks. A concept for an EOOS is presented with scientific, technological, social and economic drivers and feedbacks. It is proposed that a 'step change' in coordination is required across the marine and maritime stakeholder community to capitalize on common requirements and promote cost-effective multi-use observation infrastructure. This can be achieved through the formation of beneficial partnerships across marine and maritime sectors and geographical regions. In addition, new models of governance and funding are discussed that could support the sustainable operation of ocean observing systems. This is vital to secure the delivery of key environmental datasets, products and services of benefit to society. A truly integrated EOOS would empower European nations to take control of assessing marine environmental status, predicting future scenarios and making informed decisions about ocean governance that balances economic growth with environmental protection. This would ultimately lead to new opportunities in many marine and maritime sectors. Such a system would also progress Europe's position as a worldwide science and technology leader and further establish Europe's contribution to global initiatives such as the GEOSS, through initiatives such as EuroGOOS and Copernicus (formally GMES).

[1] Towards European Integrated Ocean Observation (http://ec.europa.eu/research/infrastructures/pdf/toward-european-intagrated-ocean-observation-b5_allbrochure_web.pdf)

11.2 Research frontiers driving next generation ocean observation

A variety of *in situ* and remote platforms enable ocean observations at multiple temporal and spatial scales, thus increasing the flexibility of the observation system.



Credit: Olav Rune Godø, Institute of Marine Research, Bergen, Norway.

Scientific discovery and understanding of the oceans has paved the way for human activities in the marine environment. Significant progress in international ocean observation has been made over the past decade (Busalacchi, 2010) and ocean observatories now produce crucial datasets to further our knowledge on oceanic processes including, for example, heat content, ecosystem and carbon dynamics, air-sea interaction, ocean acidification, and ocean floor substrate-fluid processes. In addition, combined *in situ* and remote sensing techniques such as ocean colour radiometry (OCR) have revolutionized our understanding of surface ocean processes and our ability to characterize global marine pelagic ecosystems and habitats (Yoder *et al.*, 2010). As the demand for marine geospatial information grows, basic science through sustained observation will continue to serve an important purpose, pushing the boundaries of our knowledge of the temporal and spatial variability of the marine environment and driving new research frontiers leading to innovation and socio-economic benefits.

Identifying science priorities, critical parameters and geographical regions to observe now and into the future is the first step towards an Ocean Observing System that will serve societal needs and drive of oceanography activities. Various studies and initiatives have systematically identified research drivers and needs across the physical, geological, biogeochemical and biological oceanographic sciences that can be addressed by ocean observation (e.g. Ruhl *et al.*, 2011; OceanObs'09 Plenary and Community papers; MRI expert group final report; GEO Work Plan 2012-2015). The Global Ocean Observing system (GOOS) has also played a part in assessing the current status of ocean observations and linking research priorities with societal needs (see also the US NRC Report on Critical Infrastructure for Ocean Research and Societal Needs in 2030). The following section does not attempt to provide a comprehensive list of research priorities, but highlights some identified areas and gaps that may drive the design and operation of next generation ocean observation.

11.2.1 Temporal and spatial variability

Marine ecosystem dynamics are inherently non-linear and resolving temporal and spatial variability in the oceans remains notoriously difficult. Interpretation of ocean processes is often further hindered by a lack of multidisciplinary oceanographic time-series datasets at high enough resolution or from specific locations of interest. The non-linearity means that perceived trends in ecosystem indicators can be short-lived and variables often display a delayed response time to pressures and larger-scale climate drivers. Indeed, studies have shown that statistically robust trend analysis requires long-term time-series datasets and that a high variance of ecological indicators can reduce the statistical power for detecting trends in series of less than 10 years (Blanchard *et al.*, 2010). In turn, studies have shown that for remotely sensed data, 40 years of ocean observations are required to separate natural modes of climate variability from longer-term trends of a changing climate and ocean. (Henson *et al.*, 2010).

Next generation ocean observation can build on existing infrastructure to develop multi-platform networks combining space and *in situ* ocean observation data. Each new combined data acquisition system should be designed according to a very precise scientific objective (e.g. sensor resolution, deployment strategy, acquisition frequency and duration). This will enable short-term and episodic events to be not only captured, but tracked and longer-term change to be monitored. For example, this will facilitate a new level of understanding of ocean energetics and related biological activity at the meso-scale e.g. eddies which are focused within spatial scales of tens to hundreds of kilometres (Godø *et al.*, 2012). Understanding the effects of climatic phenomena such as the North Atlantic Oscillation (NAO) on marine ecosystems and biogeochemical cycles is also crucial if global ocean dynamics are to be understood.

11.2.2 Integrated coastal to open ocean processes

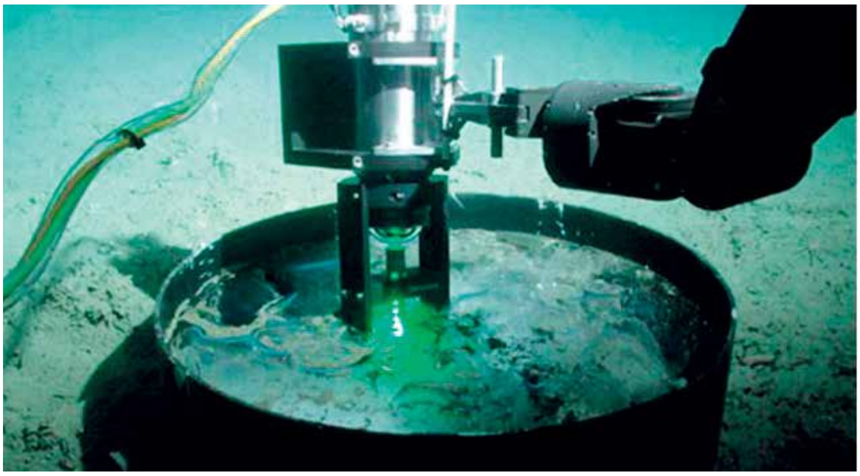
A real challenge for an integrated EOOS is to create integrated coastal to open ocean monitoring systems that will revolutionize observing and modelling of basin-scale change, allowing gradients to be assessed across major biomes (e.g., equatorial upwelling bands, sub-polar gyres). Identifying and monitoring a common set of key variables is essential to achieve this. However, the added complexity of coastal waters requires a targeted monitoring of additional variables to take account of the higher concentration of human activity in these regions. Combining advanced observation techniques is also presently under-utilized. For example, the use of satellite sensors for surface observations and vessel-based acoustic sensors for characterizing the open ocean interior can permit a renewed understanding of mesoscale phenomena and ecological responses caused by their physical forcing.

11.2.3 Rates and Fluxes

Whilst many key oceanic variables can now be monitored autonomously, the next level of complexity, rates and fluxes, remains less well constrained. Advancements in monitoring fluxes in real-time (e.g. ocean-atmosphere gas exchanges) and fluxes of particulate inorganic and organic carbon will significantly further our understanding of fundamental oceanic processes including atmosphere-land-ocean interactions, elemental cycling and connections with larger climate indices such as the North Atlantic Oscillation (NAO). As ocean instrumentation systems (e.g. sensors, platforms, data transmission) become more advanced and reliable, a future observing system will routinely monitor deeper into the interior of the oceans than ever before. This may profoundly change our current understanding of heat storage, boundary layers and ecosystem functioning of under-sampled areas including, for example, the mid-water meso-pelagic zone and the deep-sea.

11.2.4 A new era in biological observations

The past decade has seen a major effort towards developing marine observations targeted at a better understanding of biogeochemical cycling and ecosystem services. The international Census of Marine Life consolidated a global effort to address marine biodiversity observations (Ausubel *et al*., 2010; see Chapter 8 on the Deep-Sea for further information)[2] . Projects such as the Continuous Plankton Recorder (SAHFOS) have provided unique biological datasets on the ecology and biogeography of plankton since 1931. Marine research stations have also been crucial to provide access to a comprehensive set of coastal ecosystems and state-of-the-art experimental facilities for marine research (see FP7 ASSEMBLE research infrastructure initiative[3]). In addition, the autonomous monitoring of increasingly complex biological variables is possible such as using *in situ* laser spectrometry to determine the composition and chemical bonding of solids, liquids and gases within marine sediments and overlying water. Despite these achievements, a need has been identified at European level to further develop automated biological observations to characterize ecosystem health and pressures on marine biodiversity (see MRI expert group report). Furthermore, present observation systems suffer from their inability to observe basic ecosystem processes at the scales of time and space in



Credit: MBARI, 2005

MBARI's deep-sea laser Raman spectrometer being used to study a tubeworm colony, about 2,300 meters below the surface of Monterey Bay. The laser Raman spectrometer can determine the composition and chemical bonding within many solids, liquids, and gases.

[2] http://www.sahfos.ac.uk/

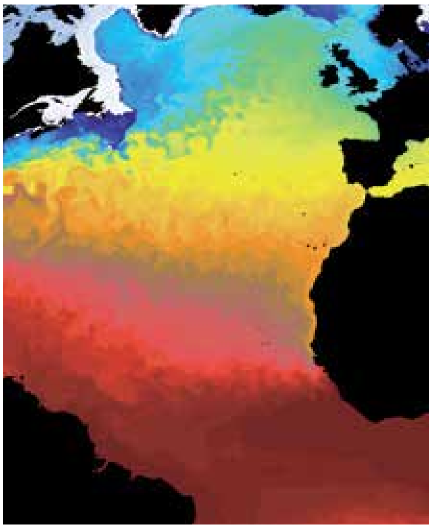
[3] http://www.assemblemarine.org/

which they occur, e.g. net samples volumes are generally much larger than those representing life bearing processes of individuals and patches. The next decade is expected to produce technological advancements building on existing capabilities including *in situ* sensors and samplers for DNA barcoding and omics studies and new platforms with acoustic and satellite tracking techniques (see Chapter 10 on Blue Technologies for further information).

For enhanced spatio-temporal sampling, novel acoustic and optic sampling techniques will inform about key processes from the mm to 10s of km scales and thus strengthen our ability to quantify basic ecosystem processes. Using acoustics over an extended frequency band will not only enhance spatial resolution but also better characterize *in situ* the recorded biological components (biodiversity). This will support research on the understanding of ecosystem functioning and biodiversity through high resolution, long-term time-series observations (see MRI expert group report recommendations). However, this will also raise a number of important issues. As technological breakthroughs begin to offer the reality of routine, automated biological observation, a key question will be how much detail is required to monitor marine biodiversity and what are the "sentinel" species or taxa that should be monitored (O'Dor *et al.*, 2010)? In addition, as the infrastructures for biological observation grow, how will these be coordinated into an integrated and sustained system (Heip and McDonough, 2012)? An observation infrastructure initiative like the European Marine Biodiversity Observatory System (EMBOS) aims to implement a network of observation stations with an optimized and standardized methodology. These will contribute to global initiatives such as the Group on Earth Observation Biodiversity Observing Network (GEO BON) and, in particular, the Panel for Observations of Coastal and Ocean Biology and Ecosystems, which will coordinate such efforts and contribute to the Group on Earth Observation (GEO).

11.2.5 Marine Modelling

Models are a key research tool for ocean observation, providing insight into the past, present and future. Service providers such as the Marine Core Service of the European Copernicus[4] initiative now routinely utilize ocean datasets for retrospective analysis and to develop predictions of future scenarios for stakeholder use and to aid decision-making. However, models are almost always data limited, requiring observational data for model development (e.g. choosing parameterizations and parameter values), forcing, data assimilation and data-based evaluation (e.g. validation) (Doney, 1999). In addition, a key challenge for modelling is to retain essential information without being overloaded with unnecessary detail (Levin, 1992). Interaction between modelling and observation methods also needs to be strengthened so that models are integrated from coast to open ocean and developed to take advantage of emerging datasets. The availability of real-time multidisciplinary ocean datasets will be critical for the next generation of ocean models, including multi-scale coupled and nested models for producing inter-disciplinary predictions of complex environments, for example coastal marine hazard tracking.



Credit: Marine System Modelling NOC

Simulated Sea Surface Temperature (SST) and sea-ice cover from a global 1/12th degree ocean model

[4] Copernicus, the European Earth Observing Programme (http://copernicus.eu/)

Credit: A. Gerdes, IODP

Core Splitting onboard an International Ocean Drilling Project research cruise.

The Greatship Manisha, drillship IODP Baltic Sea Paleoceanography Expedition

Credit: Geoequip Marine, Island Drilling Singapore Pte. Ltd.

11.2.6 Risk mitigation against geo-hazards

Ocean observation measurements are essential to understand, monitor and inform mitigation against geo-hazards such as gas-hydrate stability, submarine landslides, seismic activity and fluid flow along the seabed. Seismic activity and seafloor slippages, in particular, can have direct impacts on human activities and wellbeing, such as causing damage to offshore industry infrastructure and catastrophic impacts on citizens through the formation of earthquakes and tsunamis. In order to produce robust forecasting, measurements need to be carried out continuously over sufficiently long periods of time to be able to differentiate between episodic events and trends or shorter period variations.

11.2.7 The importance of long-term ocean drilling

The Earth is a dynamic, continuously changing system. These changes occur at different time scales, from the slow building of the ocean crust and ocean basin formation, through climate fluctuations to sudden, dramatic events such as earthquakes, slope failure and volcanic eruptions and associated tsunamis. The answers to many questions regarding Earth-system processes are found beneath the seafloor. The archives of past environments and climates are recorded in sediment layers that have slowly accumulated on the seabed. Reconstructions of dramatically different past climates challenge the modelling community to improve the physics and chemistry represented in numerical climate simulations.

Many of the most devastating natural events are triggered underwater. To better understand the processes that cause sudden events, long-term monitoring of active areas is required. The recent events in the Indian Ocean in 2004, and in Japan in 2011, stress the urgency for progress in deciphering the triggering mechanisms and in facilitating early prediction. The development of borehole instrumentation linked with seafloor observatories provides the potential to monitor active processes in earthquake zones in real time and understand, in particular, the relationships between fluid circulation and stress release.

The only way to access the sub-seafloor environment is by drilling to collect samples. Ocean drilling also provides the opportunity for *in situ* measurements and long-term monitoring. Initiated in the USA in the late 1960s, scientific ocean drilling rapidly became an international venture, which led to the current Integrated Ocean Drilling Program (IODP)[5] established in 2003. Sixteen European countries (and Canada) participate in IODP as part of the European Consortium on Ocean Research Drilling (ECORD)[6]. The most recent phase of the IODP program concludes in 2013.

With the new 2013-2023 International Ocean Discovery Program set to get underway, it is essential to maintain the successful global approach that has been established by the IODP participant core group, consisting of the US, Europe and Japan. Scientific ocean drilling must continue with the collection of cores from key areas of interest and the deployment of instruments and technologies to achieve the measurements of parameters that are essential in understanding, and possibly predicting, unknown biosphere frontiers, climate and ocean change, and natural hazards. Some of the key future challenges and goals include further drilling expeditions in the Arctic, the Antarctic and the Mediterranean.

[5] http://www.iodp.org/

[6] http://www.ecord.org

11.2.8 Integrated observations for evidence-based ocean governance

Marine environmental datasets are vital to support the maritime economy including marine and coastal safety, marine resources, shipping and transport, tourism. Such marine knowledge also underpins coastal and marine governance supporting a knowledge-based society. However, in a rapidly changing Earth System and dynamic human socio-economic landscape, datasets solely from the natural sciences are no longer sufficient to make informed decisions in support of Ecosystem Based Management. Close integration with the social sciences is key to delivering solutions to current and future challenges from mitigating climate change to discovering novel resources and meeting energy needs. There is particularly high demand for such datasets in the European coastal zone; an area of intense human activity that is also subject to National and European legislation. Multidisciplinary real-time ocean data support marine and coastal safety and operations and underpin weather and climate forecasting leading to enhanced understanding of ocean-climate interactions and the impacts of climate change.

Empirical data from the oceans must be interpreted alongside societal indicators to allow observations of environmental status and change to be linked to social and economic drivers and trends. Indicators of change are a powerful way to address this, offering a means to translate empirical natural science datasets into ecological indicators to assess pressure-state relationships, exploitation impacts and trends for informed marine management and policy. However, for the indicators to be effective, they must be based on a robust and sustained environmental observing programme designed to tackle issues of ocean variability. Fifty GCOS “Essential Climate Variables” (2010) have already been identified, allowing a systematic observation of the global Climate to support the work of the UNFCCC and the IPCC. The concept of EOVs (Essential Ocean Variables) was recently introduced as an approach to build a Framework for Ocean Observing (see UNESCO 2012 report ‘A Framework for ocean observing’). These EOVs are set to provide a valuable way to enhance communication and understanding across disciplines and for policy makers to have a clearer picture of changes and trends across the ocean-earth-climate system.

Clear mechanisms, such as coordination through the Scientific Committee on Oceanic Research (SCOR), will be required for defining EOVs, particularly in light of the considerable technological advances in autonomous measurement of some key biological parameters. Such environmental indicators can then be linked with socio-economic marine indicators such as those proposed by the World Bank in its ‘Little Green Data Book’ initiative. International declarations (e.g. the 2012 Rio Ocean declaration) and European legislation (e.g. the Marine Strategy Framework Directive) indicate that the demand for marine environmental assessment, monitoring, and prediction will continue to grow. Next generation ocean observation should, therefore, continue to provide new scientific knowledge and better advice for evidence-based policy assessments such as environmental status and development and management of Marine Protected Areas.

11.2.9 Geographical gaps and priority areas

The vast majority of ocean observation research and operations (with the exception of remote sensing) are focused in coastal regions and associated with the EEZs of various nations (O'Dor *et al.,* 2010). Future coordination will be facilitated through the GOOS coastal implementation plan. However, much of the open ocean, seafloor and subseafloor remains under-sampled. Observing offshore regions remains crucial, not only because little is known of this vast environment, but because such open ocean systems drive many global oceanic and climate processes and are likely to be increasingly exploited as commercial activities move further offshore. This includes, for example, biologically sensitive but resourcerich regions such as the deep seafloor, sub-seafloor and hotspot areas of biological endemism. Ocean observation of ultra-deep water, the deep seafloor and sub-seafloor will also be crucial to identify and effectively manage ecologically significant regions as industry moves towards exploiting marine biological and mineral resources from these remote environments (Weaver and Johnson, 2012; see also Chapter 8 on the deep sea).

The high latitudes have also historically been under-sampled (Busalacchi, 2010), although monitoring of polar regions is becoming an international priority because of their recognized high climate sensitivity and the growing demand to exploit the increasing areas of international open waters resulting from Arctic summer sea-ice retreat. Scientific research through ocean observation will be crucial to provide data for understanding the rapid changes in this dynamic system, validate and constrain model predictions, and underpin informed decision making and future international agreements for polar maritime navigation and marine resource exploitation (e.g. commercial fishing, oil/gas exploration), particularly in off-shore regions. Again, coordination between countries and across sectors will be essential to achieve the scale of observations necessary to provide a thorough baseline knowledge of the Arctic ecosystem before commercial exploitation takes off (Haugan, 2013).

11.2.10 Future ocean trends

The global ocean is a dynamic system and the science priorities and key variables of tomorrow are likely to be different or even include currently unknown phenomena. Natural science and a future ocean observing system should be adaptable and resilient to known and unknown future trends e.g. ocean warming, enhanced stratification and increase in mid-water oxygen minimum zones. Each of these trends would in turn influence the biogeochemical signatures of oceanic regions with implications for ocean productivity, nutrient cycling, carbon cycling, and ecosystem functioning. Across European closed and semi-enclosed seas (e.g. the Baltic, Mediterranean and Black Seas.) these changes will potentially have a profound impact on the marine and maritime sectors including tourism and aquaculture.

11.3 Building on the existing ocean observation capability

Infrastructure is the foundation for an ocean observing system, providing the platforms and services to deliver environmental data, information and knowledge. Essential components include both the hardware and core resources including people, institutions, data and e-infrastructures that maintain and sustain operations. A relatively mature ocean observing capability already exists across Europe. This can be split into four infrastructure fields (as identified by the EU FP6 MarinERA project), namely (i) research fleets; (ii) observing and monitoring systems; (iii) land-based infrastructures e.g. marine stations; and (iv) data management. The ocean observing and monitoring systems include established networks of space-based, airborne, and *in situ* platforms and sensors, e-infrastructure components for data management, and the computing power necessary for maintaining these systems and delivering data, knowledge and services. Such infrastructures are maintained by experienced operators including technical experts, engineers and scientists that are crucial for the maintenance and sustainability of the system. The section below provides information on the current state-of-the-art of European ocean observing infrastructure. A more detailed European MRI inventory and mapping has been prepared by the SEAS-ERA project[7] and the final report of the EC MRI expert group.

Credit: NIOZ

Albex Lander used for seafloor observation

11.3.1 *In situ* observation

Methods for ocean observation are constantly evolving and innovation is an essential driver for science and engineering excellence and technological advancement. New smart sensors, techniques and platforms are emerging to provide automated solutions to multidisciplinary marine monitoring. In terms of *in situ* ocean observation, improvements to sensitivity, accuracy, stability, resistance to oceanic conditions and depth rating are all key to ensuring high quality, sustained data. An increased interest and effort in ocean observation in the 1990's led to a huge technological advancement in automated sensors for monitoring physical variables such as temperature, salinity and currents. Today, thanks to global projects such as ARGO[8] and OceanSITES[9] and European initiatives including EuroSITES[10], JERICO[11], EMSO[12] and Esonet[13], such variables are monitored and provide datasets which underpin the operational Global Ocean Observing System (GOOS[14]).

Over the past decade, there has been a drive to advance biogeochemical and biological sensors and samplers (Gunn *et al.,* 2010). As a result, novel sensors for the autonomous measurement of variables from nitrate to methane and from micronutrients (e.g. iron and manganese) to alkalinity, are emerging. Accurate and high precision sensors for such variables are urgently needed to contribute to an operational GOOS. A similar technological leap is now required to enable routine autonomous *in situ* biological and chemical measurements of marine biodiversity (e.g. molecular methods using genomics). Much work is focused on minimizing power requirements and reducing the size of sensors towards miniaturized lab-on-a-chip micro sensors to minimize the pay load and enable multi-parametric observation from single platforms such as gliders and drifting buoys. Micro sensors can also be fitted to marine organisms (e.g. seals or small whales) which act as biological observatories, often producing vital profile information (Boehme *et al.,* 2010).

7 www.seas-era.eu/np4/19.html
8 www.argo.net
9 www.oceansites.org
10 www.eurosites.info
11 www.jerico-fp7.eu
12 www.emso-eu.org
13 www.esonet-noe.org
14 www.ioc-goos.org

Credit: HCMR

Ocean buoy and mooring for fixed-point measurements

Operational robustness and automation of advanced scientific equipment (e.g. Ferrybox) allow data to be collected by the commercial fleet thus expanding observations in time and space to an extent that would otherwise not be possible. Utilization of these opportunities is still in its infancy and will be important for large and power-hungry systems (e.g. acoustics) that cannot yet be deployed on autonomous platforms. However, whereas the space component of the European ocean observing system is managed and developed by the European Space Agency, the Copernicus (GMES) in-situ component is not yet coordinated by one overarching structure but is sustained by the numerous stakeholders, which often leads to duplication.

Credit: Ambra Milani, Sensors Group, NOC, Southampton and SENSEnet, Marie Curie Initial Training Network (ITN).

Iron and manganese sensor in insulating case, attached to CTD-Pump carousel, ready for deployment in the Baltic Sea(IOW, Warnemunde, Germany).

Credit: David White, National Marine Facilities, NOC, UK

Autosub-3 being recovered from the Black Sea in 2010 onto the Turkish research vessel “Piri Reis” as part of a scientific study led by Leeds University, UK looking at the flow in the deep saline channel from the Bosphorus to the Black Sea in May 2010.

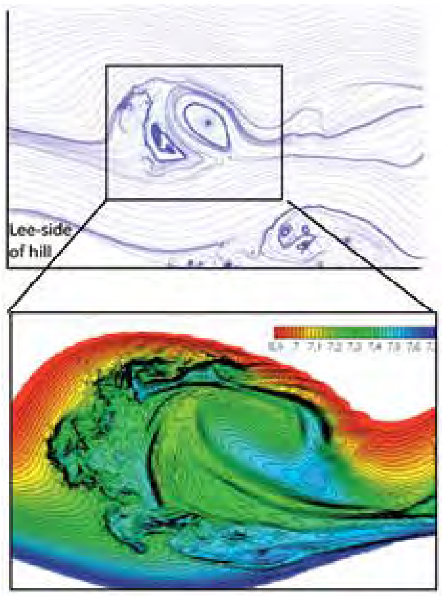
11.3.2 Sentinel satellites

The future ocean observation space component includes sentinel satellites in support of ocean forecasting systems, and for environmental and climate monitoring (see EC COM(2012) 218 final). Such developments in space-borne sensors and algorithms for satellite ocean colour radiometry (OCR) missions will expand the scientific and societal applications of ocean remote sensing. Monitoring of optically complex coastal regions will be greatly enhanced by multiple spectral bands providing more detailed information on the constituents of suspended particulate and dissolved matter. Current capabilities for monitoring polar regions will be improved by increasing the quality of moderate resolution polar orbiting observations (Yoder *et al.,* 2010). In addition, the ability to calculate indices of ecosystem structure, including phytoplankton cell size, would add significant value to current capabilities for studying marine ecosystems from space (Kostadinov *et al.,* 2009).

11.3.3 Oceanographic information in the new data age

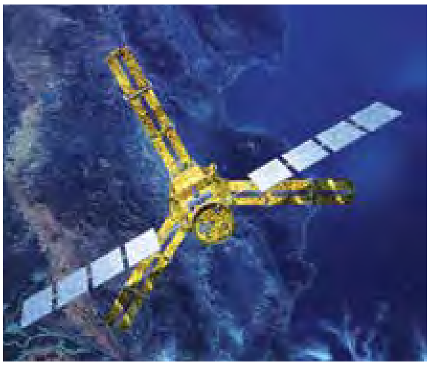
Next generation ocean observation will enable rapid and wide distribution of information (data, methods and products) (Busalacchi, 2010). However, real-time delivery of large, multivariate data sets, with increasing temporal and spatial resolution, will demand a new approach to data stewardship from storage and open access, to integration and standardization. The field of Information and communication technologies (ICT) will be an increasingly crucial component of the marine data management infrastructure. Future observing systems will need to be adaptable to new ICT approaches in order to embrace the exponential growth in multivariate data and the ongoing progression towards interoperable systems using agreed standards (e.g SeaDataNet). In particular, this will lead to the requirement for a new bio-physical data framework to allow complex biogeochemical and biological datasets and their metadata components to be available alongside climatic and physical oceanographic datasets. (Vanden Berghe *et al.,* 2010).

High performance computing facilities and e-infrastructure, including cloud computing and internet-enabled 'smart' infrastructures, may revolutionize data storage, accessibility and integration which will, in turn, drive new innovations and capabilities in environmental modelling. For example, the UK National Supercomputing Service, HECTOR, is a high-performance computing facility that has greatly enhanced the capacity to study ocean turbulence, utilizing a billion grid points to conduct Direct Numerical Simulations (DNS) of entire wind flows (Yakovenko *et al.,* submitted). A major challenge is the development of new methods for analysis of these complex spatio-temporal data types that yield information not just about the ocean state, but also the underlying dynamical processes. Model data fusion (or data assimilation) algorithms provide an attractive approach to exploit these new data streams within a robust statistical framework and to explore optimal use of observing capabilities for given monitoring, assessment or forecasting goals.



Visualisations of a Direct Numerical Simulation (DNS) of an entire wind flow on ocean turbulence investigation

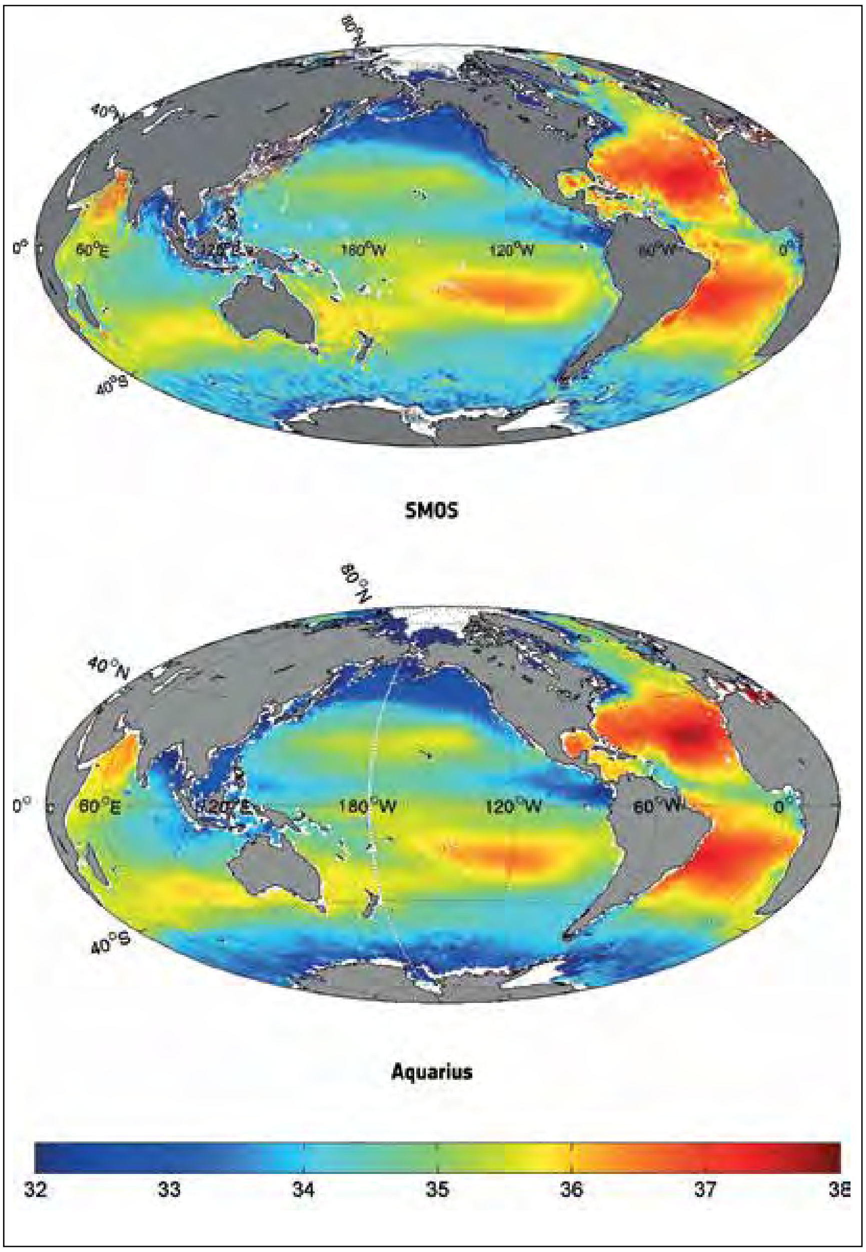
Credit: EPCC, University of Edinburgh. HECTOR project, UK



Credit: ESA - P. Carril

↑The Soil Moisture and Ocean Salinity Earth Explorer satellite

→Global salinity maps from the European Space Agency's Soil Moisture and Ocean Salinity (SMOS) (top) and Aquarius (bottom). satellites. SMOS and Aquarius are complementary by way of their spatial and temporal coverage and their viewing angles. By combining their data, maps of ocean salinity will be even more accurate and robust



Credit: IFREMER/ESR/ESA/NASA)

11.3.4 Intelligent infrastructure

The growing application of "intelligent sampling" is transforming event-driven scientific research and marine management, offering the chance to interact with autonomous sensors in near real-time and to change the sampling time, resolution, depth profile or trajectory of the platform. Some extra assets are required to allow for redundancy in the system. This is important for two reasons. Firstly redundancy allows strategic planning in the event of failure of equipment or technology before scheduled maintenance or in the case of a surge. Secondly, having a common European pool of assets allows equipment to be used as a rapid response mechanism to ensure that re-directed or additional monitoring could take place in case of an episodic event or environmental disaster such as an oil spill, earthquake or tsunami. In addition, science and technology are continuously evolving and an effective and relevant ocean observing system needs some level of adaptability to respond to new breakthroughs and insights permitted by new knowledge (see GEO 2012-2015 Work Plan).

11.3.5 European context and policy frameworks

Ocean observation is a key component to the EU Strategy for Marine and Maritime Research (MMRS), providing marine environmental datasets as a solid science base to support delivery of the societal needs specified in the Integrated Maritime Policy (IMP). In the past decade, with the success of global projects such as Argo (and its European contribution, EuroARGO[15]) and the launch of inter-governmental initiatives such as GEOSS, ocean observation has become a higher priority on the worldwide environmental political agenda. At a European level, this has been further supported by community responses such as the EurOCEAN 2010 Ostend Declaration which stated that *"Addressing the Seas and Oceans Grand Challenge requires the development of a truly integrated and sustainable European Ocean Observing System."*

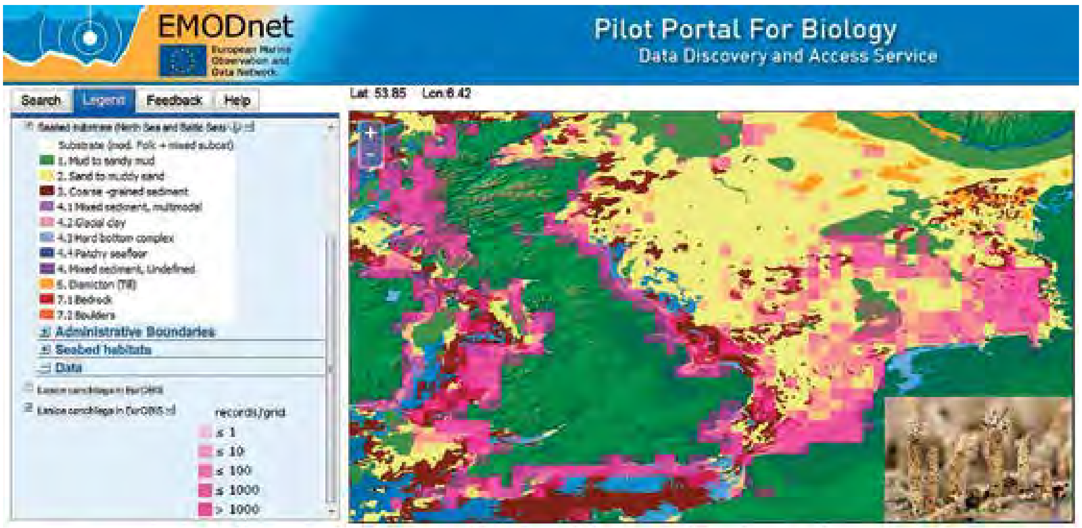
However, despite progress towards increased integration of marine infrastructures at a pan-European scale, there remains a complex landscape of ocean observation infrastructures across Europe. The Marine Knowledge 2020 initiative provides a potential unifying framework for a future European Ocean Observing System (Marine Knowledge 2020; EC COM(2012) 473 final). In addition, high investment is often required both for the hardware itself and for its ongoing maintenance and operation. The sustained funding necessary to achieve this is often difficult to secure. Such infrastructure costs are predominantly funded by Member States, although preparatory actions for pan-European marine research infrastructures, networking and integration activities are funded by the European Commission through EU research funds. A number of European initiatives have been funded to assess the current state of play of research infrastructure in the environmental and earth sciences domain (MRI expert group final report). The adoption of legal instruments such as the ERIC[16] may facilitate the Member States in enabling collaborative funding of research infrastructure projects from national budgets. This route is currently being pursued by EMSO and EUROARGO, two marine research infrastructures on the ESFRI roadmap.

[15] http://www.euro-argo.eu/

[16] http://ec.europa.eu/research/infrastructures/index_en.cfm?pg=eric

Despite the fact that EU funds support pan-European marine data service initiatives such as Copernicus, there may be an increasing call for Member States to mobilize structural funds to support such programmes (see the "Funding MRIs" section of MRI expert group final report). As a result, it is likely that novel funding models and dynamic governance will be required to establish long-term commitments into the future (GMES Copenhagen Resolution and EC COM(2012) 218 final). Ongoing evaluation of the socio-economic and environmental contributions of marine research infrastructures is, therefore, crucial to establish the impacts (both positive and negative) of such infrastructures on employment, GDP, education and innovation (see MRI expert group final report, Annex 2 and Figures 1, 2 & 3). In addition, it is likely that legislation such as the Marine Strategy Framework Directive (MSFD) will become one of the most important policy divers for MRI development at a European scale in coming decade.

11.3.6 Geo-spatial data and information systems



Credit: European Ocean Biogeographic Data System (EurOBIS))

EMODnet Biology data portal providing a view from the southern North Sea combining an integrated broadscale seabed sediment map (1:1 million scale) and distribution data (aggregated per 15 by 15 minute grid with a temporal scope from 1977 till 2009) from the reef building Polychaete worm (Lanice conchilega, Pallas, 1766).

At present many ongoing observational and data networks are producing openly accessible, high quality data, services and products for society, contributing to initiatives such as SEADATANET[17], EMODnet (see Marine Board-EuroGOOS EMODnet Vision Document[18]; EMODnet Road Map[19]), the Ocean Biogeographic Information System (OBIS) (Vanden Berghe *et al.*, 2010), GMES Marine Core Services and international initiatives such as the Global Earth Observation System of Systems (GEOSS). These initiatives utilize ocean datasets to provide societal products including ocean analyses and forecasts for applications ranging from maritime safety to climate monitoring. However, there is a real need for such initiatives to become more operational and to interlink the full data pathway from observation to analysis and product/service. At present, shortages or gaps in national commitments are still resulting in gaps to crucial datasets that feed into downstream services. The requirements of both space and *in situ* ocean observation systems should, therefore, be evaluated to ensure that a future ocean observing system can deliver uninterrupted data streams and can react to new priority areas as science and societal needs change.

17 www.seadatanet.org

18 http://www.marineboard.eu/images/publications/EMODNET-7.pdf

19 EMODNet Roadmap https://webgate.ec.europa.eu/maritimeforum/system/files/roadmap_emodnet_en_0.pdf

In recent years there has been a growing need to assess the costs and benefits of key ocean observing infrastructure components (e.g. see FP7 project SEAS-ERA Deliverables 2.2. and 2.4 and FP7 GISC project final deliverables). These would now benefit from a strategic overview aided by observing system simulation experiments and data assimilation in models to assess the added value and complementarities of all assets (space and *in situ*) to ensure that the most cost-effective system is in place and that data management and services initiatives receive the optimum datasets in a timely manner. The enormous data stream from the envisioned observing system will also require a periodic and systematic prioritization to ensure that the optimum infrastructure is in place as scientific and societal demands for certain essential datasets change. Regional monitoring systems in the context of EuroGOOS and projects such as BONUS and regional agreements have taken a basin-scale approach to interface science and governance. There is a real need for member states and third countries to share a collective responsibility for the delivery of healthy seas. However, reconciling these different viewpoints towards an integrated approach whilst maintaining member state commitments is vital to ensure a balance between environmental health and socio-economic viability and the importance of societal values in evaluating stakeholder perspectives and trade-offs (Ounanian *et al.,* 2012).

11.4 Towards an integrated, efficient and sustained ocean observing system

A Concept for a European Ocean Observing System

It is strategically important that a truly end-to-end European Ocean Observing System (EOOS) is developed to provide the environmental data essential for the next generation of ocean science and growing maritime activities. The EOOS should be smart, resilient and adaptable, with constant feedbacks to enable each stage to inform, drive and deliver high quality, relevant and timely environmental products and services for society (see Figure 11.1). This circular, inter-dependent system, is comprised of four pillars namely stakeholders, infrastructure, data services and outputs (products and services). These four pillars are all crucial to provide relevant and timely products for society in areas including stewardship of the marine environment, understanding the ocean and climate and supporting the marine economy and maritime safety (see MRI expert group report; Section IV). The system should be inherently open to adaptation and innovation, ensuring enhancements can be made to each component that promote innovation, growth and knowledge across the whole system, e.g. to the observation network or to the harmonization of data management protocols and data portals.

A future European Ocean Observing System (EOOS) should build on the wealth of existing infrastructure capabilities and multi-platform assets already in use across European marine waters, further integrating infrastructures, institutions and resources and information to deliver societal benefits (see GEO WP2012-2015 Work Plan). There is, therefore, an ongoing need for evaluating observation networks to identify gaps and priorities, as highlighted in the Green Paper on “Marine Knowledge 2020: from seabed mapping to ocean forecasting” (Marine Knowledge 2020 COM (2012) 473 final).

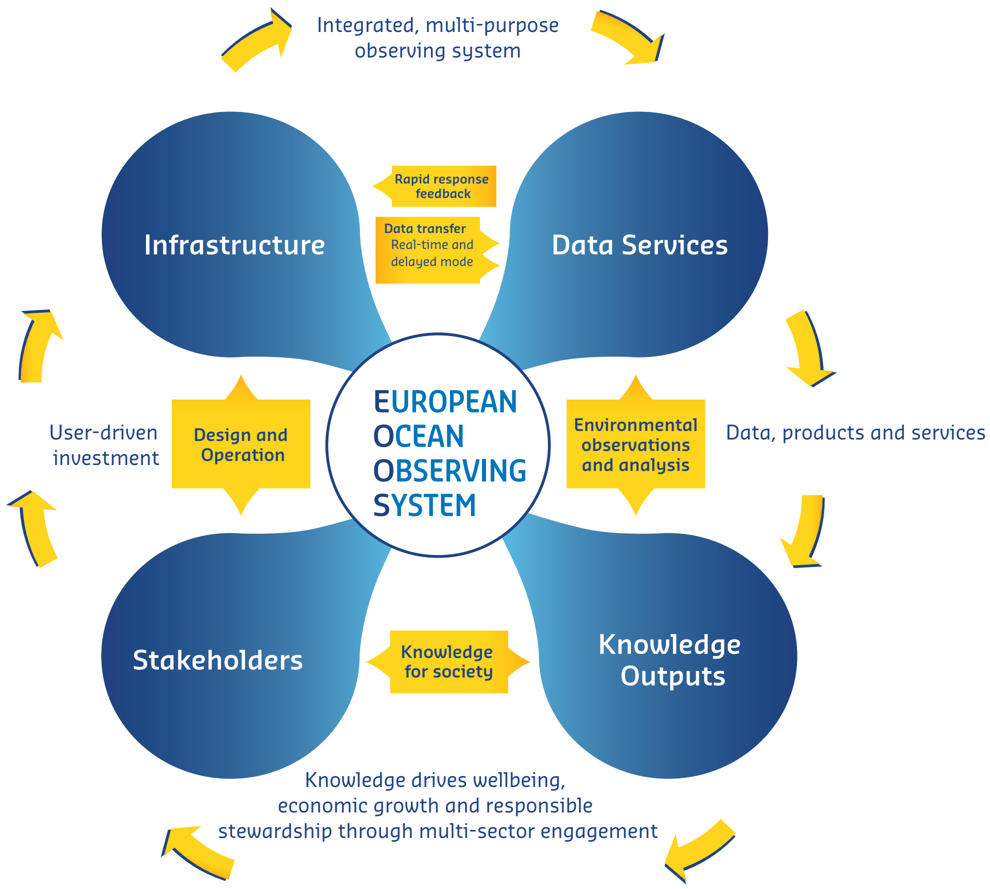


Figure 11.1

Conceptual diagram of the European Ocean Observing System showing its key components (stakeholders, infrastructure, data services, knowledge outputs), drivers, inter-dependencies and applications (a more detailed breakdown of each component is provided in the table below). A future integrated EOOS should form the European contribution to the Global Ocean Observing System and to the European marine component of the Global Earth Observation System of Systems.

Credit: K. Larkin, European Marine Board Secretariat

EOOS Infrastructure	EOOS Data Services
Integrated Remote and In situ hardware providing a multi-purpose observing system, including: • Platforms (e.g. ships, satellites, moorings) • Computing and modeling facilities. • Resources (e.g. technical, scientific and administrative personnel) are also vital to support sustained core operations	Complimentary Data management centres, online portals and repositories providing open access to data, observations and knowledge for EOOS Stakeholders. • Real-time / operational services including forecasting, maritime safety and security • Delayed Mode including non-autonomous observations
EOOS Stakeholders	**EOOS Knowledge outputs Products and services for Society**
• European citizens • Member States and Funding agencies • European policy makers • Scientists (natural and social), engineers and technologists • Environmental data / IT managers • Marine and maritime industries e.g. fishing, tourism, navigation, offshore energy (oil/gas; renewable), security. • Non governmental Agencies	• Environmental Analyses (trends, ranges), Assessments and prediction forecasts for marine and maritime policy, environmental hazards, defense and security. • Fundamental and applied science driving Innovation and Growth. • Sustainable use of the coastal and marine environment for resources (e.g. food, fuel, pharmaceuticals) tourism and recreation

Initiatives including the EMODNet data portals in combination with SeaDataNet are already implementing this by identifying and mapping existing data and observation networks. The ongoing effort to determine gaps in data and observation systems (e.g. EMODNet phase 2 'Sea-basin checkpoints') will allow further definition of additional sea basin observation and data needs to address societal challenges and EU marine and coastal policy requirements. Successful implementation of an EOOS should form the overarching umbrella for coordinating Europe's ocean observation capability. This should utilize existing networks such as EuroGOOS which plays a key role in the area of operational oceanography; a role that is likely to grow as EuroGOOS moves towards consolidation as a legal structure. A strong EOOS will also require improved coordination between research and operational platforms forming beneficial partnerships between public and private sectors and integrating at local, national and regional scales.

Multi-purpose ocean observation

Historically, the ocean observation system has developed independent components to meet the needs of the oceanographic research and operational communities. However, partnerships between the public and private sector are emerging as a relevant way to serve the needs of users (Rio Ocean declaration, 2012), increase efficiency and drive growth in employment, GDP, education and innovation (see valuation of Marine Research Infrastructures in MRI expert group report). Next generation integrated infrastructure will therefore enable research and operational systems to be mutually supportive and beneficial (Busalacchi, 2010). In many cases, such collaborations are already in existence, combining academic research with service provision to address environmental legislation and policies, and societal needs. The growing potential for "intelligent sampling" is supporting interdisciplinary research and beneficial partnerships between stakeholders, fostering multi-use of observing platforms. For example, in the Mediterranean, there are a number of underwater arrays of sub-surface moorings funded largely to study neutrino particles. However, in many cases, oceanographers are collaborating with particle physicists to conduct mutually beneficial interdisciplinary research, e.g. bioluminescence studies, ecosystem dynamics.

There are also examples of public-private partnerships and multi-sector investment where stakeholders are working together to produce sustained ocean observing platforms for both fundamental and applied research (e.g. SmartBay, Ireland). In Norway, fishing vessels have been designed and equipped for collecting ecosystem information, thus extending the possibilities to collect data in time and space in support of management. The petroleum industry has a unique network of cables and seabed installations that support most essential sensors for marine monitoring. The extended focus on sustainable development has made industry more interested in collaboration and there is a large potential for stimulating integration of marine monitoring instrumentation in industry-owned infrastructure.

It is clear that shared ocean infrastructure investment and maintenance (including the full life cycle of infrastructure) could ultimately reduce costs, lead to more efficient and harmonized use, surge capacity and produce new opportunities. A step-change is now required to take the current observing capacity, designed for understanding the marine environment, towards a user-driven operational ocean observing system. Long-term research drivers and needs should still be at the core of the design process, but these need to be clearly linked to social, economic and infrastructure requirements with feedback by multi-sector stakeholders to drive innovation in the system.

Fundamental science discoveries of the future may pave the way for applied research and ecosystem based management. For example, as pressure mounts to explore and exploit potential natural resources in the polar regions and the deep-sea, there is a need for the research community to discover and identify hotspot or ecologically and biologically significant areas (EBSAs) to facilitate ecosystem based management in the future. Despite the existing capability of observing platforms covering the space, air and sea, the disparate nature of the disciplines, stakeholders, datasets and focused expertise of researchers and specialists, means that few studies are truly holistic, creating further issues for policy makers requiring synergistic summaries regarding the status of a research field. For example, the impact of ocean acidification on an entire coral reef ecosystem will have both environmental and economic consequences in terms of potentially negative impacts on tourism and coastal defence. The current lack of cross-sector communication makes it difficult to assess the full human footprint on an oceanic region and the likely trajectories for marine variables and indicators in the region based on economic growth models. Innovation will also be driven by cross-collaborations between scientific disciplines and domains. For example, the fields of medicine, marine biotechnology and robotics are already providing applications which can be applied to enhance ocean observation of the marine environment.

Flødevigen marine research station, Norway

Credit: Institute of Marine Research

11.5 Recommendations

Credit: IFREMER

Remote underwater video system on a New Caledonian reef as part of a Marine Protected Area monitoring programme

In reality, the future EOOS will be a system of systems, building on existing initiatives and establishing long-term support through mixed funding models, utilizing a wide range of funding. There is a real need for cross-disciplinary research and multi-stakeholder engagement. Natural and social science questions and research topics need to be mapped against societal challenges, policy needs and economic opportunities to ensure the observing system supplies relevant products and services for society. However, the added value and benefit of an integrated system will be enormous. The simultaneous and synthetic observation of multi-variable physical, biogeochemical and biological information from space-borne and *in situ* surface water column and seabed components will revolutionize our understanding of various oceanic processes. Through mutually beneficial partnerships and effective science-policy interfaces, such information and knowledge will empower society with the tools to monitor, understand and predict ocean processes and the tools for sustainable management of the ocean into the future.

There is a clear need to integrate and enhance the existing European ocean observing capacities to enable a fully integrated, sustained system that can deliver high quality information and knowledge to underpin environmental policy and management. To this end, a future European Ocean Observing System (EOOS) will need to further integrate marine observations from the coast to the open ocean and from the surface to deep sea, promote multi-stakeholder partnerships for funding and sharing of data, and align with global efforts within a coherent framework to engage all countries and work towards a truly integrated global ocean observing system.

Key recommendations for the future operation, funding and sustainability of EOOS include:

1. **A common vision for the EOOS**

   A common vision should be developed for a system of systems with individual ocean observation infrastructure assets contributing to a wider, strategic network. Coordination could include establishing an independent leadership council to maintain an overarching/strategic outlook of the independent funding mechanisms for EOOS and the different stakeholder interests and priorities.

2. **Promote excellence and quality**

   Scientific excellence and high quality environmental data delivery should remain a key priority so that the infrastructure design and location of observing systems can accommodate operational services in tandem with higher-risk, blue skies research. Research can, in turn, drive technology breakthroughs and allow scientific experimentation and hypothesis testing to establish ranges, thresholds and trends of marine ecosystems, helping to constrain future scenarios. There should be more emphasis on an interdisciplinary approach and the socio-economic value of the information produced to support future research priorities.

3. **Develop the EOV concept**

   The concept of Essential Ocean Variables (EOVs) should be further developed as a way of translating marine environmental data into indicators of change that can be used by policy makers and wider stakeholders in tandem with Essential Climate Variables (ECVs) for assessments of variability and trends across the ocean-earth-climate system.

4. **Gap analysis – societal needs**

   Conduct periodic critical gap analyses through stakeholder consultation to assess the environmental and societal relevance of marine research infrastructures and identify future priorities and capabilities based on societal needs and state-of-the-art science and technology developments in all areas of infrastructure from ocean platforms to high power computing/modelling facilities.

5. **Gap analysis - modelling**

   Continue to support the use of environmental models and statistical data assimilation methods for predictive capabilities and as a tool for identifying gaps in the current observing system. Many environmental models are now at a mature, highly complex stage of development. The use of models for gap analysis is currently under-utilized and largely centered around data assimilation to produce future scenarios or retrospective reanalysis for validation.

6. **Training**

   Networking and training of scientific users will continue to be essential to define common standards of practice and to ensure Europe maintains and develops an expert pool of personnel to support the ocean observing system from infrastructure development to maintenance, data management, analysis, and delivery of goods and services.

7. **Access**

   Facilitate access to ocean infrastructure by the European and global community across stakeholder groups and sectors (engineers, natural and social scientists) providing an opportunity for international collaboration and interdisciplinary studies of oceanic systems in the context of societal drivers.

8. Data standardization

Encourage the further development of a coordinated data management infrastructure (building on SEADATANET and EMODNET) so that European marine data management adopts common (or interchangeable) standards to maximize the outputs and synergies between these data centres and portals.

9. Adaptability

Ensure that the ocean observing system addresses risk, factoring in a degree of redundancy for crucial time-series and developing a plan for enabling rapid and coordinated pan-European responses to monitor and understand rare/unexpected events, including environmental disasters (e.g. oil spill), natural hazards (e.g. storm surge, earthquake/tsunami, volcano) or biological responses (e.g. Harmful Algal Blooms).

10. Innovation in observing

Invest in research and development for the continued innovation of EOOS infrastructure. This should include funding for ocean sensors (e.g. biological, acoustics), platforms and cross-sector research to ensure marine science takes advantage of state-of-the-art developments across other sectors (electronics, energy, communication and information technology).

11. Sustainable funding mechanisms

Innovative funding mechanisms should be developed to sustain the European Ocean Observing System. Funding should be secured for the full life-cycle of ocean observation, from deployment, maintenance and operation to retirement/decommissioning or movement of assets to a new location depending on evolving science needs. It is likely that a mixed model will be the most robust funding strategy for long-term sustainability.

Funding opportunities could include:

- Mutually beneficial public-private partnerships and stakeholder investment for research infrastructures that support the development (and investment) of marine industries and other stakeholders, e.g. from the marine renewable energy and off-shore aquaculture sectors.

- European structural funds for marine research infrastructures to support innovation, sustainable development, better accessibility and regional cohesion across European ocean observation capabilities.

- European funding to support the research infrastructure networks to develop longer-term frameworks (e.g. I3 initiatives) and pan-European legal instruments (such as ERIC) that will enable coordinated Member State investments. Improved coordination of Member State investments could be achieved through JPI-Oceans.

12

Training and careers for the next generation of marine experts

Credit: NOC

12.1 Introduction

Establish appropriate training and mobility opportunities for marine researchers and technologists to deliver both stable and attractive career pathways and the highly skilled workforce that will be needed to support expanding marine and maritime sectors (Ostend Declaration, 2010)

The workforce for tomorrow's marine research, policy and industry sectors will be largely drawn from a pool of graduates who are currently receiving training in higher education institutions. European programmes and systems of training in marine science and technology are, therefore, of the utmost importance. The challenging questions for marine sciences in this century revolve around systems and their interactions, and addressing scenarios that include the role of people, economics and policies. Tackling climate change, understanding ecosystem function, managing sustainability: all of these require a much more extended mindset than was typical even a decade ago. The truly ambitious goal is to create synergies that will ultimately lead to a convergence in understanding which will help to facilitate workable solutions.

The EU Blue Growth initiative [1] is designed to develop and maximize the potential of Europe's oceans, seas and coasts and to support jobs and growth. The marine and maritime sectors that make up the "blue economy" could provide up to 7 million jobs in Europe by 2020[2], representing an increase of 1.6 million on today's figures. New jobs will be spread between expanding traditional sectors (e.g. maritime transport, seafood processing) and emerging sectors (e.g. marine renewable energy, deep sea mining). In order to facilitate this expansion, a skilled workforce will be required, comprised of graduates from many different levels of the educational system. Education and research are, therefore, central components of the blue growth strategy and it is recognized that training itself, and the delivery of high-quality graduate programmes, is part of the engine which drives innovation and technology development in maritime sectors.

The marine and maritime sciences have a significant role to play in supplying high-quality graduates through training programmes and initiatives which are designed to address the needs of industry, science and policy. Achieving these goals will require restructuring the educational landscape of marine sciences in Europe.

[1] COM(2012) 494 final
[2] COM(2013) 279 final

12.1.1 Current status of marine science training in Europe

Dedicated degree programmes in marine sciences first appeared in the 1960s and are, therefore, a relatively recent development. Many educational programmes in ocean science and technology grew out of classic disciplines which were "marinated" by focusing on challenges and questions associated with the seas and oceans. This can represent both a strength and a weakness. It is a strength when, for example, advanced mathematics or physics expertise is applied to ocean science questions and when preparing students for an academic career. However such traditional tracks are not always successful at delivering a graduate ready for a career in industry or policy.

The FP7 EuroMarine project[3] recently compiled an inventory of the educational landscape for marine sciences training in Europe. Dedicated marine science programmes currently account for less than 10% of higher educational (degree) programmes. The EuroMarine inventory results are presented in a database and cover some 210 trainings, courses and degree programmes. The inventory identifies approximately 50 MSc programmes but only 12 PhD programmes. This seemingly low number is an underestimate as doctoral programmes are not usually labelled so specifically. For example, a degree in conservation, in modelling, or in engineering could well be directed towards marine systems but this would not be indicated by the specific university programme. Thus, many of those who will work in the marine sectors in the future may not have received training through a dedicated marine science graduate or post-graduate programme. Moreover, the application of expertise from non-marine science and engineering to marine issues is to be welcomed and encouraged.

Credit: Joana Rodrigues, CIIMAR

Credit: Joana Rodrigues, CIIMAR

Further complicating the marine science educational process is the physical distance and often tenuous bonds between many marine laboratories and their parent universities. Such isolation has produced a fragmented marine sciences community. Some universities are beginning to look towards the formation of national level networks to help remedy the situation, but they are exceptions.

[3] www.euromarineconsortium.eu

The EU has supported the creation of networks of excellence at European level, but further incentive to support the creation of national networks as an intermediate step could help to dissolve some of the structural barriers that currently exist.

An additional obstacle concerns the underutilization of coastal marine or oceanographic institutes as facilities for training activities, as traditionally these facilities have been largely engaged in research. However, some coastal labs also act as bases for student training and field courses. Several European coastal marine laboratories provide the opportunity and facilities for hosting students and visiting researchers, including local or on-site accommodation, teaching laboratories, research laboratory bench space, or access to the marine environment through vessels and equipment. The Biological Institute Helgoland of the Alfred Wegener Institute in Germany, for example, supports some 100 visiting researchers and 700 training places each year. Where such important and unique services are provided by marine laboratories, particularly in support of graduate training, they should be protected and developed. To support this process, it may useful to provide a basis for improved networking and promotion of the training facilities at coastal marine laboratories at EU level. This would have the additional benefit of providing some level of choice through access to a range of marine environments with very different characteristics.

The Biological Institute Helgoland of the Alfred Wegener Institute, Germany, is recognized as a training centre of excellence in marine sciences.

One of the accomplishments of the former FP6 marine Networks of Excellence (MarBEF, Eur-Oceans, Marine Genomics Europe) and continued via the FP7 EuroMarine initiative, is the creation of networks and clusters for teaching and training. This takes many forms including mobility schemes for PhD students and post-docs, summer schools of 2-3 weeks and shorter foresight workshops. While these are undoubtedly important and productive training opportunities, they are short-term *ad hoc* initiatives which cannot address the deeper structural problem of degree programmes. Finding the right balance of initiatives which are bottom-up (scientists, educators) and top-down (several hierarchical levels: EU, member states, universities) needs further investigation, but for now these elements are not well connected.

12.1.2 Key challenges in marine graduate training

In the U.S., the term "team science" is used to describe initiatives designed to promote collaborative and often cross-disciplinary approaches to answering research questions. The challenging questions for the marine natural sciences in areas such as ecosystem function, trophic dynamics, biogeochemistry, biodiversity, climate change and adaptation studies, cut across all ecosystems. However, in practice the framing of the questions, the hierarchical level of approach (ecosystem, community, population) and methodologies used (e.g., modelling, genomics, biogeochemical, descriptive vs. experimental) are often radically different and opportunities for cross-training remain difficult. For example, a biogeochemist working on process functions in the open ocean could benefit from being aligned with a microbial ecologist working on the functional metagenomics of phytoplankton, bacteria and viruses. Ecosystem modellers dealing with, for example, niche models and functional pathways via an omics framework, could benefit from being aligned with biogeochemists interested in biodiversity and ecosystem functioning questions.

This demonstrates the need to reframe training for the 21st century marine scientist in a more cross-disciplinary manner. In this context, cross-disciplinary means within the natural sciences; while trans-disciplinary means a link outside of the natural sciences, e.g. with socio-economics, policy, law, and maritime industry. Extending to the trans-disciplinary level will require yet another level of interaction, which is currently difficult to achieve.

Some additional hurdles in the development of a team science approach in Europe include:

- PhD studies are necessarily focused on the specialties of the supervisors in a particular institute or institutes. Mobility programmes are an important tool in promoting cross-training but remain non-structural in most cases.

- Faculties and Schools within universities are not generally aligned to support team science in the teaching context (i.e. trans-disciplinary training) and are often actually competing with one another internally; yet this is precisely the structure within which the training of PhDs is currently implemented.

- Summer schools and extended workshops facilitated through national or European networks are useful but still insufficient because they are too short and transient. Teaching is provided through goodwill and typically with little or no acknowledgement from the home institution.

- Required infrastructure in oceanographic institutes (blue water, ship-based, open ocean pelagic or deep sea benthic) and coastal marine laboratories (intertidal or shallow sub-tidal, boat or ship-based, coastal benthic and pelagic) can be quite different which can further subdivide domains and questions in an artificial way, again hindering cross-training.

- Team science often means relinquishing control and authorships in large projects which, in turn, is not rewarded because of requirements for tenure and other promotions that reward individualism.

Credit: Marine Institute

Collaborative research programmes funded through EU and national agencies facilitate primary level team science to some extent but it remains challenging to push this agenda forward at the level of educational structures that last beyond the funding period. The Erasmus Mundus joint MSc and PhD programmes are important but are generally too small to reach the level of integration required, although from 2014 the new Erasmus for Allt[4] programme will provide greater opportunities for mobility and career development for students, trainees and teachers. The Marie Curie ITN programme has also been highly effective though it tends to target very specific research topics. The main concern with these programmes in their current formulations is their limited scope and duration and that they are managed in isolation from one another. Thus, training and mobility schemes could benefit from being better aligned and more fundamentally structural in their intent.

From an industry perspective, marine graduate training in Europe must also take account of the ever-changing demands of maritime sectors which require access to a steady output of highly-skilled marine graduates. According to the European Commission Action Plan for a Maritime Strategy in the Atlantic Area[5], there is likely to be a shortage of suitably skilled workers to meet the requirements of rapidly developing sectors such as marine renewable energy, seabed mining and blue biotechnology. Emerging maritime sectors themselves rely on research and innovation as key drivers of growth, which further emphasizes the need for tailored education and training programmes and a closer alignment of education and industry. The management and governance of maritime activities in crowded European waters is already becoming a critical issue and graduates will also be required to work in the largely government-run marine policy and management sectors, able to support the complex planning and decision making requirements which facilitate a modern ecosystem based management of marine resources.

Credit: M. Thorndyke

[4] http://econsort.ugent.be/exhibit/euromarine.html

[5] EC COM(2013) 279 final. Action Plan for a Maritime Strategy in the Atlantic area: Delivering smart, sustainable and inclusive growth.

12.2 Recommendations

Addressing the above challenges can be achieved through the refinement of existing programmes and initiatives, coupled with the planning and development of new and innovative solutions. With respect to existing initiatives, utilization and widening (in scope and duration) of Marie Curie International Training Networks (ITN) would represent an important first step. A more sustainable framework to support thematic summer schools, foresight workshops and continuation of short-term mobility programmes of 1-3 months in duration would also be beneficial. Significant training opportunities can also be provided by Framework Programme infrastructure initiatives (e.g. EMBRC[6] and ASSEMBLE[7]) and there is also potential for the EU Joint Programming Initiatives to support long-term programmes for trans-national educational collaboration in marine sciences. All of these existing options should be considered as part of a future strategy for marine graduate training.

In addition to refinement and better support to existing initiatives and programmes, there are a number of ways in which marine graduate training could make a quantum leap, through new structures, training initiatives and the use of modern ICT technologies and interfaces. Some possible ideas which deserve further investigation include:

1. **Development of a Khan Academy[8] focused on marine sciences.**
   The Khan Academy is an online educational tool providing free access to a significant and continually expanding selection of quality-controlled educational tools and resources across a range of disciplines and subjects. The concept of web-based education is growing steadily and a number of prestigious universities have already established programmes but, as yet, none are available in marine sciences. Europe could be the first to spearhead the development of a Khan Academy in Marine or Ocean Sciences. A Marine Science Khan Academy could be realized with proper financial backing in a cooperative effort between scientists and business or a public-private partnership.

2. **Industry-funded third-level training**
   Industry is interested in recruiting personnel highly qualified in the marine and maritime sciences. If large companies (e.g. engineering firms, maritime firms, pharmaceutical companies interested in marine natural products and resources, etc.) could be engaged in providing a structured long-term commitment, this could help to cement permanency (as is often done in law, economics and business schools). Marine scientists must learn how to engage more closely with industry to better align graduate training programmes with the requirements of potential employers of marine graduates.

3. **EU programme for integrative graduate education and research training**
   Develop and support at both national and EU level programmes similar to the integrative graduate education and research training (IGERT)[9] , programme of the US NSF. The Scripps Institution of Oceanography (California) has developed such a programme at the Center for Marine Biodiversity and Conservation Biology (CMBC) which integrates conservation, socio-economics and law.

[6] European Marine Biological Resource Centre; www.embrc.eu

[7] Association of European Marine Biological Laboratories; www.assemblemarine.org

[8] www.khanacademy.org/about

[9] www.igert.org

4. **Ocean Schools**
   Europe's unique spectrum of bordering seas offers tremendous opportunities for clustering educational schemes, marine stations, museums, aquaria and regional vessels into large, regional "Ocean Schools", which can develop an educational critical mass and promote a pooling of resources. A scientific rationale in a bordering sea can moreover easily blend with a cultural and a heritage dimension. Such Ocean Schools could primarily provide graduate education and doctoral research, but they equally will be the centres for life-long learning, where professionals and policy people can refresh their knowledge and re-source their skills.

Careers beyond the sea – an ocean of opportunities

Training at sea need not to be confined to the generation of human resources for the marine and maritime sectors alone. There is no better school for leadership, entrepreneurship and team building than the ocean. This opportunity is of special importance for young people. Being removed from artificial "bubbles" of permanent and instant communication and confronted with nature, allows young people to gain a sense of responsibility and of self-confidence, blended with modesty. Solidarity and team spirit build up naturally. The opportunity to offer young people – between secondary school and higher education – an internship at sea, could help to support personal development and the making of informed career choices, in addition to a greater appreciation of the scale and importance of the ocean and the natural world. This would pay off in educational performance, and in a higher return to society. Pioneering efforts such as the IOC-UNESCO "Training Through Research" (TTR; the "Floating University")[10] have already proven their value and generated a tightly-knit global network of alumni. Educators and industry need to be challenged to provide a blueprint for maritime placements and internships.

Credit: Marine Institute

The Science@Sea training courses provided by Marine Institute (Ireland) offer students opportunities to gain work experience onboard a research vessel.

[10] www.unesco.org/new/en/natural-sciences/priority-areas/sids/natural-resources/coastal-marine-resources/training-through-research-the-floating-university

12.3 Conclusion and vision

The demands and opportunities for education, training and career development differ from sector to sector and from discipline to discipline. Nevertheless, educators need to keep abreast of the specific and evolving needs of science (curiosity-driven and applied), industry and policy; and of young scientists themselves. A strong vision for the future of marine science education and training must, therefore, be based on the needs of these four key stakeholder interests.

No single programme can cover everything (all of the applied aspects, all priority areas such as energy, water, human health, climate change, public outreach, technical-vocational training, etc.). The focus of the message in this chapter is on establishing a new and permanent educational landscape for the training of a new generation of MSc and PhD graduates able to take on the challenges of cross- and trans-disciplinary research focused on the seas and oceans, or to enter the workforce in the maritime and policy spheres without the requirement for extensive retraining. This is a major challenge and will not be achieved easily. Inherent to this is the need to identify ways to improve the capabilities of the next generation of marine scientists and engineers to work at a systems level, applying multi-disciplinary knowledge to address complex marine issues which cut across scientific, environmental and social systems. To achieve this, it is necessary to examine the very complex educational landscape that currently produces our professional marine experts, to identify some of the key issues and challenges faced by educators, and to make recommendations on how to improve marine graduate training in Europe.

Training breeds expectations. A key challenge is to match the expectations of early career scientists with the needs of society. The traditional disciplinary track for marine graduates through the university system places an emphasis on developing a skill set suitable for a career in academia and research. At the same time, there are many opportunities for marine graduates in maritime industrial sectors, although the skill sets don't always match. An important way to meet the future needs of the maritime industry and avoid a brain drain and loss of trained academic researchers, will be to build stronger bridges between the marine sciences and the maritime sector at the educational level. This will require profound structural changes, perhaps in the direction of the above-mentioned Ocean Schools to breed both maritime graduates and engineers with a scientific knowledge and marine scientists with a maritime and technological culture, capable to meet the fluctuating dynamics of the market with a greater flexibility.

A vision for the 21st century (marine) scientist

The "new 21st century" scientist will need to possess both a cross and trans-disciplinary perspective. The new generation of marine scientists will not be scientists who know a little bit about all disciplines (a "jack of all trades and master of none"), but scientists with deep knowledge in one discipline and basic "fluency" in two to three others (National Research Council, USA 2009), one of which needs to ensure trans-disciplinary fluency in order to communicate and create broader partnerships. This will help to close the gap between engineering, environmental and social sciences; and enable policy makers to better understand the opportunities, as well as limitations, in tackling the particularly complex problems and questions that we face. In short, the vision is to train a marine expert who is "jack of all trades and master of a few," and who has a much shorter leap to make from education to the workforce.

Credit: VLIZ

Credit: VLIZ

Professor Mike More, chair of the European Marine Board working group on Oceans and Human Health giving a lecture at the VLIZ Young Marine Scientists' Day 2012

13

Towards effective European marine science-policy interfaces

13.1 Introduction

Marine knowledge is increasingly in demand to inform evidence-based decision-making across environmental and wider societal policy areas (e.g. climate, energy, food security). However, the full uptake of this knowledge into European policies is often hindered by a lack of effective interfaces that bridge the gap between the science and policy fields (Briggs and Knight, 2011) and a need has been identified at European level to enhance knowledge transfer and ultimately to increase the delivery of policy commitments (SOER, 2010; see also proposal for a General Union Environment Action Programme to 2020, COM(2012) 710 final)[1]. Science-policy interfaces (SPIs) can be defined as "social processes which encompass relations between scientists and other actors in the policy process, and which allow for exchanges, co-evolution, and joint construction of knowledge with the aim of enriching decision-making" (definition from van de Hove, 2007; see also Heip and Philippart, 2011). SPIs are implemented to promote the interplay between the science and policy domains, fostering exchange between knowledge producers (e.g. the research community) and knowledge users (e.g. policy makers).

[1] http://ec.europa.eu/environment/newprg/pdf/7EAP_Proposal/en.pdf

Credit: European Marine Board

For the EurOCEAN 2010 conference, the European Marine Board prepared a set of 10 posters highlighting the Grand Challenges for marine research in the next decade. The themes for the EurOCEAN 2010 conference and the posters are also used in the structure of this document.

13.2 Knowledge transfer and the science-policy process

Science is a crucial component of the wider knowledge base utilized to enrich decision making which includes scientific, technological, social, economic and political (e.g. governance, legislation) considerations (Hulme *et al.*, 2011). Marine knowledge providers (e.g. research performing organizations, NGOs, industry etc.) play an important role in producing and making available knowledge that can be used in the policy process. Science-policy interfaces are, therefore, essential to maximize knowledge transfer and ensure relevant scientific information is available for consideration by knowledge users across the marine stakeholder and policy sectors. Figure 13.1 is a conceptual diagram representing the role of science-policy interfaces in the European policy process. Such interfaces are crucial as bottom-up mechanisms to engage stakeholders from all relevant sectors and to optimize access to relevant knowledge for the decision-making process. It is also vital that science-policy interfaces can communicate top-down recommendations from policy makers including policy decisions and future needs to help identify gaps in current knowledge and drive new knowledge production.

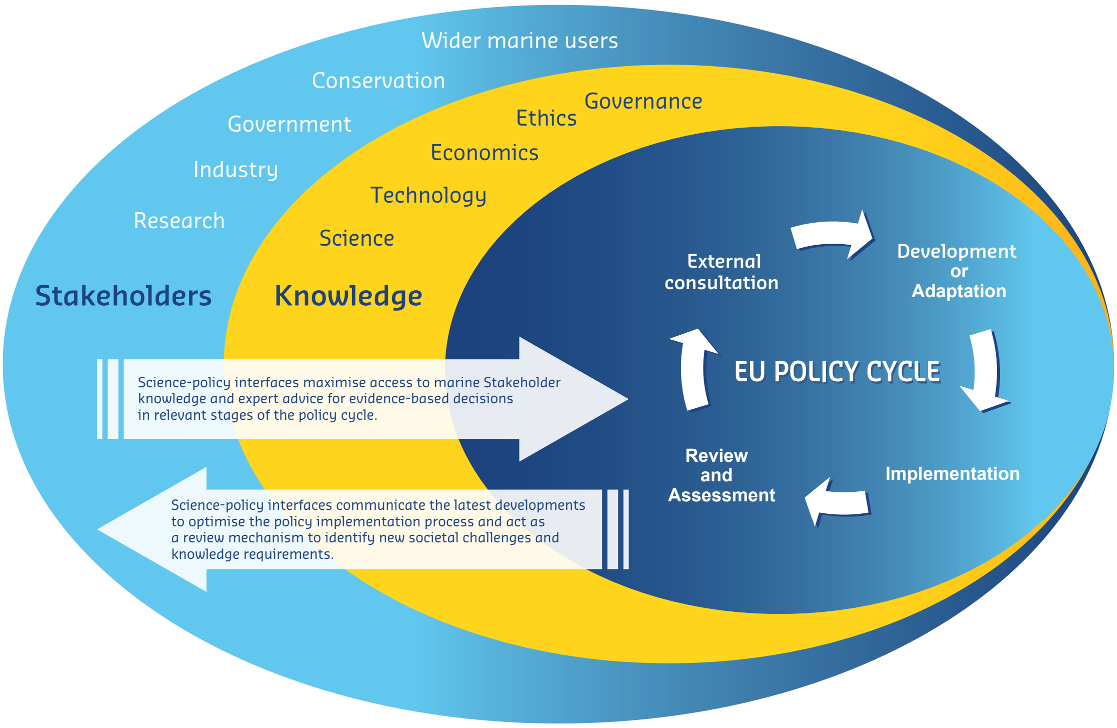


Figure 13.1. Schematic diagram illustrating the role of science-policy interfaces in maximizing the transfer of knowledge in the marine environmental decision-making process. A simplified policy cycle is presented and the involvement of knowledge producers and stakeholders is key to each stage. External consultation is shown as a discrete separate stage but in fact this should be a continuous process as part of an effective SPI. Examples of knowledge and stakeholder sectors are provided but this is not an exhaustive list. Credit: K. Larkin, European Marine Board Secretariat.

13.3 The European marine science-policy landscape

Human activities across European seas and oceans are increasing and there is a real need for stakeholders to engage in the science-policy process to meet legislative demands. As a result, considerable emphasis is being placed on science driven by policy needs to support key marine policies such as the Common Fisheries Policy (CFP) and the Marine Strategy Framework Directive (MSFD). However, while the CFP has long-established mechanisms for scientific advice, the interface between marine science and the environmental policy process (e.g. MSFD) is less well developed. In response to these needs, the European Commission has launched a number of science-policy initiatives directly targeted at enhancing environmental policy implementation. These include the 'Science for EU Environment Policy Interface' (SEPI) launched in 2010 by the EU Environment Commissioner, Janez Potočnik, which aims in particular to strengthen the science-policy interfaces of DG Environment of the European Commission. Building on this, a series of workshops took place in 2010 and 2011 along with a review of theoretical models, best practice and existing initiatives (see DG Environment Technical Report 59, 2012). In September 2012, the European Commission Directorate General for Research and Innovation led discussions with key stakeholders on the needs and benefits for boosting Europe's innovation capacity by improving access to scientific information and knowledge (see also Commission Communication on Open Access to research data (IP/12/790) released in July 2012).

In addition, the European Commission has recognized the increasing need for knowledge transfer of basic science for wider public use and has supported many projects through the Seventh Framework Programme (2008-2013) to develop and assess science-policy interfaces (see Box 13A for examples). These projects are offering new perspectives on the link between marine science and socio-economics and many are delivering proposals for improved future governance models and mechanisms for stakeholder participation and engagement in the science-policy process. In line with this, linking marine science to societal challenges is a key aspect of Horizon 2020, - the Research and Innovation funding programme of the European Commission (2014-2020). A number of other key European science-policy platforms are also in place to offer the research, technology and development (RTD) communities a mechanism to engage with the European policy domain. The European Commission periodically convenes and coordinates expert groups on a range of strategic issues (e.g. Marine Research Infrastructures expert groups[2]), composed of experts from across the European research and wider stakeholder communities. However, these are *ad hoc* initiatives and run for a limited duration.

This Navigating the Future IV position paper is in itself part of a long-standing science policy activity of the European Marine Board (EMB), providing strategic recommendations for future European research on seas and oceans in the context of current scientific and societal challenges. The EMB provides a pan-European platform for marine research institutes and funding agencies to advance marine research by developing common priorities on strategic marine issues and fostering

Examples of European science-policy outputs (from top to bottom): (a) report from European Commission expert group on Marine Research Infrastructures (b) Future Science Brief on Marine Biodiversity by the European Marine Board (c) Fact Sheet on Marine Litter by HERMIONE FP7 project

2 http://ec.europa.eu/research/infrastructures/pdf/toward-european-intagrated-ocean-observation-b5_allbrochure_web.pdf

science-policy dialogue. Such knowledge transfer is undertaken in the form of written outputs (e.g. position papers, vision documents) and by working with the European Commission to facilitate forum and dialogue through conferences such as the EurOCEAN conference series (see Box 13B). More recently, Joint Programming Initiatives (JPIs) have been launched in various domains e.g. Water, Climate and Oceans. The Joint Programming Initiative (JPI) "Healthy and Productive Seas and Oceans, with membership of government ministries and funding agencies, is also set to play a key coordinating and integrating role for marine sciences across European Member States and Associated Countries.

A number of European initiatives and information systems have been developed to increase the availability and exchange of environmental information produced by the public and private research communities (see box 13A). These include the WISE-RTD knowledge portal which offers an information exchange service for the water sector, helping to bridge the gap between water research and technology development and policy implementation. Other examples aim to improve the transfer of knowledge from research projects. The Biodiversity Information System for Europe (BISE), for example, has been designed as a single entry point for data and information on biodiversity in Europe and Eye on Earth is an innovative data presentation tool for creating and sharing environmental information (see Factsheets produced by the FP7 SPIRAL project[3]). Pan-European information services and knowledge platforms such as EMODnet and the Marine Core Service of Copernicus (formerly GMES) will also play a key role in coordinating marine data management and offering online platforms for marine data and products (Marine Knowledge 2020 COM (2012) 473 final; GMES COM (2012) 218; see also Chapter 11 on the European Ocean Observing System for more information).

In addition to significant developments at the European level, science-policy interfaces are also crucial at regional sea, sub-regional sea and national levels. For example, Regional Sea Conventions are already key co-operation structures fostering science-policy exchange, particularly regarding issues of national and European legislation (e.g. assessments of "good environmental status" under the Marine Strategy Framework Directive). However, the governance structures and participatory mechanisms currently used vary greatly between marine regions and even more so at Member State level. It is anticipated that the JPI Oceans process can have a role in sharing best practice between Member States.

Science policy briefings held in the European Parliament bring key messages directly to decision makers.

Credit: VLIZ.

[3] www.spiral-project.eu

BOX 13A Examples of current environmental science-policy projects and information systems in Europe

(the list focuses on the marine/water sector and is not exhaustive)

EU projects ongoing (as of June 2013)

DEVOTES: Development of innovative Tools for understanding marine biodiversity and assessing good Environmental Status. FP7 2012-2016 http://www.devotes-project.eu/

KnowSeas: Knowledge-based Sustainable Management for Europe's Seas. FP7: 2009-2013. http://www.knowseas.com/

ODEMM: Options for Delivering Ecosystem-Based Marine Management. FP7 2010-2013 http://www.liv.ac.uk/odemm/

PERSEUS: Policy-oriented marine Environmental Research in the Southern European Seas. FP7 2012-2015 http://www.perseus-net.eu/site/content.php

SPIRAL: Science-Policy interfaces for Biodiversity: Research, Action and Learning. FP7 2010-2013 http://www.spiral-project.eu/

STAGES: Science and Technology Advancing Governance on Good Environmental Status. FP7 2012-2014. www.stagesproject.eu

VECTORS: Vectors of Change in Oceans and Seas Marine Life, Impact on Economic Sectors. FP7 2011-2015 http://www.marine-vectors.eu/

EU projects completed (as of June 2013)

COEXIST: Interaction in Coastal Waters: A Roadmap to sustainable integration of aquaculture and fisheries. FP7 2009-2012. http://www.coexistproject.eu

CLAMER: Climate Change and Marine Ecosystem Research Results. FP7 2010-2011. http://www.clamer.eu/

HERMIONE: Hotspot Ecosystem Research and Man's Impact on European Seas. FP7 2009-2012. http://www.eu-hermione.net/

MEECE: Marine ecosystem evolution in a changing environment. FP7 2008-2013 http://www.meece.eu/

PISCES: Partnerships Involving Stakeholders in the Celtic Sea Ecosystem. LIFE+ 2009-2012. (see also follow-on project Celtic Seas Partnership project: LIFE+ 2013-2016). http://www.projectpisces.eu

PSI-Connect: Connecting Policy and Science through Innovative Knowledge Brokering in the field of Water Management and Climate Change. FP7 2009-2012. http://www.psiconnect.eu/

SPI Water: Science-Policy Interfacing in Water Management. Cluster of 3 FP7 projects STREAM, WaterDiss2.0 and STEP-WISE. http://www.spi-water.eu/

European environmental information and exchange services (not exhaustive) **Biodiversity Information System for Europe (BISE).** Funded by the European Commission (DG Environment, Joint Research Centre and Eurostat) and the European Environment Agency (EEA). http://biodiversity.europa.eu/

Eye on Earth (EoE). Facilitated by the European Environment Agency (EEA), is a 'social data website' for creating and sharing environmental information. http://www.eyeonearth.org/en-us/Pages/Home.aspx

Science for Environment Policy is a free environmental news and information service published by Directorate-General Environment, European Commission http://ec.europa.eu/environment/integration/research/newsalert/index_en.htm

WISE-RTD. Web portal funded by the European Commission and the WISE-RTD Association for policy, research and industry resources in the water sector http://www.wise-rtd.org/

BOX 13B The EurOCEAN conference series, a key platform for marine and maritime stakeholder dialogue and interaction

In partnership with the European Commission and national hosts, the European Marine Board have co-organized (since 2000) the EurOCEAN conference series (www.euroceanconferences.eu). These are major European marine science-policy conferences that offer an interactive forum for dialogue between marine scientists, wider stakeholders and policy makers. The associated declarations serve as a powerful tool to communicate a longer-term pan-European message including recommendations and priorities for marine science and blue growth (e.g. Ostend Declaration, 2010 www.eurocean2010.eu/declaration). The consequent uptake of these declarations by marine and maritime stakeholders and policymakers further reinforces the importance of marine science in effective maritime policy making (see JPI Oceans contribution to the Green Paper "From Challenges to Opportunities: Towards a Common Strategic Framework for EU Research and Innovation funding". The next EurOCEAN conference will take place on 7-9 October 2014 in Rome, Italy as an official event of the Italian EU presidency.

The EurOCEAN 2010 conference was a Belgian EU Presidency event which addressed future grand challenges for seas and oceans research and supported the final agreement and launch of the Ostend Declaration.

13.3 New approaches for effective marine science-policy interfaces

Despite the significant progress in science-policy interface developments across Europe, many bottlenecks and missed opportunities remain that prevent the full exploitation of marine environmental knowledge by policy makers and marine managers. Increased knowledge exchange is crucially needed for pan-European marine legislation such as the Marine Strategy Framework Directive (MSFD). Global recognition of the need for evidence based policy in the area of biodiversity has been recognized in the establishment in 2012 of the 'Intergovernmental Platform on Biodiversity and Ecosystem Services' (IPBES)[4]. With a membership of more than 90 governments, IPBES will be a leading global body providing scientifically sound and relevant information to support more informed decisions on how biodiversity and ecosystem services are conserved and used around the world. However, the European contributions to IPBES and national and regional sea level are in need of further definition (Heip and McDonough, 2012). New approaches are required to address these issues and to propose targeted science-policy interfaces for specific needs.

Credit: IPBES Secretariat

First Session of the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES), Bonn, Germany, 21-26 January 2013

13.3.1 Bridging the mind-set: from data to decision making

People are at the heart of any science-policy interface and a successful structure should enable the bridging of mindsets between the scientific and policy communities. However, achieving the uptake of scientific knowledge into the policy cycle is often far from straightforward and it is difficult to assess the full impact. This requires effective science-policy interfaces that are credible, relevant and legitimate and there are often trade-offs that must be made (Sarkki *et al.* in press; see also SPIRAL project Fact Sheets[5]). An increasing importance is being placed on the co-production of knowledge where stakeholder engagement is integral throughout the knowledge production process, leading to co-design of research programmes that meet both scientific and societal needs resulting in more cost-effective policy implementation. An example at National level is the UK initiative, "Living With Environmental Change," which acts as a mechanism for stakeholder engagement and promotes co-design of UK research programmes.

Knowledge Brokers are increasingly recognized as key facilitators of this process with personnel (or organizations) acting as intermediaries in the coordination and exchange of information between the scientific and policy domains (Michaels, 2009).

4 www.ipbes.net

5 SPIRAL project Fact Sheets
a) CRELE choices: trade-offs in SPI Design http://www.spiral-project.eu/sites/default/files/13_Brief_CRELE-choices.pdf
b) Improving Interfaces between EU research projects and policy-making http://www.spiral-project.eu/sites/default/files/Recommendations_Spiral workshop_Oct2012_final.pdf
c) Tools for Science-Policy Interfaces: Recommendations on BISE and Eye on Earth http://www.spiral-project.eu/sites/default/files/18_WS recs_BISE EoE_3.pdf

Knowledge brokering is required across a range of geographical levels and thematic areas to maintain an interactive and dynamic interface promoting knowledge discovery and exchange of information. In addition, effective communication strategies to the wider stakeholders are key to improve public engagement with marine science in the future (see Buckley *et al.*, 2011; European Commission report, Communicating Research for Evidence-based Policymaking).

Strategic high level appointments such as the European Commission's Chief Scientific Adviser (since 2012) have provided for the first time the opportunity for high-level and independent scientific advice to support policy development and delivery. However, such engagement across the science-policy domain should start at grass-roots level and environmental policy makers and scientists of tomorrow will need to be both science and policy literate to drive forward science-policy interactions. This may require new training programmes (e.g. integrated science-policy courses, bi-directional internships, etc). Such training will also need to address the changing role of environmental managers who must also take account of other societal challenges such as the current financial crisis. However, in order to engage the scientific community in shaping the scientific advisory process, there need to be career incentives and quantifiable impact metrics. This has been clearly shown in the wide engagement in science-policy platforms such as the Intergovernmental Panel on Climate Change (IPCC) which is considered as internationally credible by the RTD community (Fritz, 2010).

Training course for environmental professionals, hosted by the NIMRD, Romania

Credit: National Institute of Marine Research and Development (NIMRD) Grigore Antipa», Romania)

13.3.2 Packaging marine science for policy

Despite the wealth of scientific information produced across Europe, much of this is currently not openly available or in a form that can be used by policy makers. This can result in a mismatch between the type of knowledge produced, e.g. environmental datasets of variables and fluxes, compared to what policy and marine stakeholders need, e.g. indicators of change, knowledge of pressures and impacts. The need for tailoring of marine knowledge for policy was identified by the European marine research community in the Ostend Declaration (2010) which stated that Europe needs "integrated knowledge products to facilitate policy development, decision making, management actions, innovation, education and public awareness." For an ecosystem management approach to be realized, policy makers need scientific syntheses of key ecosystem datasets to inform assessments and meet regulatory needs (Johnson, 2008; Rice *et al*., 2010; US National Research Council. 2007). A recent pan-European example of a science-policy synthesis report is the European Environment Agency State and Outlook Report 2010 produced in cooperation with the European Commission (DG Environment and the Joint Research Centre) and Eurostat (Martin and Henrichs *et al*., 2010). However, this focuses predominantly on Europe's terrestrial environment and more emphasis could be made on status and trends of the marine environmental component.

Current and developing marine indicators include the 11 descriptors of "Good Environmental Status" identified by the MSFD, the concept of "Essential Ocean Variables" (see chapter 11 on EOOS) and Multi-Criteria Decision Analysis (MCDA) which has been shown to have a wide application to fisheries resource management. Understanding and integrating environmental information with societal and economic state-of-the-art is also increasingly essential if policy-makers are to tackle global problems such as climate change and unsustainable resource use. Indicators that link ocean variables with social and economic indicators such as World Development Indicators will be increasingly crucial to assess the role of oceans in economic development.

A wide range of products can be used to increase the availability and uptake of knowledge including online open access data portals, expert groups, consultations, and topic-focused written communications e.g. policy briefs. Syntheses of European research are also crucial to inform policy makers of the state-of-the-art in a particular area, and the gaps in knowledge which still exist. For example, the CLAMER FP7 project delivered a synthesis of European Climate Change and Marine Ecosystem Research (Heip *et al*., 2011; Philippart *et al*., 2011). There is a recognized demand at European level for more of such projects to consolidate and summarize the key outputs from European research across a range of thematic marine science areas.

13.3.3 Engaging the wider marine and maritime stakeholder community

In 2008, the European Commission published the 'European Strategy for Marine and Maritime Research'. This encouraged the marine and maritime scientific communities to engage more with policy communities and to develop scientific advisory processes and interfaces that are relevant and fit for purpose. More communication across stakeholder groups and policy makers is still required to raise awareness of the wealth of scientific knowledge being produced and the value of using this knowledge both in the policy process and for wider marine activities, e.g. by stimulating improvements in the state of the marine environment, society and economy. As the marine and maritime sectors grow, integrated decision making and cross-sectoral cooperation will be increasingly crucial to ensure stakeholder needs and expectations are met and that knowledge from a range of producers is made available to the policy process. Identifying and consulting with these respective stakeholders (both public and private) at national, regional and European level is key to assess user needs and requirements and to identify improvements to existing structures. Marine and maritime stakeholder networks, better integration with the RTD communities and open access to information will all be essential drivers for innovation along with mechanisms to achieve a greater consensus amongst stakeholders.

13.4 Conclusions and recommendations

Marine scientific knowledge is essential in the development of evidence-based, forward-looking policies that promote sustainable marine and maritime activities whilst preserving the integrity of our seas and oceans. Science-policy interfaces are central to the knowledge transfer process, maximizing the availability of knowledge and promoting information uptake, dialogue and stakeholder engagement. Whilst many key initiatives exist across Europe, there is a pressing need to develop long-term effective science-policy interfaces at multiple levels (e.g. European, regional sea and national level) to ensure that European policy capitalizes on the wealth of marine knowledge and expertise available for environmental decision-making.
To support this process, the following key recommendations are proposed:

1. Build on existing science-policy platforms for biodiversity (e.g. IPBES) and Good Environmental Status (e.g. MSFD governance) to create targeted European marine science-policy interface platforms to enhance knowledge uptake and exchange and to inform the marine environmental policymaking process.

2. Further define how scientific information and knowledge can be best packaged for policy implementation and develop mechanisms to assess the impact of knowledge used in the policy process. This could include making a closer link between indicators and descriptors used to define "good environmental status" and World Bank marine indicators, taking into account ways to factor natural capital into economic decision making.

3. Build on the European Commission support for open access to knowledge, engaging the public and private sector in providing data and information for an effective science-policy interface.

4. Promote new training e.g. in environmental science and policy, to ensure that policy makers of tomorrow are science literate and scientists are policy literate, to move beyond a linear and fragmented approach.

5. Develop effective communication strategies to the wider stakeholder community to improve public engagement and mechanisms for interaction with marine science in the future. Mechanisms should be developed that enhance communication across national, regional and European levels in science-policy interfaces.

6. Promote networks of maritime clusters and better integration with the RTD communities to drive stakeholder dialogue, consensus building and innovation.

7. Develop career incentives to engage the scientific community in shaping the scientific advisory process (e.g. international accreditation by the RTD community) and develop metrics to determine the effectiveness of these.

8. Encourage strategic appointments relevant to the promotion of science-policy interfaces. This can include high-level positions such as the recent appointment of the first Chief Scientific Adviser to the European Commission and other positions including Knowledge Brokers for marine themes and research areas at the European, regional and national levels.

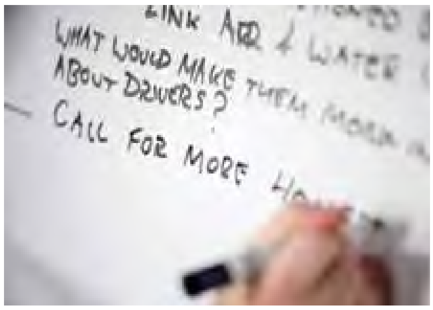
9. Optimize the opportunities for the marine and maritime community to engage in and shape the science advisory process and provide incentives for engagement by the RTD communities.

10. Promote interdisciplinary work between the natural and social sciences to foster knowledge transfer and literacy between these domains.

11. Encourage mechanisms at national and European level for stakeholder engagement in the co-design and the co-production of research programmes and marine knowledge.

Credit: VLIZ

Science-policy discussions at the International CLAMER conference, *Living with a Warming Ocean,* Brussels, 2011



14
Europe's maritime ambitions require an ocean literate population

Credit: M. Santos, CIIMAR

14.1 Introduction

Ocean literacy is about understanding the ocean's influence on people and the influence of people on the oceans. It is also about assessing what the public knows, wants to know and should know about the oceans. As a particular goal, it redresses the lack of ocean-related content in science education standards, instructional materials in informal educational initiatives (aquaria, science centres, museums, media, etc.), and leads to more public involvement and active participation. Ocean literacy is also a prerequisite for Europe's quest for a more marine-oriented society and economy. In fact, preparing an entire community for a closer relationship with the sea is rewarding for the marine research community and science policy-makers as a more informed public will better understand and support investments in ocean science and be better aware of the need to sustainably manage vitally important marine ecosystems.

Since 2003, the U.S. ocean literacy movement[1] has managed to change the perception of marine education as merely an enrichment topic, taught by a handful of teachers with a special passion, to a widely supported and implemented nationwide system. Essential principles and fundamental concepts about the functioning of the oceans have been identified and integrated into educational curricula. Marine scientists and educators are working closely together in whole-school interdisciplinary ocean science immersion programmes (e.g. MARE[2]) and within National Centres for Ocean Sciences Education Excellence (COSEE[3]). Recently, the movement has also spread towards the Pacific (IPMEN[4]) and beyond, including an open invitation by the US consortium to Europe to collaborate within this wider, international context.

In Europe, the limited information on ocean literacy levels seems to indicate that ocean knowledge amongst the wider public is not strong and that in most European countries, ocean sciences are not an integral part of the educational curricula. In addition, 57% of Europeans believe that scientists do not put enough effort into informing the public about new scientific and technological developments[5].

Credit: The Cartoon Bank (New Yorker, 21 March 1983)

"I don't know why I don't care about the bottom of the ocean, but I don't."

[1] www.coexploration.org/oceanliteracy
[2] www.lawrencehallofscience.org/mare/
[3] www.cosee.net
[4] International Pacific Marine Educators' Network – www.ipmen.net
[5] Eurobarometer Survey - http://ec.europa.eu/public_opinion/archives/ebs/ebs_340_en.pdf

Although communication and outreach is considered very important and much needed at the higher European policy levels, no direct reference is made in any of the key marine-oriented policy documents to strengthening the position of ocean sciences in science standards and educational curricula. Simply assuming that all the standards can and will be taught using ocean examples - thus, without changing the overall programmes but by "marinating" their content – has proved to be insufficient. As the ocean has distinct, intrinsic, significant importance, it is argued by some ocean literacy advocates that 'ocean studies' should become a subject on the curriculum in its own right.

Credit: Miguel Santos, CIIMAR

Teaching children about the importance of the seas and oceans is the best way to improve ocean literacy.

14.2 Marine eduction and communication

In general, communicating about the oceans is challenging. It generally requires making visible the invisible and what many people consider as a hostile and remote environment. "Blue" knowledge and interest is generally restricted to the oceans as a place for leisure only. On the other hand, the fact that ocean science is multi- and interdisciplinary by nature and thus complex, has clear advantages when being used in a project-learning approach. It adds to the fascination that oceans and ocean life can engender in people, and to the exploratory character of marine research and new technologies. The latter (e.g. Smart Boards, interactive web sites and lesson plans combined with digital images and film material) now makes it far easier and more visually exciting to explain complex concepts about the ocean and to reveal images of the deep sea never before seen by students.

There is a growing need for training of the next generation of scientists to communicate their scientific knowledge with the general public and for introducing formal educators to some of the knowledge rules and norms of the scientific community. Beyond the formal education system, Europe should stimulate partnerships between informal science educators (museums, science centres, aquaria, etc.) and marine scientists.

Credit: INCDM, Romania

Museums, science centres and aquaria play an important role in promoting ocean literacy.

These new partnerships could also play a role in bringing ocean messages to a wider public through the media. The large variety in languages, educational systems and ways of interacting with the sea across Europe, complicates the implementation of pan-European Ocean Literacy initiatives. Moreover, the many new technologies being developed in education for the dissemination of complex educational material in easily understandable formats, are not equally accessible across the continent.

A key priority in developing a strategy for improved ocean literacy in Europe is to build baseline information on the current state of knowledge. There is very little quantitative material on what the European population knows and wants to know about the oceans. This requires the improved application of socio-economic expertise. There is a need to convene European ocean scientists and educators to agree upon overall essential principles (based on those developed in the U.S.). This process was finally launched in Europe with the 1st European Ocean Literacy Conference, which took place in Bruges, Belgium, in October 2012. Presentations from scientists, educators, media professionals and policymakers provided an interesting mix of perspectives but also demonstrated the commonly held view from these different sectors on the importance of delivering an improvement among the general public on ocean knowledge and issues.

The First European Ocean Literacy Conference was made possible by the formation of a new European network to partner the US National marine Educators' Association. EMSEA[6], the European Marine Educators' Association, was established in 2012 and its first major initiative has been to organize the Bruges conference and a second conference in Plymouth, UK, in September 2013. The work of EMSEA and a range of other marine science communication organizations, collectively referred to as the "Ocean Literacy in Europe Consortium,"[7] has been critical in raising the profile of ocean literacy with European policy makers, notably with the European Commission DG Research and Innovation. The inclusion of Ocean Literacy as one of the themes for greater trans-Atlantic collaboration in the Galway Statement on Atlantic Ocean Cooperation[8] is clear evidence of major progress in this area.

6 www.emsea.eu

7 European Marine Science Educators Association (EMSEA), World Ocean Network (WON), Flanders Marine Institute. (VLIZ), Marine Biological Association (MBA) and European Marine Board Communications Panel (EMBCP)

8 www.marine.ie/home/ceanresearchallianceinGalway.htm (May 2013).

14.3 Recommendations

Real progress in developing the structures to advance ocean literacy in Europe and in convincing key science policymakers has, therefore, been made. However, these are merely first steps in a long process. Looking ahead, the next goals for the Ocean Literacy in Europe Consortium include:

1. Stimulating the coordination of ocean science education efforts across Europe;
2. Stimulating nations to adopt the principles of Ocean Literacy;
3. Developing an action plan to upgrade and reinforce ocean literacy in Europe including:
   - an inventory of ocean literacy and information needs,
   - refining essential principles and fundamental concepts of ocean science for Europe (based on the 7 U.S. Essential Principles and 44 Fundamental Concepts),
   - a screening of educational curricula in all European countries for ocean content, and
   - an inventory/compilation of existing high-quality educational ocean science material and educational resources (portal);
4. Assisting in the integration of the essential principles of ocean science into educational curricula across Europe;
5. Stimulating a more intensive information exchange with other ocean literacy-initiatives (e.g. NMEA and IPMEN);
6. Addressing the need for active collaboration between marine scientists, ocean educators and the public in future European projects.

Participants at the First Conference on Ocean Literacy in Europe (October 2012, Bruges)

Credit: VLIZ

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List of Abbreviations and Acronyms

ABNJ	Areas Beyond National Jurisdiction
AIS	Automatic Identification Systems
AMOC	Atlantic Meridional Overturning Circulation
AR	Augmented Reality
ARGO	Array for Real-Time Geostrophic Oceanography (International project)
ATLANTIS	An ecosystem model, developed by CISIRO (Commonwealth Scientific and Industrial Research Organisation) researchers
AUV	Autonomous Underwater Vehicle
BaltSeaPlan	Planning the future of the Baltic Sea
BISE	Biodiversity Information System for Europe
BONUS	EC Article 185 initiative for collaborative marine research in Baltic Sea
CAREX	Coordinated Action for Research on Life in Extreme Environments
CCS	Carbon Capture and Storage
CFP	Common Fisheries Policy
CLAMER	Climate Change & European Marine Ecosystem Research (EU FP7 project)
CMSP	Coastal and Marine Spatial Planning
COEXIST	Interaction in Coastal Waters: A Roadmap to sustainable integration of aquaculture and fisheries (EU FP7 project)
CoML	Census of Marine Life (international project)
Copernicus	The European Earth Observation Programme (formally GMES)
CoralFISH	Ecosystem based management of corals, fish and fisheries in the deep waters of Europe and beyond (EU FP7 project)
COSEE	Centers for Ocean Sciences Education Excellence
DDT	Dichlorodiphenyltrichloroethane
DG	Directorate General (European Commission)
DS3F	Deep Sea and Sub-Seafloor Frontier (EU FP7 project)

EA	Ecosystem Approach
EBM	Ecosystem Based Management
EBSA	Ecologically and Biologically Significant Area
EC	European Commission
ECORD	European Consortium on Ocean Research Drilling
ECVs	Essential Climate Variables
EDIOS	European Directory of the Ocean-observing System
EEA	European Environment Agency
EEZ	Exclusive Economic Zone
EFARO	European Fisheries and Aquaculture Research Organization
EMB	European Marine Board
EMBOS	European Marine Biodiversity Observatory System
EMMRS	European Marine and Maritime Research Strategy
EMODNET	European Marine Observation Data Network
EMSEA	European Marine Educators' Association
EMSO	European Multidisciplinary Seafloor Observation
EOOS	European Ocean Observing System
EOR	Enhanced Oil Recovery
EOV	Essential Ocean Variable
ERA	European Research Area
ERIC	European Research Infrastructure Consortium
ESFRI	European Strategy Forum for Research Infrastructures
ESONET	European Sea Observatory Network
EU	European Union

EuroARGO	European contribution to the global ARGO ocean observation project
EuroCoML	European Census of Marine Life
EuroGOOS	European Global Ocean Observing System
EurOCEAN	Marine Science Policy Conference series
EuroSITES	European open ocean observatory network (EU FP project)
FAO	Food and Agriculture Organization
Ferrybox	Automated instrument package on surface ships (previously EU FP project)
FP	Framework Programme (European Commission funding)
GCOS	Global Climate Observing System
GDP	Gross Domestic Product
GEO BON	Earth Observation Biodiversity Observing Network
GEO	Group on Earth Observation
GEOSS	Global Earth Observation System of Systems
GES	Good Environmental Status
GIS	Geographic Information System
GISC	GMES in situ coordination (EU FP7 project)
GMES	Global Monitoring for Environment and Security (see Copernicus)
GOOS	Global Ocean Observing system
GO-SHIP	Global Ocean Ship-based Hydrographic Investigations Programme
HAB	Harmful Algal Bloom
HELCOM-VASAB	Helsinki Commission-Vision and Strategies around the Baltic Sea 2010
HERMES	Hotspot Ecosystem Research on the Margins of European Seas
HERMIONE	Hotspot Ecosystem Research and Man's Impact on European Seas (EU FP7 project)
HF Radar	High Frequency Radar

HPC	High Performance Computing
I3	Integrated Infrastructure Initiative (EC Capacities funding)
IBM	Individual Based Model
ICES	International Council for the Exploration of the Seas
ICT	Information and Communication Technologies
ICZM	Integrated Coastal Zone Management
IFSOO	Integrated Framework for Sustained Ocean Observations (Task Team from OceanObs'09 conference)
IMP	Integrated Maritime Policy
INTERREG IVC	Funding for Interregional Cooperation
IODP	Integrated Ocean Drilling Program
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IPMEN	International Pacific Marine Educators' Network
ISA	International Seabed Authority
JERICO	Towards a Joint European Research Infrastructure Network for Coastal Observatories (EU FP project)
JPI	Joint Programming Initiative
JPI-Oceans	Joint Programming Initiative for Healthy and Productive Seas and Oceans
MARE	Marine Activities, Resources & Education
MAR-ECO	Patterns and processes of the eco-systems of the northern mid-Atlantic (EuroCoML project)
MARS	Monterey Accelerated Research System
MASPNOSE	Maritime spatial planning in the North Sea
MCCIP	Marine Climate Change Impacts Partnership
MCDA	Multi-Criteria Decision Analysis
MESMA	EU-FP7 project: Monitoring and Evaluation of Spatially Managed Marine Area

MFF	Multiannual Financial Framework (Framework for EU expenditure)
MMRS	EU Strategy for Marine and Maritime Research
MPA	Marine Protected Area
MRI	Marine Research Infrastructure
MSFD	Marine Strategy Framework Directive
MSP	Maritime Spatial Planning
MSY	Maximum Sustainable Yield
MyOcean	Copernicus (GMES) Marine Core Service EU projects MyOcean and MyOcean 2
NAO	North Atlantic Oscillation
NEPTUNE	North-East Pacific Time-Series Underwater Networked Experiments
NGO	Non-Governmental Organization
NMEA	National Marine Educators Association
NRC	National Research Council
NSIDC	National Snow and Ice Data Center
OBIS	Ocean Biogeographic Information System
OCCAM	Oxford Centre for Collaborative Applied Mathematics
OceanSITES	Global Network of deep water reference stations
OCR	Ocean Colour Radiometry
ODEMM	Options for Delivering Ecosystem-Based Marine Management
OHH	Ocean and Human Health
OOI	Ocean Observatories Initiative
OSPAR	Oslo-Paris Convention for the protection of the marine environment of the North-East Atlantic
OTEC	Ocean Thermal Energy Conversion
PAH	Polycyclic Aromatic Hydrocarbons

PCB	Polychlorinated Biphenyl
Plan Bothnia	Maritime Spatial Planning preparatory action for the Baltic Sea
PRO	Pressure-Retarded Osmosis
RED	Reverse Electro-Dialysis
REE	Rare Earth Elements
ROV	Remote Operated Vehicle
RSN	Regional Scale Nodes
RTD	Research, Technology and Development
SCOR	Scientific Committee on Oceanic Research
SEA	Strategic Environmental Assessment
SeaDataNet	Pan European Infrastructure for Ocean and Marine Data Management
SEIS	Shared Environmental information System
SEPI	Science for EU Environment Policy Interface
SMOS	Soil Moisture and Ocean Salinity
SOER	State and Outlook of the European Environmental Report
SOO	Ships of Opportunity
SPI	Science-Policy Interface
SST	Sea Surface Temperature
STAGES	Science and Technology Advancing Governance on Good Environmental Status (EU FP project)
SUGAR	German gas hydrate initiative "Submarine Gas Hydrate Reservoirs"
THC	Thermohaline Circulation
UNCLOS	United Nations Convention on the Law of the Sea
UN	United Nations
UNEP	United Nations Environment Programme

UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
VME	Vulnerable Marine Ecosystem
VMS	Vessel Monitoring Systems
VOS	Volunteer Observing Ships
WISE	Water Information System for Europe
WKMCMSP	A Multi-Disciplinary Case-Study of MSP

Annex

Participants in the Navigating the Future IV Brainstorming Workshop, 13 March 2010.

Antonio Bode, Spanish Institute of Oceanography (IEO), Spain
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Participants at the Navigating the Future IV Brainstorming Workshop in Ostend, Belgium (3-4 March 2010).
From left: Jan-Bart Calewaert, Hein de Baar, Edward Hill, Tomas Brey, Maud Evrard, Reidar Torensen, Geoffrey O'Sullivan, Niall McDonough, Antonio Bode, Baris Salihoglu, Aurélien Carbonnière and Jan Mees.

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