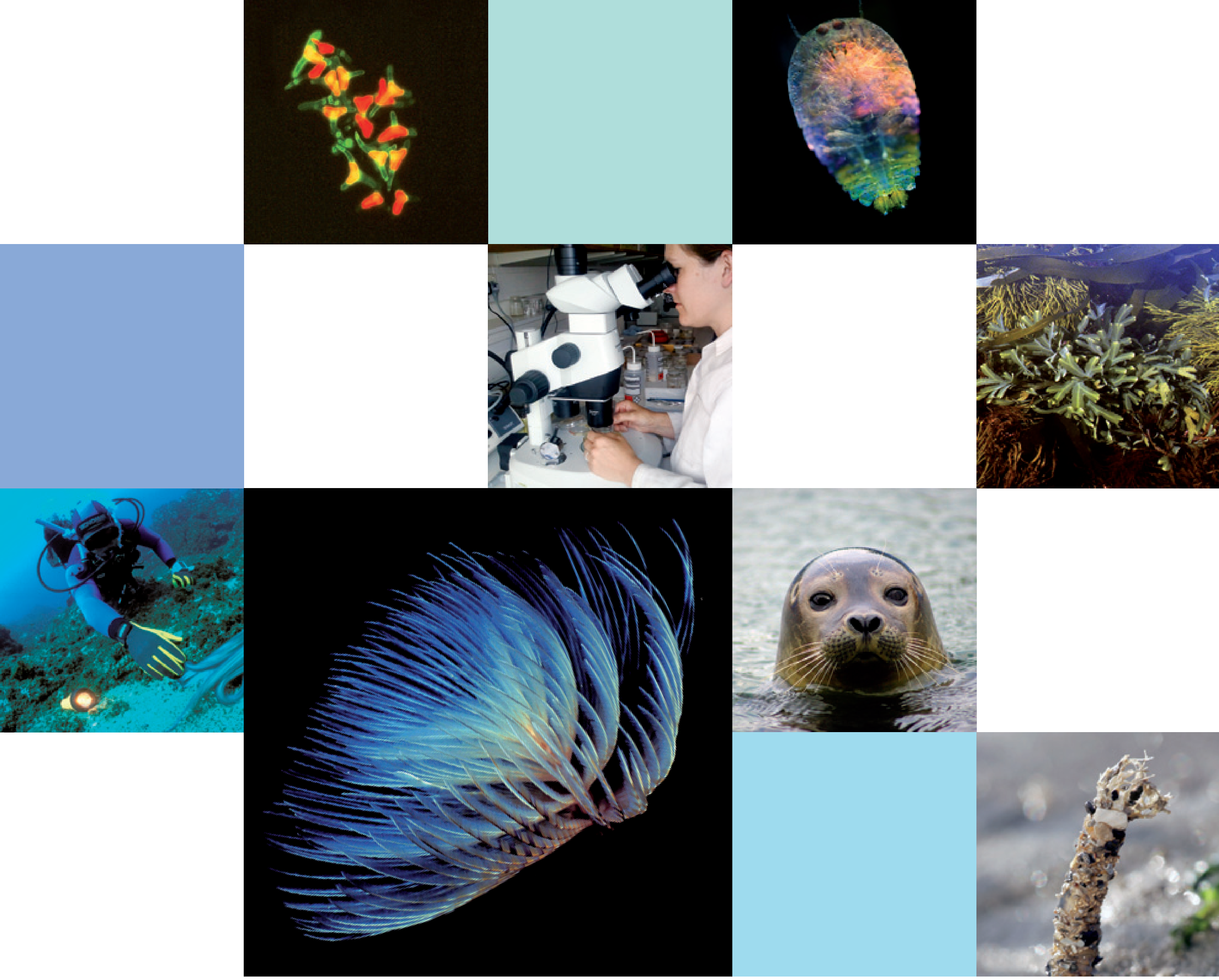

MARINE BOARD FUTURE SCIENCE BRIEF #1

Marine Biodiversity: A Science Roadmap for Europe

EUROPEAN SCIENCE FOUNDATION

MARINE BOARD

European Marine Board

The 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 Marine Board was established in 1995 to facilitate enhanced cooperation between European marine science organizations towards the development of a common vision on the research priorities and strategies for marine science in Europe. Members are either major national marine or oceanographic institutes, research funding agencies, or national consortia of universities with a strong marine research focus. In 2012, the Marine Board represents 34 Member Organizations from 20 countries. The Board provides the essential components for transferring knowledge for leadership in marine research in Europe. Adopting a strategic role, the Marine Board serves its member organizations by providing a forum within which marine research policy advice to national agencies and to the European Commission is developed, with the objective of promoting the establishment of the European Marine Research Area.

www.marineboard.eu

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Foreword

Kostas Nittis
Chair, European Marine Board

It is now more than a decade since the Marine Board published two related science policy papers on the subject of marine biodiversity[1]. There has followed a period of significant progress and advancement in biodiversity knowledge and research capacity. Notable initiatives included the EU FP6-funded *Marine Biodiversity and Ecosystem Functioning (MarBEF)* Network of Excellence and the global *Census of Marine Life* programme, both of which significantly improved the interaction and coordination among a global community of marine biodiversity researchers.

Some suggest that we are in a truly golden age of ocean discovery. However, we must equally struggle with the reality that the seas and oceans, and the enormous diversity of life which they contain, are under significant threat from climate change, ocean acidification, and from numerous and increasing human impacts. In 2010, the Marine Board members decided that it was timely to reassess both the state of our marine biodiversity knowledge, and the implications of a changing biodiversity for the health of our marine environments and for human well-being. In light of a complex landscape of policies, directives and international conventions, it was also considered important to examine how research findings are being used to inform evidence-based policy making and effective management actions.

This is the first in a new series of Marine Board science policy documents called Future Science Briefs. Future Science Briefs are designed to be considerably shorter than standard Marine Board position papers. However, the purpose is the same: to inform European science agendas, while placing the European research effort in a global context. In this paper we take an objective look at recent achievements and, more importantly, at the gaps which remain in our knowledge and understanding of marine biodiversity. We set out a roadmap for future marine biodiversity and related research in Europe which includes both high-level research priorities, and recommendations for supporting actions addressing issues such as biological observation and human capacities.

The core message of this document is that despite the significant progress made and the considerable funding targeted at marine biodiversity research in the 2000's, we are still a very long way from a true knowledge of the extent and nature of biodiversity in the seas and oceans, its fundamental role in the functioning of marine ecosystems, and of the implications for humans of a changing biodiversity. For this reason, European biodiversity research and observation needs continued support to address critical knowledge gaps, but also to ensure that the EU and European nations can meet both internal biodiversity targets, and the requirements of key global conventions on biodiversity and sustainable development.

Although many people gave generously of their time and expertise in the production of this document, I would like to pay particular tribute to Professor Carlo Heip, who has led this Marine Board initiative since its inception. Carlo was also the lead author of the two earlier Marine Board documents, and coordinated the formative MarBEF Network of Excellence. I extend sincere thanks to Carlo for his dedication and leadership in once again charting a course for marine biodiversity research in Europe for the years to come. Perhaps in a decade from now we will be able to reflect that this truly is a golden age of ocean discovery.

1
A European Science Plan on Marine Biodiversity (1998);
Establishing a Framework for the Implementation of Marine Biodiversity Research in Europe (2000).

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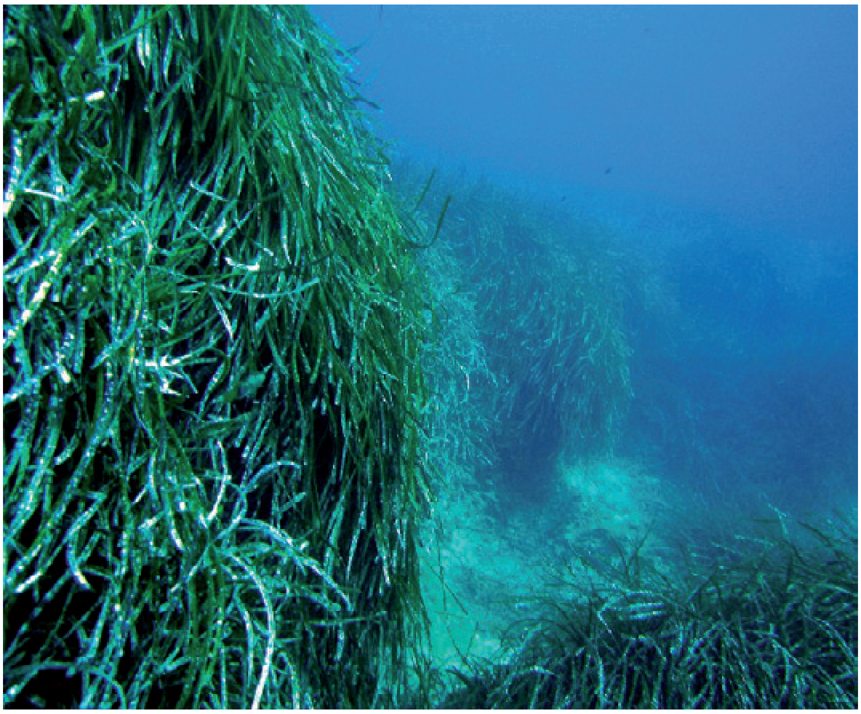
Key Message

In the past ten years, Europe has made significant progress in marine biodiversity research and knowledge generation owing to strong support, funding, and coordination of research effort. However, there is still a major knowledge deficit and many of the important programmes and initiatives which have driven this progress have now ended. While biodiversity policy has also advanced, Europe has failed to achieve the biodiversity targets it has set itself. To meet these targets, effective science-based decisions and management will be necessary. This requires good science, strong European research collaboration, enhanced observing and research capacities, and effective science-policy interfaces.

1 What is biodiversity?

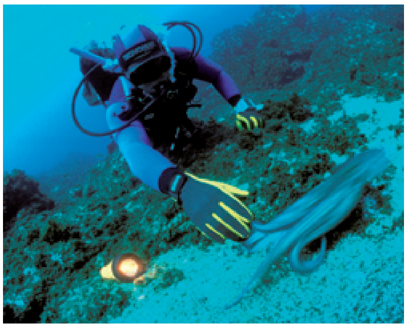
According to the Convention on Biological Diversity (CBD), biodiversity is defined as: *"the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems."*

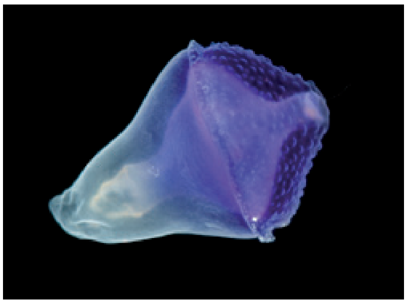
Biodiversity thus encompasses genetic diversity, species richness and habitat heterogeneity. The three components are linked; genes and species obviously so but also species and habitats, as species often create habitats.



The Mediterranean seagrass, *Posidonia oceanica*
© David Balata

Left page
A deep sea Acorn worm or Enteropneust of the phylum Hemichordata.
© David Shale.





A diver examines marine life in the waters off the Azores
© F. Cardigos

A planktonic protist photographed by the Tara Oceans expedition
© M. Ormistad-Kahikai

2 Why do we need knowledge of marine biodiversity?

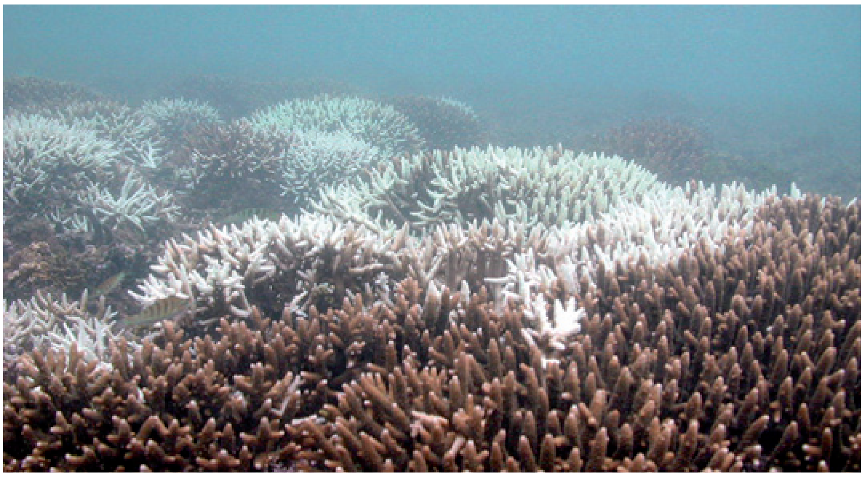
Marine biodiversity is changing rapidly as a result of natural and human pressures. Such change can lead to environmental, economic and, ultimately, social problems, but also to new opportunities for people and industry. Biodiversity underpins the health of the oceans and their productive ecosystems which, in turn, support sustainable fisheries and provide enormous possibilities for new biotechnological applications. To explore, conserve, and make better use of marine biodiversity, we need a deeper understanding of its origin, its composition and its role in ecosystem functioning. We also need improved approaches and tools to monitor and quantify marine biodiversity and to better inform policy makers and the public on its value in environmental, social (including cultural) and economic terms.

3 What is the purpose of this document?

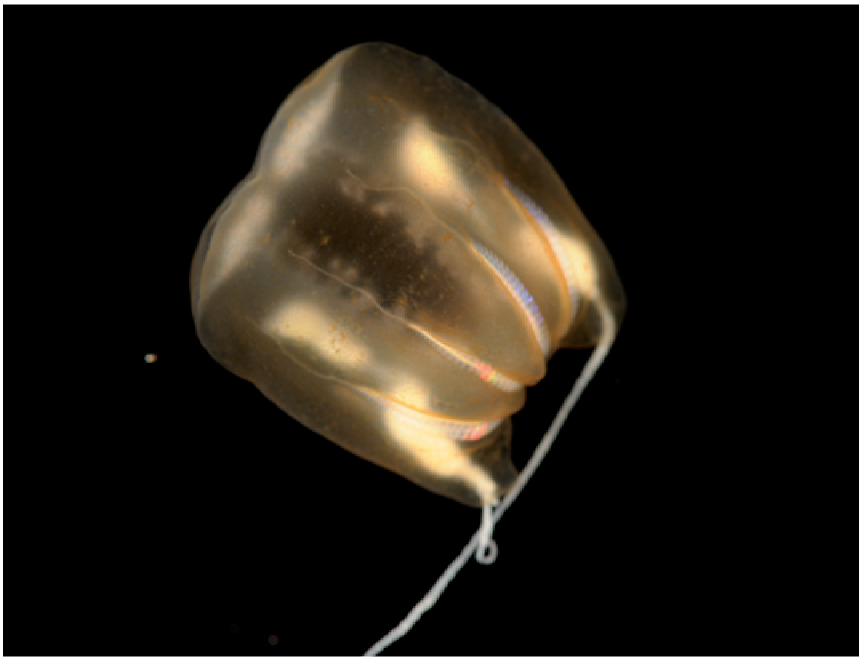
Significant progress has been made in recent years to improve our knowledge of marine biodiversity, its role in ecosystem functioning and its connection to societal well-being. Important advances have also been made in our ability to track changes in biodiversity, to understand the natural and human pressures driving biodiversity loss, and the need to adapt to changes which are already underway or beyond our control.

Biodiversity policy has also advanced considerably to provide clear and interlinked frameworks at national, European and international levels for the protection and restoration of marine biodiversity and ecosystems. However, while ambitious policies may be in place, significant gaps in knowledge, observation and coordination, coupled with inadequate management and implementation actions mean that we are falling far short of achieving EU and international biodiversity targets.

There is still an enormous requirement for research to provide both a theoretical understanding and an applied knowledge of the factors that control marine biodiversity and the environmental and societal implications of a changing biodiversity. For this we need to study biodiversity in all its facets, from phenotypes to genotypes, ecological niches, life cycles, populations and communities (Boero, 2010), and we need to understand better the relationship between biodiversity and human well-being.



Under stress, corals can expel their zooxanthellae and become “bleached” in appearance. One third of all corals worldwide are at risk of extinction, making them one of the most endangered animal groups on the planet (Carpenter *et al.*, 2008).
© Monger, B., NOAA



↖ A bathypelagic ctenophore
© David Shale

↑ The deep sea physonect siphonophore, *Marrus orthocanna*
© Kevin Raskoff, NOAA

With the recent completion of some major marine biodiversity initiatives such as the Census of Marine Life (CoML) and the Marine Biodiversity and Ecosystem Functioning (MarBEF) Network of Excellence (see Infoboxes on pages 8 and 11 respectively), it is now timely to consider the next steps for marine biodiversity research in Europe. In this Marine Board Future Science Brief, we take a look at the progress that has been made to date in developing a clearer knowledge and understanding of marine biodiversity, and the major gaps in our knowledge and research capacities which still exist. We also examine the policy landscape for biodiversity both in Europe and internationally and highlight the critical role of science-policy interfaces in transferring the knowledge generated from research to support effective decision-making and marine stewardship. Finally, we propose a high-level roadmap to guide future marine biodiversity research in Europe which builds on the progress already made. This includes ten recommendations on future research priorities linked to marine biodiversity and six high-level strategic recommendations which are essential both to support European biodiversity research and, ultimately, to guide appropriate management actions required to meet biodiversity targets.

4 What do we already know about marine biodiversity?

Major investments have been made in the past ten years to support European and global initiatives which have advanced marine biodiversity knowledge, research capacities, observations, data management and policy support. There is a critical need to build on this progress. Europe must continue to lead and drive global progress in marine biodiversity research.

Because life originated in the oceans and has been evolving there for an estimated 2.8 billion years, biological diversity is much greater in the sea than on land. Within the animal kingdom, for example, all but two of the 35 currently recognized

Deepwater fish
© MAR-ECO / Uwe Piatowski

phyla have marine representatives (where phylum refers to the broadest hierarchy of classification for eukaryotes, i.e. organisms with cell nuclei). Moreover, there are thirteen exclusively marine animal phyla, compared with just one exclusively terrestrial and one exclusively freshwater phylum. The seas and oceans thus support adapted life forms which flourish across a wide range of environmental conditions and habitats, resulting in the highest genetic diversity on earth (Heip *et al*., 2009).

The recently completed Census of Marine Life[1] estimates that there are approximately 240,000 marine species known to science, while current estimates of the total number of living marine eukaryotic species range from 0.7 million (Appeltans *et al*., 2012) to 2.2 million (Mora *et al*., 2011), indicating that at least 70% of marine eukaryotic species are yet to be described, including many which live in more accessible shallow and coastal environments. Curini-Galletti *et al.* (2012), for example, recently discovered 100 unknown species of meiofauna in coastal sands in Italy and Norway.

The above figures exclude entirely the microscopic *Bacteria* and *Archaea* that likely include millions of different types. Indeed, recent research has also begun to shed light on the enormous diversity of marine microbes, which is awe-inspiring in both its extent and intricacy. It is estimated that coastal seawater contains in the region of one billion microorganisms per litre, including up to 10,000 bacterial types alone (Glöckner *et al*., 2012). Planktonic and benthic microbes such as *Bacteria*, *Archaea*, viruses, *Fungi* and protists, including microalgae, comprise up to 90% of the living biomass in the oceans. These microbes play a crucial role in ecosystem functioning by producing organic matter and the oxygen required to sustain life, and facilitating the storage, transport, and turnover of key biological elements.

New theoretical and experimental approaches and techniques have driven advances in our understanding of the role and importance of biodiversity, including its role in ecosystem functioning. For example, biomarkers, stable isotopes and mathematical models enable us to better analyze and understand food webs.

The Census of Marine Life

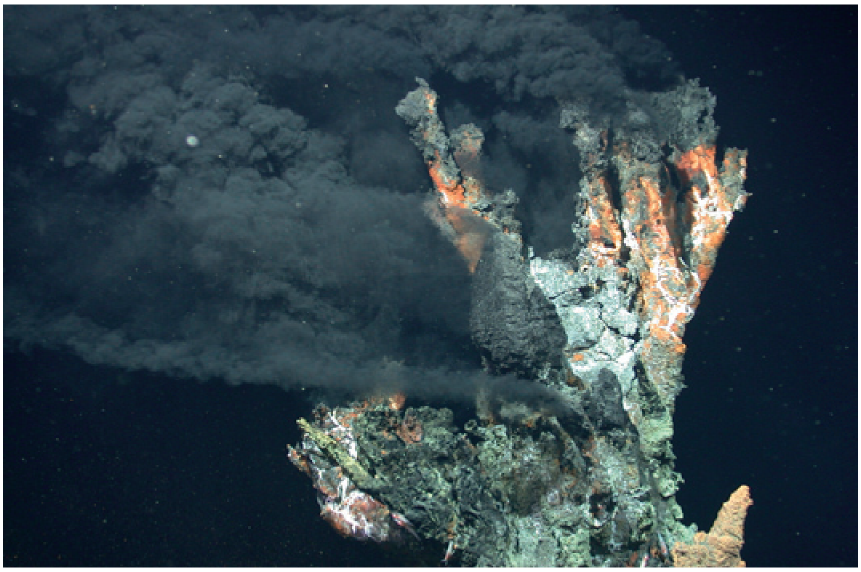
CENSUS OF MARINE LIFE

Completed in 2010, the **Census of Marine Life** (CoML) was a ten-year international research programme which brought together more than 2,700 scientists from 500 institutes to establish a baseline of the diversity, distribution and abundance of life in the world's oceans, against which future changes can be measured. The Census produced the most comprehensive inventory of known marine life ever compiled, aggregated more than 30 million species-level records obtained before and outside the census and millions more from its own field work, including 1,200 newly discovered and described species.

The Census investigated life in the global ocean from microbes to whales, from the surface to the sub-seabed, from pole to pole. Census investigators documented long-term and widespread declines in marine life as well as resilience of the ocean in areas where recovery was apparent. This first baseline picture of ocean life – past, present, and future – is being used to forecast, measure, and understand changes in the global marine environment, to inform the management and conservation of marine resources, and to better prioritize future conservation and research initiatives

www.coml.org

[1] http://www.coml.org/



↖ A black smoker at a the Rainbow hydrothermal vent field located on the Mid-Atlantic Ridge, SW of the Azores.
© Ifremer

↑ The heat and emissions in the vicinity of hydrothermal vents often give rise to unique faunas dependent on chemosynthesis rather than photosynthesis for primary production.
© Ifremer

Moreover, rapid advances in sequencing and molecular technologies, including progress in bioinformatics, have contributed to systematics and taxonomy to provide, in some cases, a clearer view of species and their inter-relationships.

Technology has also been important in gaining greater access to unexplored marine environments and biotas. Using exploration tools such as ROVs and ocean drilling, we are increasingly accessing remote environments such as cold-water coral reefs, the Mid-Atlantic Ridge, submarine canyons and the biosphere deep within Earth's crust. Such exploration has shown us that marine organisms live to an extreme water depth of up to 11km, and in ocean sediments several kilometers below the seafloor. Many previously unknown small-scale seafloor habitats have also been discovered and explored including new hydrothermal vents, mud volcanoes, cold seeps, brine pools, exposed gas hydrates, carbonate hills and chimneys. All of these habitats are characterized by unique faunas which are often dependent on chemosynthesis rather than photosynthesis as their source of primary production.

In recent years, a more sophisticated appreciation of the value of marine biodiversity and associated ecosystem services to human well-being has begun to emerge. Marine organisms, including both microorganisms and higher taxa, provide beneficial goods and services which include food and genetic resources, primary production, oxygen production, nutrient cycling, climate regulation, waste treatment and a range of cultural benefits (aesthetic, educational, recreational), all of which are very difficult to quantify, either in monetary or non-monetary terms.

Major international initiatives such as TEEB (The Economics of Ecosystems and Biodiversity) and the Millennium Ecosystem Assessment (see Infobox on page 16) have highlighted the need for better strategies for measuring the goods and services which humans derive from ecosystems and biodiversity, and the threat to society resulting from their overexploitation and depletion. Natural scientists have begun to work with social scientists and economists to develop mechanisms to quantify and measure the "value" of concepts such as biodiversity which can, in turn, be used to support policy and management decisions (e.g. Beaumont *et al*., 2008). The emerging importance placed on implementing an ecosystem approach to management of marine resources also takes into account the complexity of marine ecosystems and the fact that humans are part of the ecosystem.

↑ Students participating in a Euromarine marine field course at Viana do Castelo, Portugal
© Jack Sewell

↗ The 36 metre schooner, Tara, carried a team of scientists and crew on a on a 2.5 year global study of marine plankton
© Bollet, S., Tara Expeditions

Europe has a long tradition of marine biodiversity research. Inventories of marine plants and animals have been compiled for many European regions over hundreds of years, mainly through the work of scientists working in universities, museums, marine stations and fisheries institutes. However, progress on the basic descriptors of biodiversity has accelerated in the last ten years. At the beginning of 2012, the European Register of Marine Species contained 33,000 marine plant and animal species, up 12 % since 2006, with 753 species new to science having been described since 2000. As part of the Census of Marine Life and the FP6 Network of Excellence, MarBEF, over four million geo-referenced records of marine plants and animals were collected and archived in the Ocean Biogeographic Information System (OBIS, see Infobox on page 19) and the Global Biodiversity Information Facility (GBIF, see Infobox on page 20). These facilities represent open access databases on marine biodiversity knowledge that continue to expand. In the best traditions of the early Challenger cruise (1872-1876) which catalogued more than 4,000 previously unknown species, international expeditions still play an important role in marine biodiversity research and discovery. The recently completed, three-year Tara expedition[2], which circumnavigated the globe, collected more than 27,000 plankton samples, and will provide the most complete census of oceanic protists ever undertaken.

While biodiversity discovery and monitoring has generally been the preserve of scientists, there has long been an enthusiastic amateur interest in marine animals and plants. For example, there is a history of public participation in the reporting and surveying of sea birds and marine mammals. Increasingly, school and university students, fishermen, divers and amateur scientists are contributing to the accessible knowledge pool of species occurrence and abundance. A recent development is the CIESM Jellywatch[3] programme, a citizen science initiative which relies on information from the public to generate a picture of jellyfish abundance and distribution. Jellywatch began as a trial in Italy in 2008 and is now being implemented in ten Mediterranean countries, while a similar project, ECOJEL[4], is in operation in the Irish Sea. The advancing use of information technology tools such as smartphone apps can provide further opportunities to encourage this kind of citizen science.

2
www.taraexpeditions.org

3
www.ciesm.org/marine/programs/jellywatch.htm
www.focus.it/meduse/

4
www.jellyfish.ie

Marine Biodiversity and Ecosystem Functioning Network of Excellence (MarBEF NoE)

MarBEF, a Network of Excellence funded by the European Union Sixth Framework Programme, created a platform of 94 European marine institutes for the integration and dissemination of knowledge and expertise on marine biodiversity, with links to researchers, industry, stakeholders and the general public.

MarBEF brought together the critical mass of researchers who generated a series of project proposals in topics related to marine biodiversity. In doing so, MarBEF also strengthened the European contribution to international programmes such as the Census of Marine Life. The 18 different projects within MarBEF created important networks in themselves that continue to operate until today.

Following completion of the FP6 funding in 2009, the MarBEF Network of Excellence was formally consolidated as the legal association, MarBEF+. MarBEF+ is currently engaged in discussions concerning the creation of a new marine consortium, EuroMarine (see below).

www.marbef.org

EuroMarine

EuroMarine is a European Union 7th Framework Programme coordination action that seeks to develop and implement an agreed framework for the long-lasting and durable co-operation between the research institutions that were partners in the three FP6 marine Networks of Excellence (MarBEF, EUR-OCEANS and Marine Genomics Europe) in order to achieve further integration of marine research in Europe. Cooperation is focused on research strategy, joint development and use of databases, training and mobility of researchers, joint programming, and use of research infrastructures. One of the key objectives of the EuroMarine project is to deliver agreement on a legal framework which will form the basis of institutional commitment to this durable collaboration and a potentially significant contribution to implementation of the European Research Area (ERA).

www.euromarineconsortium.eu

Deepsea Jellyfish
© David Shale

5 What are the gaps in our knowledge of marine biodiversity?

European research has considerably advanced our knowledge of marine biodiversity in recent years but it is clear that there is still much work to do. While the number of described marine species increases by, on average, 1,500 each year, the vast majority of species living in our seas and oceans have yet to be discovered or described. Moreover, for most species known to live in European waters, there is a complete lack of knowledge of the full life-cycle, ecological niche and role, population structure and status, pathogens, symbionts, and interactions with other components of the ecosystem. In addition, little is known of the factors that control the generation of diversity itself and its function in regulating many marine processes.

Although Europe's marine biodiversity of higher organisms is probably the best known in the world (Costello and Wilson, 2011), in fact very little is known about the variation in space and time for all but a few commercial and key species, and major regions such as the eastern Mediterranean remain relatively understudied. From the findings of the MarBEF project, it is not even clear whether, at the European scale, marine biodiversity is being lost. Indeed, there is evidence that in many regions marine biodiversity is increasing owing to the introduction, spread or shift in range of non-native species. In short, there are major and important gaps in our knowledge of the natural histories, abundance, distribution, interactions, life cycles and ecological functions of European marine species. This is true from the shore to the deep ocean; the Census of Marine Life found that every second specimen collected from waters deeper than 3,000 m belongs to a species new to science (Crist *et al.*, 2009).

The fragmented approach to biodiversity science has left a legacy of poor coordination of knowledge and capacities. No quantitative assessment has been made of biodiversity status and trends in Europe. In general, biodiversity observa-

Marine organisms preserved and stored in a reference collection.
© NOC

tions have been made and samples collected and curated in an uncoordinated way. Most culture collections are heavily biased towards groups of organisms for which culturing protocols have been known for decades. Faunal and floral inventories are fragmented and often very old. Many animal and plant identification guides are completely outdated or out of print, and some aspects of the knowledge-base have actually declined. Traditional taxonomy (based on morphology), for example, one of the core disciplines for the study of marine biodiversity, is in serious decline. At the beginning of the 21st century, there are entire animal groups, even phyla, for which there is not a single expert alive. Historically a leader in this area, Europe has largely failed to transfer the extensive taxonomic knowledge it once possessed to a new generation of scientists.

Major gaps also exist in our knowledge of marine microbial diversity, but for different reasons. Estimations of the number of marine microbial types (operational taxonomic units or OTUs) range from tens of thousands to tens of millions, yet only a few thousand OTUs of marine prokaryotes have been described. It is not only necessary to obtain a realistic estimation of microbial diversity, but even more so to understand which taxa play essential roles in the ocean's biogeochemical cycles and food webs. To date, understanding the role of microbes in the oceans has focused on taxa that occur in high abundance, yet most of the marine microbial diversity is largely determined by a much greater number of low-abundance taxa. This "rare biosphere" may represent a source of different types of organisms that become abundant when environmental conditions change (Galand *et al.*, 2009).

While we struggle to observe and understand marine diversity in space and time, we will continue to see rapid changes in species composition and, therefore, species interactions and the structure of food webs in European waters. Species

This jewelled umbrella squid, *Histioteuthis bonnellii*, is found in deep ocean waters above the Mid-Atlantic Ridge.
© David Shale

Life in a Changing Ocean

Life in a Changing Ocean is an international scientific initiative to advance and expand marine biodiversity discovery and knowledge to support healthy and sustainable ocean ecosystems. Its research is designed to establish and enhance global baselines, define the role of biodiversity in ecosystem functions and services, and understand the impact of environmental and human-derived changes on biodiversity and ocean ecosystems.

Life in a Changing Ocean was developed by an international community of researchers who worked together for the first time during the Census of Marine Life. The initiative should specifically act as a follow-on programme to CoML, and to build on the enormous momentum and global network which that programme delivered.

Life in a Changing Ocean seeks to address three scientific themes that will work independently and collaboratively to generate a clearer picture of marine biodiversity in the global ocean: (i) Biodiversity Discovery in Space and Time; (ii) Biodiversity and Ecosystem Functions and Services and (iii) Biodiversity and Human Exploitation. Each will address basic research questions and use the results to provide policy makers and ocean stakeholders with data, insights, tools, and indicators that can be used to better manage ocean resources.

http://lifeinachangingocean.org

This furry-clawed crab appeared so unusual when scientists discovered it 1,500 metres deep on a hydrothermal vent south of Easter Island, that they designated it not only a new genus, *Kiwa*, but a new family, Kiwidae – both named for the mythological Polynesian goddess of shellfish. It's likely blind and may use bacteria in its furry claws to de-toxify its food.
© Fifis, A., Ifremer

interactions from the microbial domain to the classical marine food web are changing with the changes in biodiversity caused by species loss (local extinctions) or gain (introductions, invading species) resulting from climate change, acidification, overfishing, eutrophication, and other factors. In coastal areas and enclosed sea basins, these changes are often influenced by what happens on land, and the links between land-based activities and the sea must be properly understood in order to alleviate anthropogenic pressures on marine biodiversity. Collectively, these changes threaten not only a wide range of organisms but also the functions they support.

It has been shown that northern hemisphere marine species need to move on average 37 km northwards each decade to remain at the same mean water temperature, while areas such as the North Sea have seen particular change, with spring temperatures arriving 5-10 days earlier each decade (Burrows *et al.*, 2011). Of particular importance, therefore, will be the study of adaptation, as we have no insight on how populations will adapt to changing environmental conditions or to changing species interactions. Multidisciplinary approaches will be necessary to understand, in a quantitative way, the role of biodiversity in food web stability and resilience, and hence food security. For example, new omics (e.g. genomics, transcriptomics, metabolomics) methods can help to improve our understanding

How do we measure the "value" of marine biodiversity and ecosystem services?

The most important direct drivers of global change in marine ecosystems, and marine biodiversity loss in particular, are believed to be habitat alteration (such as loss of coral reefs or damage to sea floors due to trawling), climate change, invasive alien species, overexploitation, and pollution. While the impacts of these changes on the services we derive from marine ecosystems are potentially enormous, because of the complexity of these systems, it has always proven difficult to measure these impacts and, in turn, their social and economic consequences. Robust and agreed mechanisms and tools for measuring the value of marine ecosystem services and the costs of a reduction in these services resulting from environmental change are, therefore, urgently required. Such a valuation framework may be in monetary units (price), but may also encompass social or cultural value systems. This can also help to improve our understanding of the interactions between society and marine ecosystems and the importance of these interactions.

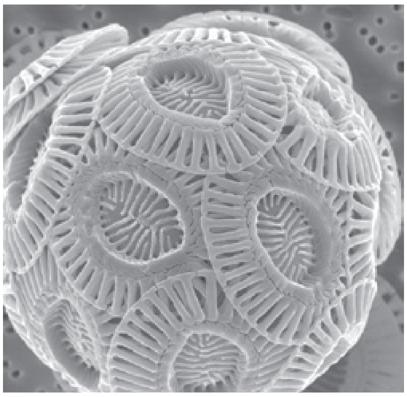
Marine research has traditionally focused on physical, chemical and biological processes in the water body and its boundaries, whereas the field of marine related socio-economics is much less studied and understood. Understanding the ways in which humans utilize marine resources and space directly or indirectly is essential for an integrated assessment and management of the coasts, seas and oceans, and will require an innovative interdisciplinary research approach. It is also an intrinsic requirement for achieving a genuine ecosystem approach to the management of marine resources.

The reduction in biodiversity and its impact on human societies and economies has been the subject of much recent research, including two major international initiatives, the Millennium Ecosystem Assessment (MA) and TEEB (The Economics of Ecosystems and Biodiversity Study) and will also be a component of the UN World Ocean Assessment for reporting on the state of the global marine environment.

of organism ecophysiology and plasticity. In addition, a major improvement in spatial and temporal modelling capabilities should facilitate the incorporation of biodiversity information within regional and global ecosystem models and the linking of these with biogeochemical models. Addressing these theoretical questions and practical issues is imperative, not just in helping to explain what we observe today, but also in helping to predict how marine biodiversity will change in the future as a result of natural and human pressures.

In addition to understanding the biological and functional aspects of marine biodiversity, the importance of marine biodiversity to human well-being and the valuation of ecosystem goods and services remain poorly understood. The lack of market prices for ecosystem services and biodiversity means that the benefits we derive from them are usually neglected or undervalued in decision-making. By externalizing environmental costs in decision-making, we are failing to take account of the implications of human-induced environmental degradation which can not only result in biodiversity loss, but ultimately impact on human well-being. We need to develop economic models and valuation tools that can be used for the management and governance of marine systems. TEEB and the Millennium Ecosystem Assessment have made progress in this area but further progress will require a much-improved collaboration between natural scientists, social scientists and economists and a greater emphasis on marine ecosystems.

It is clear that major gaps still exist in our knowledge and research capacities which could hinder European marine biodiversity research and leadership in the years to come. These can only be addressed through targeted research funding and continued cooperation at European level. However, biodiversity research and discovery no longer appear to be a priority for many research funding organizations, perhaps because there is a misguided belief that we have discovered most species or that taxonomy and biodiversity are no longer fashionable disciplines, except when new and interesting technologies are deployed (Costello *et al.*, 2010). Having clearly established biodiversity as a policy priority, Europe must again lead the way by supporting a new era of collaborative research projects and programmes and through long-term support for the enhancement of key research capacities, not least the development of an integrated biodiversity observing system and the training of a new generation of 21st century taxonomists.



Coccolithophores such as *Emiliania huxleyi* are single-celled marine phytoplankton that occur in all of the world's oceans and together represent the largest source of biogenic calcium carbonate on Earth, contributing significantly to the global carbon cycle.
© Alison R. Taylor (University of North Carolina Wilmington Microscopy Facility)

The sponge, *Amphilectus fucorum*, is commonly found in the shallow sub-littoral waters around the coasts of the British Isles.
© Bernard Picton, Ulster Museum

The Millennium Ecosystem Assessment

The Millennium Ecosystem Assessment (MA) was initiated in 2001 at the behest of the then United Nations Secretary, Kofi Annan. The objective of the Millennium Ecosystem Assessment was to assess the consequences of ecosystem change for human well-being and the scientific basis for action needed to enhance the conservation and sustainable use of those systems and their contribution to human well-being. The MA has involved the work of more than 1,360 experts worldwide. Their findings, contained in five technical volumes and six synthesis reports, provide a state-of-the-art scientific appraisal of the condition and trends in the world's ecosystems and the services they provide (such as clean water, food, forest products, flood control, and natural resources) and the options to restore, conserve or enhance the sustainable use of ecosystems.

www.maweb.org

The Economics of Ecosystems and Biodiversity Study (TEEB)

The Economics of Ecosystems and Biodiversity (TEEB) study is a major international initiative to draw attention to the global economic benefits of biodiversity, to highlight the growing costs of biodiversity loss and ecosystem degradation, and to draw together expertise from the fields of science, economics and policy to enable practical actions to address these challenges. The aims of the TEEB series of reports (published over 2010-2012) are:

- to synthesize and present the latest ecological and economic knowledge to structure the evaluation of ecosystem services under different scenarios, and to recommend appropriate valuation methodologies for different contexts.
- to develop guidance for policy makers at international, regional and local levels in order to foster sustainable development and better conservation of ecosystems and biodiversity;
- to enable easy access to leading information and tools for improved biodiversity-related business practice – from the perspective of managing risks, addressing opportunities, and measuring business impacts on ecosystems and biodiversity;
- to raise public awareness of the contribution of ecosystem services and biodiversity towards human welfare, of an individual's impact on biodiversity and ecosystems, as well as identifying areas where individual action can make a positive difference.

TEEB has now moved into a phase of implementation, facilitating governments at local, national and regional scales to initiate their own TEEB studies.

TEEB is currently supporting the development of a TEEB for Oceans Study. A working group has been established and met in August 2012 to engage with a broad, transdisciplinary audience of experts and capture relevant and valuable insight, knowledge and information. The study will examine our current relationships with the oceans from social, natural and economic perspectives and aims to foster more sustainable management of human activities on the oceans.

www.teebweb.org

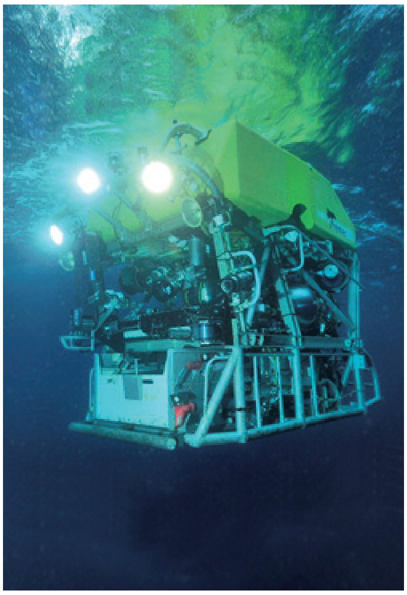
The World Ocean Assessment (UN Regular Process)

In 2005, United Nations General Assembly Resolution 60/30 launched the "Assessment of Assessments" (AoA) as a preparatory stage towards the establishment of a "Regular Process for the global reporting and assessment of the state of the marine environment, including socio-economic aspects, both current and foreseeable, building on existing regional assessments" The World Ocean Assessment (WOA) will assess both the state of the environment and the impacts of key human interactions with ocean ecosystems. The WOA will facilitate a global integrated assessment of the marine environment at five-year intervals. The first cycle started in 2010 and will end in 2014.

http://www.un.org/Depts/los/global_reporting/global_reporting.htm

6 What tools do we need to support marine biodiversity science?

To ensure that Europe maintains its position as a global leader in marine biodiversity research, future scientific investment will need to support improvements in observation systems, biological resource collection and curation, *in situ* experimental facilities, laboratory approaches, data handling, and human capacities in key areas.



The Ifremer Remotely Operated Vehicle, Victor 6000
© Ifremer

Marine biodiversity is not only changing at large scales of time (decades) and space (hundreds to thousands of kilometres), but also at smaller scales relevant for local or regional management (e.g. Marine Spatial Planning). To track these changes effectively, a major effort is required to deliver a coherent network of biological observatories in carefully selected geographical locations, based on common protocols, quality control and free access to data. A distributed system of observatories, including microbial observatories, where biodiversity measurements are combined with environmental measurements, will benefit from the use and continued development of new observation platforms and sensor systems. In addition, marine biodiversity observatories will need to be linked to national, regional or commercial data centres, which are essential to document, archive, integrate and redistribute biodiversity data, allowing, for example, the detection of patterns and trends in marine biodiversity.

While improved observations and data will be central to future efforts to track and better understand marine biodiversity, laboratory-based tools and techniques also have an important role to play. The major improvements in molecular techniques, sequencing technologies and omics approaches, coupled with the use of bioinformatics and e-science to handle large datasets of genomic information, has opened up enormous opportunities for collaborative research and discovery. Such important technological advances should not, however, detract from the need to also improve scientific efforts in traditional taxonomy, phenotypical and ecological approaches. Indeed, the large-scale application of DNA barcoding must

MAR-ECO scientists at work sorting and recording samples from mid-water trawls
© MAR-ECO / Jaime Alvarez, Institute of Marine Research, Norway

Holding crabs collected from a hydrothermal vent in a cold chamber on board l'Atlante research vessel. © Ifremer /Olivier Dugomay

work in close conjunction with traditional taxonomy and Biological Resource Centres (BRCs).

Efforts towards improved coordination of biodiversity observations, data and research tools are already underway at the international level, including, for example, GEO-BON and GBIF (see Infoboxes on page 20). At the European level, the European Commission-led EMODNET[5] initiative aims to develop a coordinating architecture for marine data and knowledge, under which the EMODNET biology portal[6] is focused on biodiversity data. In addition, two ESFRI (European Strategy Forum on Research Infrastructures)[7] programmes contribute to better coordination of biodiversity observation. LifeWatch[8] focuses on developing a pan-European e-science and technology infrastructure for biodiversity data and observatories, while EMBRC (European Marine Biology Resource Centre)[9] will provide access to marine model organisms and state-of-the-art training facilities at leading marine stations in Europe. Indeed, coastal marine stations and institutes, which in some countries already cooperate through national agreements, are uniquely placed to be at the heart of any European network of biodiversity observatories. They accommodate expert scientists and research vessels and can act as shore bases for cabled observation systems as well as service centres for monitoring equipment. They are also essential for experimental research on marine biodiversity – often supported by mesocosm facilities – which is indispensable for theory testing, and model evaluation and calibration.

Europe is already well supplied with coastal marine research stations and institutes, many of which have existed for more than 100 years. While some of these marine stations are integrated to some extent through the MARS Network[10], there is no real long-term integration of effort at the institutional level; rather this remains at the level of the individual scientist. A significant step forward may be achieved with the integration of marine stations and institutes from across Europe into a single pan-European multi-disciplinary network, which is the primary goal of the EuroMarine[11] initiative. The integration of coastal marine laboratories and stations may also help to protect these facilities as crucial resources, both for *in-situ* experiments and for the collection of long-term marine environmental datasets (biological, chemical and physical), which are of major importance for tracking and explaining localized changes in marine biodiversity.

5
http://ec.europa.eu/maritimeaffairs/policy/marine_knowledge_2020/index_en.htm
6
http://bio.emodnet.eu
7
http://ec.europa.eu/research/infrastructures
8
http://www.lifewatch.eu
9
http://www.embrc.eu
10
http://www.marsnetwork.org
11
http://www.euromarineconsortium.eu

The Sven Lovén Centre for Marine Sciences, Kristineberg, Sweden.
©The Sven Lovén Centre, University of Gothenburg.

Ocean Biogeographic Information System (OBIS)

Developed as part of the Census of Marine Life Programme (see Infobox on page 8), the **Ocean Biogeographic Information System**, or **OBIS**, is the world's largest on-line, database for accessing, modelling and mapping marine biological data in a multidimensional geographic context. OBIS acts as a portal to more than 1,000 datasets containing 32 million species records. The datasets are integrated to allow all datasets to be queried by species name, higher taxonomic level, geographic area, depth and time; and to access environmental data related to the locations where records are taken. The system is designed to stimulate and underpin research on the oceans, marine evolutionary processes, species distributions, and roles of organisms in marine systems on a global scale. For example, during the last six months of 2012 alone, 15 scientific papers are in preparation for publication using OBIS data. To provide a more scientific basis for the protection, management and conservation of our marine biological resources at the international level, especially in the open ocean and deep seas (i.e., Areas Beyond National Jurisdiction), OBIS is a key provider of data for the establishment of Ecologically or Biologically Significant Areas and Large Vulnerable Marine Ecosystems.

Following completion of the CoML in 2010, OBIS has been integrated into the Intergovernmental Oceanographic Commission (IOC) of UNESCO to continue its operations under IOC's International Oceanographic Data and Information Exchange (IODE) programme.

www.iobis.org

European Ocean Biogeographic Information System (EurOBIS)

The European Ocean Biogeographic Information System, EurOBIS, is the European Regional OBIS Node (RON) of OBIS (above). EurOBIS is an integrated data system developed by the Flanders Marine Institute (VLIZ), Belgium, for the EU Network of Excellence Marine Biodiversity and Ecosystem Functioning (MarBEF) in 2004. Its principle aims are to centralize the largely scattered biogeographic data on marine species collected by European institutions and to make quality-controlled data freely available and easily accessible for users. EurOBIS is thus a distributed system in which individual datasets go through a series of quality control procedures before they are integrated into one large consolidated database. EurOBIS is freely available online to enable consultation and downloading of marine biogeographical data with a focus on taxonomy, temporal and spatial distribution.

Within EurOBIS, the European Register of Marine Species (ERMS) functions as the taxonomic backbone; the European Marine Gazetteer as the geographical reference list, and the Integrated Marine Information System as the inventory of relevant data and other information.

EurOBIS shares data with OBIS which, in turn, shares its content with the Global Biodiversity Information Facility (GBIF).

www.eurobis.org

European Marine Biodiversity Observing System (EMBOS) – COST action

The **European Marine Biodiversity Observing System (EMBOS)** is a COST action in the area of marine biodiversity research. COST is intergovernmental framework for European Cooperation in Science and Technology, a scheme which supports the coordination of nationally-funded research on a European level.

EMBOS aims to install a large-scale network of research locations in Europe to assess long-term changes in marine biodiversity and their possible causes, taking into account natural and anthropogenic gradients. This is needed because marine biodiversity varies over large scales of time and space, and as such requires a research strategy beyond the tradition/capabilities of classical research. Research that covers these scales requires a permanent international pan-European network of observation stations with an optimized and standardized methodology.

EMBOS will extend and optimize this observatory system, including novel interdisciplinary approaches for research. The cooperation should contribute to a focused and cost-effective long term research agenda for EU marine observatories, and provide an important contribution to the European Research Agencies, LIFEWATCH and GEOSS/GEOBON actions, and supports legal obligations of the EU regarding the CBD, OSPAR and Barcelona conventions as well as EU directives (Bird and Habitat Directive, WFD, MSFD, ICZM).

http://www.cost.eu/domains_actions/essem/Actions/ES1003?

Global Biodiversity Information Facility (GBIF)

The **Global Biodiversity Information Facility (GBIF)** was established by governments in 2001 to encourage free and open access to biodiversity data via the Internet. The data are provided by more than 400 institutions from around the world through a network of national and thematic nodes. GBIF makes these data accessible and searchable through a single portal. Data available through the GBIF portal are primarily occurrence records for plants, animals, fungi, and microbes, although they also include species checklists and taxonomic information.

GBIF aims to form linkages among digital data resources from across the spectrum of biological organisation at various levels (from genes to ecosystems), and to connect these to key biological questions important to science, society and sustainability by using geo-referencing and GIS tools. Data published through the GBIF network are increasingly contributing to scientific research, with more than 200 peer-reviewed journal papers citing use of GBIF-mediated data during 2011. GBIF works in partnership with other international organizations such as the Catalogue of Life partnership, Taxonomic Database Working Group (the International Biodiversity Information Standards Organization), the Consortium for the Barcode of Life (CBOL), the Encyclopedia of Life (EOL) and the Global Earth Observation System of Systems (GEOSS).

www.gbif.org

Group on Earth Observations Biodiversity Observation Network (GEO BON)

The **Group on Earth Observations Biodiversity Observation Network**, also known as **GEO BON**, coordinates activities relating to the Societal Benefit Area (SBA) on Biodiversity of the Global Earth Observation System of Systems (GEOSS). Some 100 governmental, inter-governmental and non-governmental organizations are collaborating through GEO BON to organize and improve terrestrial, freshwater and marine biodiversity observations globally and make their biodiversity data, information and forecasts more readily accessible to policymakers, managers, experts and other users. GEO BON has been recognized by the Parties to the Convention on Biological Diversity.

www.earthobservations.org/geobon.shtml

Biodiversity Information System for Europe (BISE)

The **Biodiversity Information System for Europe (BISE)** offers a single entry point for data and information on biodiversity in the EU. Bringing together facts and figures on biodiversity and ecosystem services, it links to related policies, environmental data centres, assessments and research findings from various sources. It is being developed to strengthen the knowledge base and support decision-making on biodiversity. BISE is a partnership between the European Commission (DG Environment, Joint Research Centre and Eurostat) and the European Environment Agency (EEA). It incorporates the network of the European Clearing House Mechanism within the context of the United Nations Convention on Biological Diversity (CBD).

http://biodiversity.europa.eu

The World Register of Marine Species (WoRMS)

The **World Register of Marine Species** (**WoRMS**) is a database with the goal of providing a comprehensive and authoritative list of the names of marine organisms. The content of the registry is edited and maintained by scientific specialists on each group of organisms. These taxonomists control the quality of the information, which is gathered from several regional and taxon-specific databases. WoRMS maintains valid names of all marine organisms, but also provides information on synonyms and invalid names. It is an on-going task to continually maintain the registry, as new species are constantly being discovered and described by scientists. In addition, the nomenclature of existing species regularly requires re-evaluation.

WoRMS was founded in 2008, building on the already successful European Register of Marine Species (ERMS). It is primarily funded by the European Union and hosted by the Flanders Marine Institute (VLIZ) in Ostend, Belgium. WoRMS has established formal agreements with several other biodiversity projects, including the Global Biodiversity Information Facility and the Encyclopedia of Life. As of November 2011, WoRMS had 214,131 valid marine species, of which 195,135 were checked.

The World Registry of Marine Species (WoRMS): **www.marinespecies.org**

The European Register of Marine Species (ERMS): **www.marbef.org/data/erms.php**

7 The science-policy interface

At global, European, regional and national levels, many policies have sought to take account of the significant threat of altered or depleted marine biodiversity. However, these policies have not yet delivered sufficient improvements in the management of marine environments and resources to measure and address the changing biodiversity.
In addition to an improved knowledge and understanding of marine biodiversity, a mechanism for continuous and effective exchange of information between scientists, decision makers and the general public is increasingly important. Science-policy interfaces (SPIs) are crucial for effective policy formulation and management actions, and in setting future research agendas which address societal challenges.

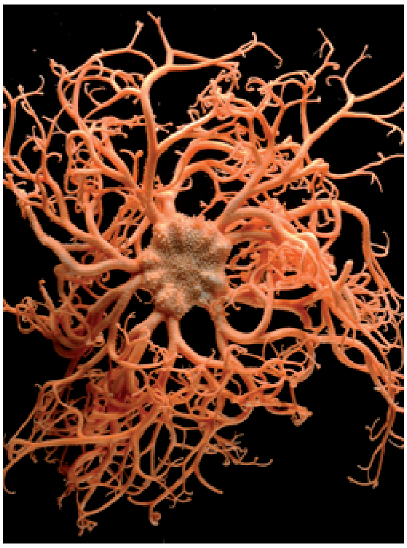
In 2002, through a decision of the Convention on Biological Diversity Conference of the Parties (CBD COP), world governments committed to achieving a significant reduction in the rate of biodiversity loss by 2010. They further agreed:

- to support the application of ecosystem approaches to marine management by 2010;
- to facilitate the establishment of marine protected areas, including representative networks by 2012; and
- to maintain the productivity and biodiversity of important and vulnerable marine and coastal areas, including areas within and beyond national jurisdiction.

Sound marine science is essential to achieving all of these goals and targets. In 2010, the CBD COP reaffirmed their commitment to reducing the rate of biodiversity loss and adopted the Aichi Targets[12] which place the conservation and sustainable use of biodiversity at the centre of sustainable development. Of particular importance to marine biodiversity, Aichi target 11 requires that: "*by 2020, at least 10% of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably*

12 http://www.cbd.int/sp/targets

The EurOCEAN 2010 Conference pre-event at the European Parliament, 11 October 2010.



Euryalid Ophiuroid or basket star
© David Shale

managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes." To date, a mere 2% of the world's ocean has been designated as protected, and this protection is almost exclusively provided in coastal and shelf areas (Weaver and Johnson, 2012). To help identify areas of particular importance for biodiversity and ecosystem services, in 2008 the CBD COP adopted scientific criteria for Ecologically or Biologically Significant Areas (EBSAs). In 2010, the COP further authorized a series of regional workshops to describe EBSAs meeting the scientific criteria. Such workshops need to be driven by the best available scientific information, creating a huge need for marine research, data compilation and synthesis.

Also at the international level, the EU and its member States have been spearheading the call for a new agreement to promote the conservation and sustainable use of marine biodiversity beyond national jurisdiction under the United Nations Convention on the Law of the Sea (UNCLOS). Improved management and conservation of the high seas and seabed in areas beyond national jurisdiction (ABNJs) is becoming an urgent issue owing to increased pressures and impacts from human activities. In 2012, a United Nations *ad hoc* open-ended informal Working Group is debating whether to proceed with such an agreement. The G77 plus China and many other states are now in favour, making it increasingly likely to go forward. The envisaged scope of the new implementation agreement includes area-based management measures (including MPAs), environmental impact assessments, marine genetic resources, including questions related to benefit sharing, capacity building and technology transfer.

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)

IPBES is an international initiative that will provide a global-level interface between the scientific community and policy makers and aims to build capacity for, and strengthen the use of, science in policy making. IPBES will collate, synthesize and analyze information for decision making in policy forums such as the global environmental conventions and development policy dialogues.

Member governments have agreed that the four main functions of IPBES will be:

- To identify and prioritize key scientific information needed for policymakers and to catalyse efforts to generate new knowledge;
- To perform regular and timely assessments of knowledge on biodiversity and ecosystem services and their interlinkages;
- To support policy formulation and implementation by identifying policy-relevant tools and methodologies;
- To prioritize key capacity-building needs to improve the science-policy interface, and to provide and call for financial and other support for the highest-priority needs related directly to its activities.

Following a planning process which lasted several years, IPBES was formally established during the second session of the plenary meeting held in Panama City in April 2012. The Secretariat for IPBES is located in the German city of Bonn.

www.ipbes.net

Fulmars in an Atlantic storm

In May 2011, the European Commission adopted a new strategy to halt the loss of biodiversity and ecosystem services in the EU by 2020. This strategy was based on commitments made by EU leaders in March 2010 towards (i) halting the loss of biodiversity and the degradation of ecosystem services in the EU by 2020; and (ii) restoring them in so far as is feasible, while increasing EU efforts towards averting global biodiversity loss. The strategy is also in line with the global commitments made in Nagoya in October 2010 in the context of the Convention on Biological Diversity.

The EU and its Member States are also signatories to the recently established Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services (IPBES, see Infobox on page 22)[13]. It is intended that IPBES will play an important role in fostering international collaboration in strengthening the use of science in policy formulation, and in stimulating the science-policy interface.

In Europe, the increasing pressure on biodiversity and on marine ecosystems, coupled with international commitments, is a direct focus of several EU policies and legislative instruments. The long-established EU Habitats Directive (1992)[14] together with the Birds Directive (1979)[15], are the basis for the formation and ecological management of a network of European Special Areas for Conservation (SACs) and Special Protection Areas (SPAs), otherwise known as the Natura 2000 network. The protection of both species and habitats under Natura 2000 is a key EU instrument for the conservation of biodiversity. Furthermore, the Natura 2000 network is the EU contribution to the "Emerald network" of Areas of Special Conservation Interest (ASCIs) set up under the Bern Convention on the conservation of European wildlife and natural habitats[16]. Natura 2000 also provides an important contribution to the Programme of Work of Protected Areas of the CBD, which is further supported by the development in several EU Member States of nationally designated Marine Protected Areas.

Notably, only 2% of the marine species and 10% of the marine habitats listed in the EU Nature Directives fall within the "favourable conservation status" category (EEA, 2011). Moreover, there is a clear terrestrial bias, illustrated by the fact the there are just nine marine habitats (and no open-water habitats) covered by the Habitats Directive, compared with more than two hundred terrestrial habitats (Fraschetti *et al*. 2011).

13
http://www.ipbes.net
14
Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora
15
Council Directive 2009/147/EC on the conservation of wild birds (codified version of Directive 79/409/EEC, as amended)
16
http://conventions.coe.int/treaty/en/Treaties/Html/104.htm
17
Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy

Euphilia ancora, a coral with large polyps
© Gustav Paulay

Since 2000, the EU Water Framework Directive[17] commits EU member States to achieving good ecological status of all water bodies (including marine waters up to one nautical mile from the shore) by 2015. The Common Fisheries Policy, which is subject to a major reform in 2012-2013, is also important for biodiversity, given that overfishing and habitat destruction (mainly by bottom trawling) have impacted significantly on marine biodiversity. Focusing specifically on marine waters, the 2008 Marine Strategy Framework Directive[18] will have important consequences for the environmental health status of Europe's marine environment. The core goal of the MSFD is the achievement of Good Environmental Status (GES) in European marine waters by 2020. This will be measured and monitored according to 11 established descriptors of GES, of which "Biological Diversity" is one.

Implementation of these commitments, conventions and directives requires scientific data, research and knowledge, which is lacking for many marine areas. The development of new science policy platforms such as IPBES represents real progress, but there remains room for significant improvement in the design and implementation of effective science-policy interfaces to ensure the best use of scientific knowledge and information. Real progress will require both scientific and policy communities to bridge the science-policy interface more effectively whilst taking account the needs of stakeholders, including industry and the public.

The message is simple: firstly we need to continue to support marine biodiversity science in Europe, to fill the significant knowledge gaps already identified above. Secondly, we need to use, more actively and effectively, the knowledge already available to guide our management decisions related to activities which impact on the marine environment.

European Platform on Biodiversity Research Strategy (EPBRS)

The **European Platform on Biodiversity Research Strategy (EPBRS)** is a forum for natural and social scientists, policy-makers and other stakeholders to identify, structure and focus the strategically important research that is essential to:

– conserve protect and restore the natural world;
– use biodiversity components in a sustainable way;
– maintain ecosystem functions that provide goods and services;
– ensure that the benefits derived from biodiversity are shared in an equitable way; and
– halt biodiversity loss.

The EPBRS maintains close connections with relevant international bodies, national governments, EU institutions and EU projects in the field of biodiversity research. Since its inception in 1999, it has gathered twice per year under successive EU Presidencies to discuss and give recommendations on strategic priorities for biodiversity research. The main deliverable of each EPBRS meeting is a short written agreement on issues that are of high scientific and policy importance. The themes addressed by the EPBRS are not only important to Europe, but of particular relevance to the participating countries as well as international organizations and events including forthcoming CBD meetings. So far, EPBRS has dealt with many topics including biodiversity and climate change, health, islands and archipelagos, invasive organisms, water and forest, the ecosystem approach, indicators, sustainable use of resources, sustainable development, and sustaining livelihoods.

www.epbrs.org

18
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 (MSFD).

8 A Roadmap for European Marine Biodiversity Science

Ten Research Priorities

To ensure a holistic and comprehensive response to the rapidly changing marine biodiversity in the seas and oceans, and to support sustainable development of living and non-living resources, future European research must be supported in the following key areas:

1. Improving the baseline knowledge of marine biodiversity from genes to ecosystems and at all relevant temporal and spatial scales;
2. Stimulating the production of new or updated electronic monographs on all European taxa (on the basis of strong support for enhanced taxonomic expertise) and of updated and cross-boundary regional field guides to the European fauna and flora;
3. Creating a better understanding of the factors which generate, maintain and deplete biodiversity in marine environments;
4. Improving the knowledge of the role of biodiversity in marine ecosystem functioning and in regulating the major biogeochemical cycles of the ocean and Earth;
5. Understanding how species and populations may adapt to changing marine environments, and the implications of such changes for ocean function and thus human well-being;
6. Developing spatio-temporal scenarios for biodiversity change supported by ecosystem, socio-economic and climatic (including ocean acidification) models and assessing the implications of those changes;
7. Understanding the link between marine biodiversity and essential ecosystem services of societal benefit, including mapping the interactions between terrestrial and marine environments;
8. Supporting policy design and implementation including, for example, the establishment of appropriate region-specific indicators, monitoring and observation protocols and environmental targets related to marine biodiversity;
9. Creating an effective value system to account for provision and loss of marine biodiversity and ecosystem goods and services and to support effective management decisions;
10. Delivering economic opportunities through the application of the knowledge generated through biodiversity research in areas such as sustainable fisheries, aquaculture, marine biotechnology, and ecotourism.

Six Strategic Recommendations

In order to support a coherent and coordinated European research effort addressing the ten research priorities listed above, it will be necessary to put in place or augment critical science supporting elements in areas such as biodiversity observing systems, data management, human capacities and science outreach. Six strategic recommendations are proposed as follows:

1. Marine Biodiversity Science Plan

Develop an integrated plan for marine biodiversity science in Europe, based on the important advances achieved over the last decade and addressing critical gaps in knowledge and capacities (e.g. observation and experimental platforms and taxonomic expertise). The plan should elaborate on the ten key scientific questions outlined on the previous page and propose hypothesis-driven experimental approaches to assess species and population level resilience to environmental changes predicted by IPCC scenarios. In addition, it should take into account both existing and emerging risks to environmental and human health, and new opportunities in fisheries, aquaculture and biotechnology arising from the changes in marine biodiversity occurring in many places in Europe.

The science plan should be anchored in, and supporting of, the global *Life in a Changing Ocean* initiative, a potentially important successor to the highly successful *Census of Marine Life*, but which currently lacks financial support.

2. European Biodiversity Observing System

Establish a formal agreement, supported by governments and funding agencies, between European marine stations and institutes to support the development of a coordinated and sustained system of biodiversity observatories combining biological, physical and chemical measurements. Notwithstanding the significantly different requirements for benthic and pelagic measurements and for researchers investigating different forms of marine life, the agreement should facilitate, as much as possible, common protocols, quality control standards and open access to data. Such cooperation is essential to allow for long-term and large-scale monitoring of marine biodiversity changes in Europe and to obtain adequate information on temporal and spatial changes and their causes and associated risks. Biological Resource Centres (BRCs) should also be supported to expand their coverage of poorly known marine taxa. The biodiversity observing system should be linked to, and build upon, the already existing EMODNET, LifeWatch and to GEO-BON initiatives and form a component of a broader European Ocean Observing System (EOOS).

3. Data management, e-science

Further develop the data management and e-science facilities that will allow for good interpretation of observations and improved modelling of biodiversity change and strengthen the links between biodiversity researchers and biological data centres.

4. Human capacity development

Support existing, and develop new, classical taxonomic expertise and in the process, develop 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. Relevant national agencies should provide incentives to support the education and training of young

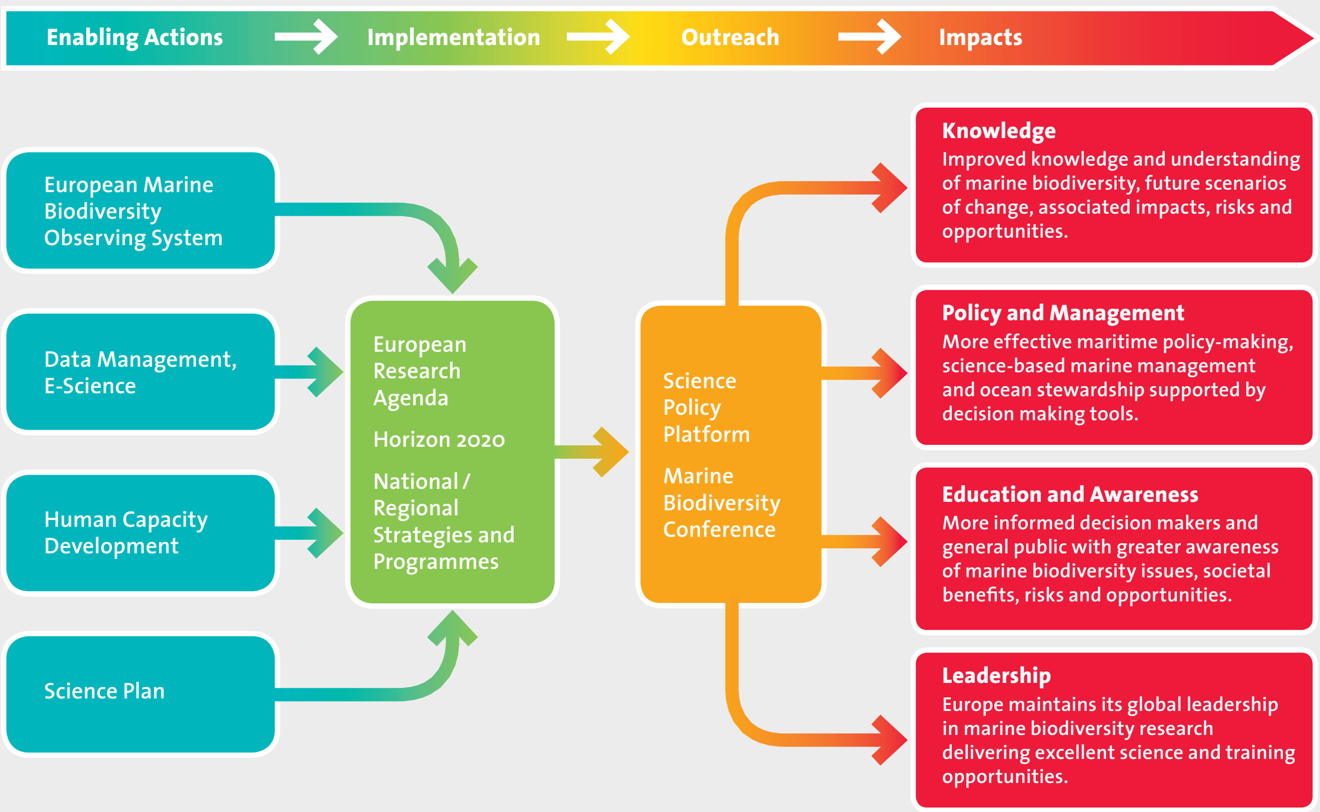
scientists in taxonomy and to enhance the taxonomic component of marine ecological research.
Support also the promotion of science communication on marine biodiversity issues and efforts to maximize the contribution of the general (non-scientific) public by promoting citizen science interest and initiatives for biodiversity observation and monitoring.

5. **Marine Biodiversity Science-Policy Platform**

Create a European Marine Biodiversity Science Policy Platform, to advise on future research needs and priorities and in the formulation of realistic and adaptive biodiversity policies. The platform should take account of wider stakeholder needs and can constitute a European contribution to the Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services (IPBES).

6. **Marine Biodiversity Conference**

Organize a European Conference on marine biodiversity research, policy and management early in the EU Horizon 2020 funding period. The conference should bring together policy makers, the science community and other stakeholders to reflect on progress and to redefine future priorities in an ever changing political and environmental landscape.



Schematic roadmap for European Marine Biodiversity science in Europe. To achieve the impacts on the right, it is necessary to put in place key strategic enabling actions and significant financial support for future biodiversity research at national and EU level. Science outreach and communication and appropriate science policy interfaces will also be essential.

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List of Abbreviations

ABNJ
Area beyond National Jurisdiction

AoA
Assessment of Assessments

ASCIs
Areas of Special Conservation Interest

BISE
Biodiversity Information System for Europe

BRCs
Biological Resource Centres

CBD
Convention on Biological Diversity

CBD COP
Convention on Biological Diversity Conference of the Parties

CIESM
Mediterrean Science Commission

CoML
Census of Marine Life

COP
Conference of the Parties

COST
European Cooperation in Science and Technology

DNA
DesoxyriboNucleic Acid

ECOJEL
Understanding Jellyfish in the Irish Sea (Project funded by the European Union Regional Development Fund)

EEA
European Environment Agency

EMBOS
European Marine Biodiversity Observing System

EMBRC
European Marine Biology Resource Centre

EMODNET
European Marine Observation and Data Network

EOOS
European Ocean Observing System

EPBRS
European Platform on Biodiversity Research Strategy

ERA
European Research Area

ERMS
European Register of Marine Species

ESF
European Science Foundation

ESFRI
European Strategy Forum on Research Infrastructures

EU
European Union

EurOBIS
European Ocean Biogeographic Information System

EUR-OCEANS
European research on Ocean Ecosystems under Anthropogenic and Natural Forcings

EuroMarine
Integration of European Marine Research Networks of Excellence

FP6
Sixth Framework Programme

G77
Group of 77 at the United Nations

GBIF
Global Biodiversity Information Facility

GEO BON
Group on Earth Observations Biodiversity Observation Network

GES
Good Environmental Status

IPBES
Intergovermental Science-Policy Platform on Biodiversity and Ecosystem Services

IPCC
Intergovernmental Panel on Climate Change

LifeWatch
E-Science European Infrastructure for Biodiversity and Ecosystem Research

MA
Millenium Ecosystem Assessment

MarBEF
Marine Biodiversity and Ecosystem Functioning

MARS network
European Network of Marine Research Institutes and Stations

MPA
Marine Protected Area

MSFD
Marine Strategy Framework Directive

OBIS
Ocean Biogeographic Information System

OTUs
Operational Taxonomic Units

ROV
Remotely Operated Vehicle

SACs
Special Areas for Conservation

SPAs
Special Protection Areas

TEEB
The Economics of Ecosystems and Biodiversity Study

UN
United Nations

UNEP
United Nations Environment Programme

WoRMS
World Register of Marine Species

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DFG Deutsche Forschungsgemeinschaft

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Marine Institute
Foras na Mara

CoNISMa
Consorzio Nazionale Interuniversitario per le Scienze del Mare

Consiglio Nazionale delle Ricerche

OGS

NIOZ
Royal Netherlands Institute for Sea Research

NWO
Netherlands Organisation for Scientific Research

INSTITUTE OF MARINE RESEARCH
HAVFORSKNINGSINSTITUTTET

The Research Council of Norway

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