Future Science Brief

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Strengthening Europe's Capability in Biological Ocean Observations

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Advancing Seas & Ocean Science

European Marine Board IVZW Future Science Brief 3

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This future science brief is a result of the work of the European Marine Board Expert Working Group on Biological Ocean Observations (WG BIO OBS - see list of WG members on page 65).

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Cover Picture: Colourful hotspot of marine biodiversity from a 23 x 16 cm photoquadrat in the North West Mediterranean.
Credit: Lisandro Benedetti-Cecchi

Foreword

The marine science community currently utilizes a wide array of biological ocean observation infrastructures, tools and techniques. These range from marine stations and taxonomic analyses to autonomous sensors, hydrophones, animal platforms, state-of-the-art laboratory facilities and -omics technologies. In Europe, there is recognition that the biological ocean observation component should be strengthened in tandem with renewed efforts to build a comprehensive, end-to-end, European Ocean Observing System[1] (EOOS). However, despite a growing appreciation of the value of marine ecosystem products and services, Europe's biological ocean observation capability lacks maturity and coordination and currently lags behind the physical and biogeochemical observation components.

This analysis helped the case for the European Marine Board to set up a working group on biological ocean observation (WG BIO OBS) in 2015. This was considered to be a timely foresight activity to strengthen Europe's biological ocean observing contribution to building a wider European Ocean Observing System (EOOS) and to international efforts for a sustained and integrated ocean observation system. Different experts on biological observation, oceanography, modelling, marine biology, ecology, biodiversity, biogeochemistry, sensor development and data management have worked intensively to deliver the document you are reading. This effort fits within a number of other ocean observation activities which are also gaining momentum in advance of the next international OceanObs[2] conference in September 2019.

On behalf of the EMB membership, I would like to congratulate the members of the EMB working group on biological ocean observation (Annex 1), contributing authors and reviewers for their contributions and dedication in delivering this Future Science Brief. Special thanks go to the Chairs of this group, Lisandro Benedetti-Cecchi and Tasman Crowe for their substantial efforts in compiling different ideas and finding common ground in the complex landscape of international and cross-disciplinary biological ocean observation. I also wish to thank past and present members of the EMB Secretariat, who enabled the publication of this document, namely Ángel Muñiz Piniella, Paula Kellett, Kate Larkin, Nan-Chin Chu, Karen Donaldson, Niall McDonough and Sheila Heymans.

The ocean and seas are complex systems and changes in marine biodiversity occur locally, regionally and globally at different time scales. Marine ecosystem and biodiversity observations are now considered crucial for understanding ecosystem change and the impacts of human and natural pressures on marine ecosystems. Enhancing our biological ocean observing capacity will, among others, strengthen the European impact on marine biodiversity conservation and enable the achievement of the Sustainable Development Goals. We are still at the start of a long road towards achieving a multi-purpose integrated biological ocean observing system for Europe. We hope this document provides a valuable synthesis and is a usable source of information for the ocean observing community.

Jan Mees
Chair, European Marine Board
July 2018

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[1] http://www.eoos-ocean.eu/

[2] http://www.oceanobs19.net/

Table of Contents

Executive summary

This publication is primarily aimed at stakeholders involved in ocean observing, spanning diverse roles from commissioning, managing, funding and coordinating, to developing, implementing, or advising on, ocean observation programmes. Such programmes will have strategic and policy drivers but their main purpose may vary from predominantly research-driven scientific purposes to environmental monitoring for providing data and reporting to legally-binding regulations or directives. The main focus is on European capabilities but set in a global context with the various actors spanning a variety of geographical scales from national to regional and European. Key stakeholder organizations include environmental or other agencies; marine research institutions, their researchers and operators; international and regional ocean observing initiatives and programmes; national, regional and European policy makers and their advisors; national stations for observations; etc.). It will also be of interest to the wider marine and maritime research and policy community.

The main aim of the publication is to increase the relevance of current (and future) European biological ocean observation capacity to strengthen global efforts towards our understanding of the ocean and enhance marine biodiversity conservation, for maintaining a healthy ocean for healthy societies.

This document explains why biological ocean observations are needed to assess progress against national and international conservation targets, the Sustainable Development Goals (SDGs), the Blue Growth agenda and to contribute to key EU directives including the Marine Strategy Framework Directive (MSFD). To achieve this, the publication highlights the need of biological ocean observations to reflect clearly defined hypotheses about potential causes of change, including the combined impacts of local and global drivers, and to support the management of our impacts on the ocean. Additionally, it calls for flexible biological ocean observing programmes to capture the relevant drivers operating at multiple spatial scales, by networking and integration of ongoing monitoring programmes, methodological standardization and appropriate policies of data integration and dissemination. It then presents key variables, elements and information products to inform on the status and trends of marine biodiversity.

The Future Science Brief finishes by recommending priorities for enhancing relevant and integrated current biological ocean observing capacity in Europe.

The main recommendations of this publication are to:

- Identify key steps for designing and implementing a strategic vision on biological ocean observations, bringing together key stakeholders, to provide the necessary long-term support to a balanced and integrated ocean observing system that is a direct contribution to the European Ocean Observing System (EOOS) and harmonized with the Global Ocean Observing System (GOOS);
- Move towards an integrated approach where expert knowledge is used to implement socially-relevant biological observations;
- Focus on multidisciplinary hypotheses and question-driven biological ocean observation collection and analysis at local and regional scales, and promote systematic network-based observations to evaluate the status and trends of marine biodiversity at the global scale;
- Design and maintain observation programmes at the appropriate spatial and temporal scales that address scientific objectives and meet the needs of environmental policy and practice, industry and wider society;
- Prioritize key questions where improved biological observations will have the largest impact: productivity and the extent of the most productive marine habitats, changes in biological diversity, environmental impacts, including population collapse, regime shifts, resilience and recovery.

Integrate biological ocean observations

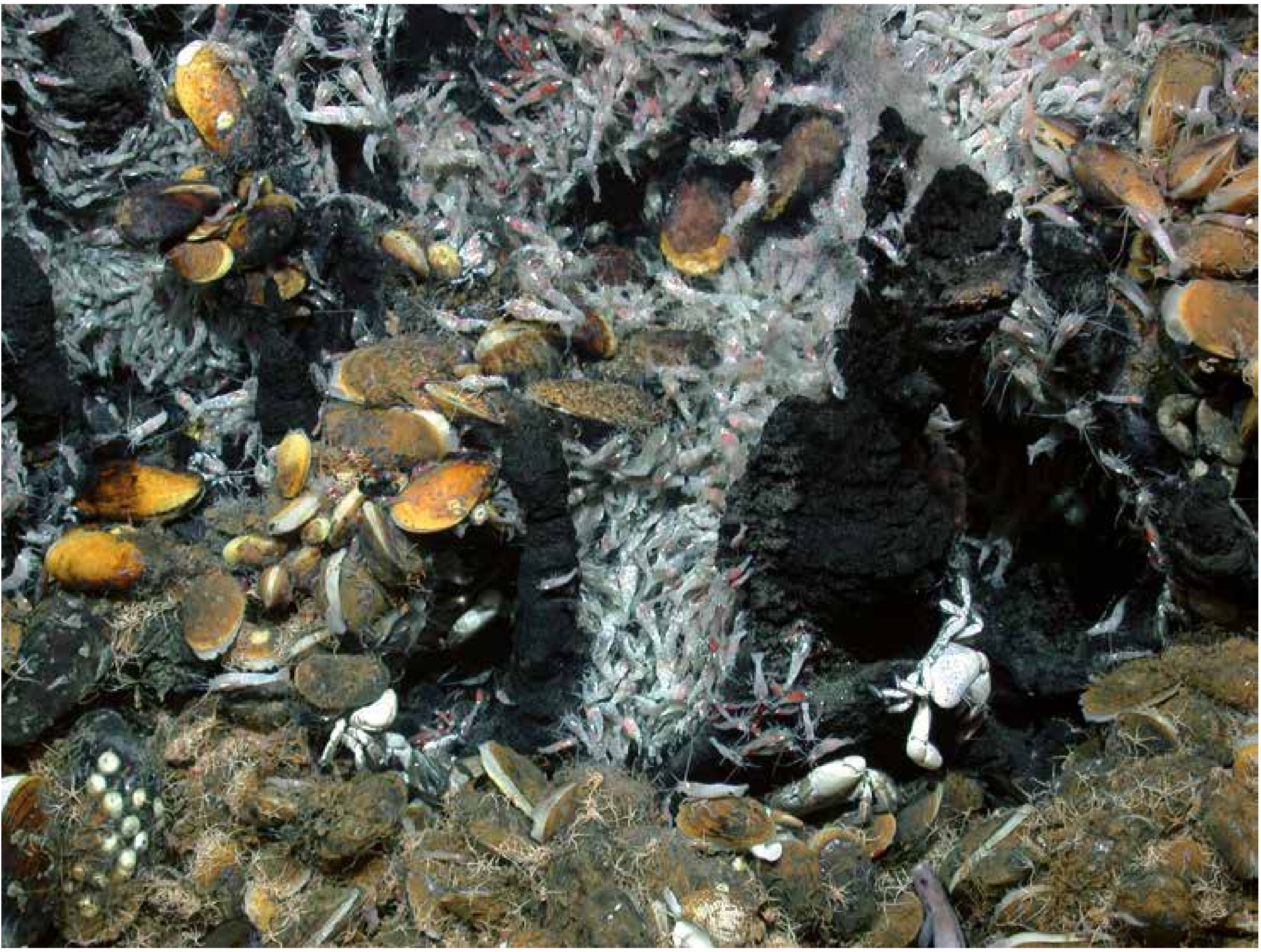
- Focus on Essential Ocean Variables (EOVs) and Essential Biodiversity Variables (EBVs), while supporting the collaboration between both GEO BON and GOOS frameworks, and considering additional variables where necessary;
- Coordinate and integrate observation programmes across scales (e.g. from coast to open sea), sources of data (e.g. fisheries programmes, Marine Protected Areas -MPAs, marine stations, satellites), habitats and taxa, and improve the connection between stakeholder communities and the use of shared infrastructure, protocols and data platforms;
- Improve coordination and integration of existing biological observation programmes with physical and chemical observing systems, technologies and modelling initiatives;
- Promote global integration through methodological standardization and best practices, allowing flexibility for biological observation programmes to match local and regional requirements.

Support current capacity on biological ocean observations

- Develop scientific capabilities to allow a greater knowledge of the biological ocean that can enhance the interpretation of data collected in observing systems, maximize their transformation into useful information and feed technological innovation;
- Support technological innovation to implement *in situ* biological observing systems and develop smart technologies for cost-effective automated monitoring of biological variables;
- Support capacity development, especially in taxonomic expertise and in the use of new emerging technologies, data science, analysis and management, as key components of biological observation;
- Promote Citizen Science, to improve observation capacity as well as increase the awareness of the importance of biological observations and their methods, to increase public confidence in science and potentially their emotional connectedness with the marine environment;
- Engage communities with observation programmes through collaboration, communication and education, to show the high value and benefits of monitoring marine ecosystems;
- Enhance biological ocean observing capacity to underpin sustainable management of human activities in the marine environment, to contribute to the achievement of key Sustainable Development Goals (SDGs) and to bring a wide range of benefits to society.

1 Why are biological observations needed?

Biological resources from the ocean and seas underpin human wellbeing in many ways and a range of policy initiatives have been proposed to promote the sustainable use and conservation of marine ecosystems. Biological observations[3] are needed to understand marine ecosystems and how they are changing. Such data and knowledge can be used for scientific research, to support the Blue economy, as environmental monitoring to produce base-lines, and assess progress against international conservation targets and agreements e.g. the Sustainable Development Goals (SDGs), and contributions to key EU directives including the Marine Strategy Framework Directive (MSFD).



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

Deep-sea ecosystems, such as this living community at hydrothermal seeps on the Mid-Ocean Ridge at a water depth of 3030m, have been only discovered recently and they are not yet fully understood.

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[3] Biological ocean observations are any data collected in a systematic and regular basis which are based on living ocean inhabitants.

Marine biological systems underpin a range of ecosystem services essential to society and human wellbeing, making extensive contributions to people (Díaz *et al.,* 2018). This is recognized, for example, in the United Nations Sustainable Development Goals, especially Goal 14 which aims to "Conserve and sustainably use the ocean, seas and marine resources" (Cormier & Elliott, 2017). Marine ecosystems are, however, sensitive to both local pressures and long-term global change, and multiple pressures can combine to affect ecosystems in unpredictable ways. We particularly lack a long-term perspective for many marine ecosystems. Knowledge on the status and trends in marine biodiversity, both at the habitat and species/population level is still very limited (EEA 2017, IPBES 2018). Sustainable use of ecosystems and management of our activities to enable their conservation requires a great improvement in our understanding of their natural dynamics, the effects of local and regional human activities and of long-term global changes. Observations and subsequent analysis of this data are one of the ways in which we can increase our understanding of ecosystems.

Biological ocean observations are any data collected in a systematic and regular basis which are based on a living ocean inhabitants. Biological ocean observations need to be combined and concurrent with physical and chemical observations at the adequate scale to help understand the structure and functioning of marine ecosystems, to determine patterns and trends and to inform the sustainable use of the ocean's living resources. Only by consolidating biological, physical and chemical observations into an integrated observing system will it be possible to really understand our changing ocean and its inhabitants, and to implement flexible management strategies that will adapt to evolving scenarios of societal and environmental change.

1.1 Why are biological observations needed for science and society?

Understanding marine ecosystems is crucial for sustainable management of the global ocean and its living and non-living resources, and to support sustainable and ethical economic development of marine and maritime industries. Society is becoming increasingly aware and connected with the global ocean and appreciating its vastness and complexity. However, ocean observation and monitoring of marine biodiversity and ecosystems are not yet fully integrated into high-level political agendas.

The marine realm has long been a source of wealth and inspiration. Throughout human history it has provided food, transport and recreation and has regulated our weather and climate. Today, these benefits are increasingly recognized. We appreciate the sea as an invaluable resource and are actively pursuing a Blue Growth agenda[4] to maximize the economic and social benefits it can provide, now and into the future. A valuation of global marine ecosystem services placed them at US$ 49.7 trillion per year (Costanza *et al.,* 2014). Ecosystem-based marine recreational activities alone generate US$ 47 billion a year and support one million jobs (Sumaila & Cisneros-Montemayor, 2010) and this is expected to increase significantly in the next decade (OECD 2016). The seas and ocean also play an essential role in global food security and human health, globally supplying 81 million tons of fish and shellfish from fisheries in 2015 and 27 million tons of fish and shellfish plus 27 million tons of seaweed through marine aquaculture (FAO, 2017a, FAO, 2017b), and harboring a wealth of bioactive substances of value for pharmaceutical purposes and the food industry. Some of the benefits we draw from the sea, such as inspiration and cultural enrichment, cannot easily be valued in monetary terms, but may be no less important to society (Halpern *et al.,* 2012).

Ecosystem services and societal goods and benefits are underpinned by ecosystem functioning and so depend on ecosystem components and their interactions (Elliott *et al.,* 2017; Turner & Schaafsma, 2015; Hooper *et al.,* 2012). It is acknowledged that environmental (climatic, physical and biogeochemical) conditions and the abundances of constituent species change naturally at a range of spatial and temporal scales. These changes and the causes behind them remain, however, poorly documented or understood, hindering our ability to predict ecosystem changes and their impact on the supply of goods and services to society (IPBES 2018).

Credit: Alpha Ventus/DOTI 2009

Many structures are installed in the sea and eventually decommissioned without really knowing the consequences for the ecosystems. More information is available in EMB Policy Brief No. 3 (2017).

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[4] https://ec.europa.eu/maritimeaffairs/policy/blue_growth_en

INFOBOX 1.1

Healthy ocean for healthy societies

Human wellbeing depends in many ways on a healthy ocean. The range of benefits that healthy ecosystems can provide has yet to be fully appreciated and new services are continuously documented. A recent study has shown that seagrass meadows can reduce exposure to bacterial pathogens of humans, fish and invertebrates, for example. Using cutting-edge genomic techniques in Indonesia, Lamb *et al.,* (2017) compared the microbiota between sites with or without intertidal seagrass meadows and found that the relative abundance of potential bacterial pathogens capable of causing disease in humans and marine organisms was 50% lower in the presence of seagrasses. Extensive surveys of approx. 8000 reef sites found that corals adjacent to seagrass meadows had a halving of bacterial loads compared to coral sites far from seagrasses (Lamb *et al.,* 2017). The generality of this service is yet to be established, but this study demonstrates how healthy seagrass meadows can effectively improve environmental quality and significantly reduce humans' exposure to pathogens.

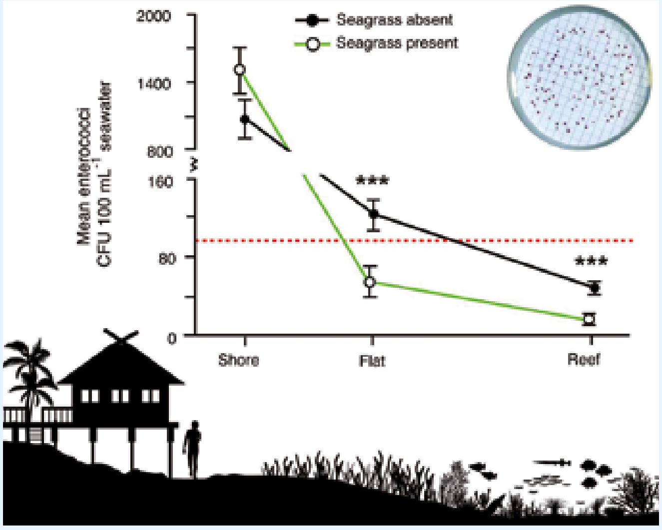

Figure 1.1 Seagrass meadows on intertidal flats reduce bacterial loads below the U.S. Environmental Protection Agency recommended human health risk exposure levels for a single water sample in recreational waters (dashed red line). From Lamb *et al.,* 2017.

The activities through which we derive benefits from the seas and ocean could also change them and introduce stressors that may affect marine life and the dynamics of marine systems (Crowe & Frid, 2015). For example, intense fisheries alter food web structures, driving a shift towards smaller fish; bottom trawling seriously affects the benthos and damages the seabed; shipping may transport non-native species in ballast water and as bio-fouling, which may become invasive and impact native populations; increasing nutrient loads from land uses may cause harmful phytoplankton blooms that threaten food security; and tourism and its associated coastal infrastructure changes coastal habitats. The energy transition also has as yet unknown impact on the sea with a steady proliferation of wind turbines and other structures (Slavik *et al.,* 2017). At the same time, long-term, large scale changes in climate and physical and chemical oceanic conditions are not only having dramatic effects in their own right, but are also combining with and modifying the impacts of local and regional stressors. The science of multiple, in-combination and cumulative effects is still in development, but combining multiple stressors in a given area can either magnify the impacts of each or reduce or nullify them (Crain *et al.,* 2008), making the overall outcome inherently difficult to predict and presenting considerable challenges for management.

To counteract the harmful effects of multiple drivers of change, a wide range of directives have been established by the European Union (EU) (see Section 1.2 for details). These require Member States to determine the current environmental status of their marine ecosystems, identify threats and establish programmes of measures to restore or maintain ecosystem health. Effective implementation of these directives is critically dependent on a good knowledge of patterns of variation in ecosystem structure and function, and an understanding of processes underpinning them at a range of temporal and spatial scales.

Many national and international initiatives have been (and still are) running to assess the physical, chemical and, to a lesser extent, the biogeochemical dynamics of the ocean (e.g. World Ocean Circulation Experiment (WOCE)[5], Joint Global Ocean Flux Study (JGOFS)[6]). This effort responded to the need to understand the role of the world ocean in the global carbon cycle and the mechanisms through which it may buffer the increase in temperature resulting from human activities. It has therefore mainly dealt with the open ocean. However, coastal systems still require attention because they are inherently complex, on society's doorstep and provide many benefits and are affected by various pressures. Large, international projects such as the Census of Marine Life (2000-2010) significantly advanced our discovery and understanding of marine biodiversity and ecosystems. In addition, there has been substantial European investment into ocean observing projects, including science, technology, innovation and coordination. However, sustained, integrated biological ocean observing is still not standardized or applied at the international scale. A biological observing system spanning both oceanic and coastal systems is of fundamental value in expanding knowledge of the world in which we live. It fulfils a critical strategic need for a more informed basis for environmental policy to safeguard our natural heritage and manage and plan its sustainable use by multiple users and stakeholders, bringing benefits now and for future generations.

A long-term, large scale integrative perspective is essential for understanding the context of current shorter term fluctuations appearing at different geographical scales and enabling us to make informed predictions of what the future may hold. The few existing long-term observation programmes for marine life, such as the Continuous Plankton Recorder (CPR)[7], have been invaluable in allowing us to recognize and understand the influence of climate change on our ecosystems, and to distinguish its signal from that of

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[5] https://www.nodc.noaa.gov/woce/

[6] http://ijgofs.whoi.edu/

[7] https://www.cprsurvey.org/services/the-continuous-plankton-recorder/

other influences (e.g. Reid *et al.,* 1998, Beaugrand *et al.,* 2008). Such insights are critical to our short- and long-term stewardship of the ocean. It is of note that the CPR data have been made freely available, providing an invaluable resource for scientists globally and an example for other observation programmes that have not yet embraced the open access philosophy. In this Future Science Brief, we argue for the maintenance of such existing programmes and the establishment of new programmes, carefully designed to address key long-term needs and hypotheses and provide strategic information about our current and future relationship with our seas and ocean.

1.2 What are the political drivers promoting ocean biological observations and their integration?

1.2.1 International

Given the value of marine ecosystems, the range of threats to them, and the lack of knowledge to support better policy and management for sustainable use, the United Nations (UN) declared the next decade (2021-2030) the “United Nations Decade of Ocean Science for Sustainable Development”. Additionally, in the UN 2030 Agenda for Sustainable Development[8], one of the 17 Sustainable Development Goals (SDGs) is specifically on life below water, SDG 14. In June 2017, the UN organized a conference to promote the implementation of this SDG and recognized the importance of the ocean in fulfilling the 2030 agenda and its 17 SDGs. The 17 overarching goals are subdivided into key targets, each with several supporting indicators. A number of these targets and indicators will be directly reliant on biological ocean observation data to demonstrate their achievement.

The 2009 International Ocean Information for Society conference (OceanObs’09) statement[9] invited governments and organizations “to embrace a framework for planning and moving forward with an enhanced global sustained ocean observing system over the next decade, integrating new physical, biogeochemical, biological observations while sustaining present observations”. The Framework for Ocean Observing (FOO) (Lindstrom *et al.,* 2012) recognized that the biological component of the Global Ocean Observing System (GOOS[10]) is much less well developed than its physical and biogeochemical counterparts.

Data on marine biodiversity and ecosystems, as obtained through biological observations, are also required in support of a vast array of assessments and conventions such as:

- The Intergovernmental Science-Policy Panel on Biodiversity and Ecosystem Services (IPBES);
- The Regular Process for Global Reporting and Assessment of the State of the Marine Environment Including Socioeconomic Aspects - World Ocean Assessments (WOA);
- The Intergovernmental Panel on Climate Change (IPCC);
- The UN Convention on Biological Diversity (or CBD Aichi Targets);
- The identification of Ecologically and Biologically Significant Marine Areas (EBSAs);
- The United Nations Convention on the Law of the Sea (UNCLOS) on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (BBNJ);
- The Convention for the International Council for the Exploration of the Sea (ICES);
- The Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR);
- The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES);
- The Convention on the Conservation of Migratory Species (CMS).

This data can either be used directly as supporting evidence for assessments, or as a means to inform how European policy and legislation are achieved (Miloslavich *et al.,* 2018).

1.2.2 European

At the European level, the EU has established a range of statutory/regulatory/legislative instruments for the management of human activities in marine environments and for the conservation of habitats and species. These are summarized in Figure 1.2 and outlined below in relation to fisheries management, conservation, maritime spatial planning (MSP) and environmental quality. Note that this simplified summary belies a far more complex array of legislative instruments (Boyes & Elliott, 2014).

Fisheries Management

The Common Fisheries Policy (CFP) sets out the framework for managing European fishing fleets and for conserving fish stocks. The CFP was first introduced in the 1970s and its most recent update took effect in 2014. It aims to ensure that fishing and aquaculture are environmentally, economically and socially sustainable and that they provide a source of healthy food for EU citizens. The 2014 reform of the CFP adopted a cautious approach which recognizes the impact of human activity on all components of the ecosystem and has provided funding for improving knowledge of seas and ecosystems.

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[8] https://sustainabledevelopment.un.org/post2015/transformingourworld

[9] http://www.oceanobs09.net/proceedings/statement/

[10] The Global Ocean Observing System (GOOS) is developing a 10-year strategy. The GOOS 2030 Strategy will be published soon. http://www.goosocean.org/

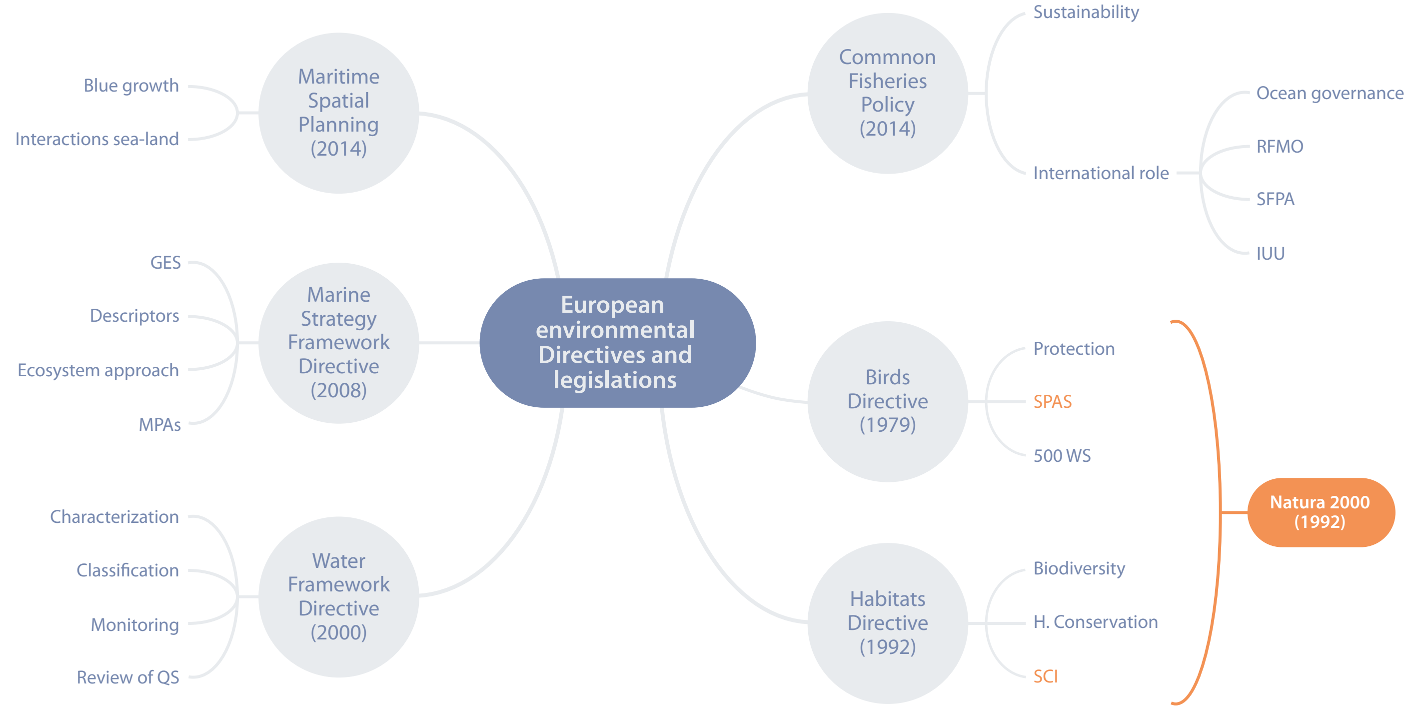

Figure 1.2. A summary of key EU legislation which requires biological observations of seas and ocean. Directives and their requirements for observation are outlined in the text. GES = Good Environmental Status, MPAs = Marine Protected Areas, QS = Quality Status, RFMO = Regional Fisheries Management Organization, SFPA = Sea Fisheries Protection Authority, IUU = Illegal, Unreported and Unregulated fishing, SPAs = Special Protection Areas, WS = Wild Species, SCI = Sites of Community Importance. Modified from E. Astoricchio, M. Caracciolo, G. C. De Lauro, D. Gallo, N. Lago, M. Mammone, students of the course Marine Biodiversity and Ecosystem Functioning of the Master Programme in Marine Biodiversity and Ecosystem Functioning of the University of Salento, under the supervision of Ferdinando Boero.


Credit: Ifremer - Olivier Dugornay

Deep-sea bottom trawl fishing in the North Sea with a fishing trawler of 23 meters long. Fisheries regulations include gathering of data that could be useful for scientific purposes.

Europe is strongly involved in the bodies established under the United Nations Convention on the Law of the Sea (UNCLOS) and the UN Fish Stocks Agreement (UNFSA), notably the Food and Agriculture Organization of the United Nations (FAO) Committee on Fisheries and the Regional Fisheries Management Organizations (RFMOs). RFMOs are international organizations formed by countries with fishing interests in a given area and they agree control measures towards sustainable exploitation of the marine species covered in their remit. The EU plays an active role in 6 tuna RFMOs and 11 non-tuna RFMOs.

Good fisheries management relies on awareness, compliance and enforcement. Sufficient and reliable data must be collected, managed and supplied by Member States. For setting European fishing quotas, extensive data on fish stocks, and associated species are also collected, collated and reported on by the International Council for the Exploration of the Seas (ICES) in the wider Atlantic and the General Fisheries Commission for the Mediterranean (GRCM)[11].

Conservation

In the European Union, nature conservation has been based substantially on the requirements of the Habitats Directive (92/43/EEC)[12] and the Birds Directive (Directive on the conservation of wild birds, 79/409/EEC)[13]. The Habitats Directive provides for the creation of a European network of Special Areas of (SACs).

[11] http://www.fao.org/gfcm/en/

[12] http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm

[13] http://ec.europa.eu/environment/nature/legislation/birdsdirective/index_en.htm

INFOBOX 1.2

G7 Science Ministers' activities on the 'Future of the Seas and Oceans'

The G7 Science Ministers at their meeting in Tsukuba (2016) recognized the 'Future of the Seas and Oceans', and the knowledge about the status of the ocean and its changes as key priorities. Groups of experts were given the mandate to develop plans towards a better coordination among existing observational activities coupled with the development of regional observing capabilities, the integration of new approaches and the improvement of global data sharing infrastructures. The improvement of observations required to monitor *inter alia* climate change and biodiversity was mentioned upfront among the actions endorsed by the Ministers. To address this issue, the technical experts highlighted the need for a deeper understanding of our ocean and seas and suggested the continuation of existing observations that are augmented by new technologies in an integrated, coordinated and consistent way that also helps to close existing gaps.

The experts also recommended that:

- The G7 work collectively to establish sustained funding mechanisms that are essential to maintain and extend the existing global ocean monitoring and observing systems in accordance with national research priorities and budgets.
- The G7 members establish a Global Ocean Observing System (GOOS) Implementation group to liaise with and support GOOS whilst coordinating enhancements to G7 observing.
- The G7 develop a strategy for extending observations focused on high-priority areas and develop associated road maps for the next 5 years.

These recommendations were welcomed by the G7 Science Ministers at their meeting in Turin (2017). At the Charlevoix 2018 Summit, a Blueprint for "Healthy Oceans, Seas and Resilient Coastal Communities"[14] was endorsed by the G7 countries, committing to "expand global observation and tracking efforts; and to improve the availability of data through enhanced global monitoring of oceans, and coordinating access to ocean science information".

The directive lists priority natural habitat types and priority species that member countries should specifically consider when designating special areas of conservation (Habitats Directive, 92/43/E). The Directive is structured around a series of Articles and Annexes; of which several are particularly relevant to this Future Science Brief. Article 6, for example, provides that the Member States have to take steps to avoid deterioration of SACs which would compromise the directive's objectives. The aim of these directives is to set conservation objectives for the designated habitats. It also requires the assessment of proposed projects that can have significant effects on the sites or species either on their own or in combination with other projects and ensure that the designated habitat is not adversely affected. Article 17 requires Member States to report on the implementation of measures required by the Habitats Directive every sixth years, which requires data to be collected about the protected habitats and species. Difficulties can arise in establishing current extent and quality of habitats and populations and in setting acceptable limits to degradation against unknown levels of natural variation for many key habitats and species (Crowe *et al.*, 2011). Non-compliance by member states can result in judicial proceedings.

The Birds Directive was adopted in 1979 with the aim of protecting 500 wild bird species. The inclusion of many migratory birds requires cooperation across borders. Member States maintain a continuous communication with the European Commission, which uses the data from different states to revise and implement the Directive. Member States must designate Special Protection Areas (SPAs) targeting species listed in Annex 1 of the Directive. Many migratory species included on the list are marine, such as the Slender-billed gull (*Larus genei*). Annex 2 restricts hunting of 82 species, including marine species such as the common gull (*Larus canus*), the Herring gull (*Larus argentatus*) and the Great black-backed gull (*Larus marinus*), which is also on the IUCN Red List of Threatened Species[15]. In Annex 5, the directive promotes research to improve the protection and management of all species of birds.

The combination of SACs established under the Habitats Directive and SPAs established under the Birds Directive constitute the Natura 2000 network of protected areas in Europe. To date more than 3000 marine Natura 2000 sites have been designated in Europe, which cover more than 5% of the total EU marine area and provide protection in a range of coastal habitats (mainly shallow coastal areas) and for a range of species covered by the Directives.

Good Environmental Status

The Marine Strategy Framework Directive[16] 2008/56/EC (MSFD) is arguably the single most important legislative instrument driving management of marine environmental quality in Europe. The objective of the MSFD is to maintain or achieve good environmental status (GES, see Box 1.3), and clean, healthy and productive marine

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[14] https://g7.gc.ca/en/official-documents/charlevoix-blueprint-healthy-oceans-seas-resilient-coastal-communities/

[15] http://www.iucnredlist.org/

[16] hhttp://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive/index_en.htm

waters compatible with the provision of goods, services and human wellbeing. The MSFD is grounded in the ecosystem-based management approach, which considers people as part of the ecosystem and involves using scientific knowledge as the basis for the protection and sustainable use of the marine environment (Borja *et al.,* 2017) and for prioritizing and applying management actions. It focuses on 11 ecosystem descriptors (Box 1.3) for which an extensive set of scientifically based indicators have been defined (Teixeira *et al.,* 2016; Zampoukas *et al.,* 2012).

In coastal and transitional waters out to 1 nautical mile, the MSFD is complemented by the Water Framework Directive[17] (WFD), which establishes a framework for the protection of all waters including rivers, lakes, estuaries, coastal waters and groundwater, and their dependent wildlife/habitats under one piece of environmental legislation. It defines water as a heritage that must be protected and defended. This Directive summarizes all the previous Directives that were concerned with protecting biodiversity (Birds and Habitats Directives), the use of water (drinking water, bathing waters and urban waste water directives) and the regulation of activities undertaken in the environment (industrial emissions and Environmental Impact Assessment directives). It has a focus on water management based on types of water resource and activities in river basins and introduced minimum water quality standards from ecological and chemical perspectives, termed good ecological status and good chemical status. The WFD led to the development of tools for indicating ecological status based on the biota present and drives extensive compliance monitoring of the majority of European coastal and transitional waters across Europe.

Maritime Spatial Planning

The rapidly increasing demand for maritime space for the production of energy from renewable sources, shipping and maritime exploration, fishing activities, aquaculture, tourism and recreation has led to the need for an integrated planning and managing approach for European waters (Elliott *et al.,* 2018). The Maritime Spatial Planning Directive[18] 2014/89/EU (MSP) works across borders and sectors and aims to ensure that human activities take place in a safe and sustainable way. In order to do so, it brings together all users of the ocean on how to make informed and coordinated decisions on the use of marine resources. MSP aims to promote Blue Growth[19], enabling sustainable use of marine areas and resources, taking into account social, economic and environmental aspects. Its effective implementation requires long term data on ecosystem changes associated with combinations of multiple proposed activities and the pressures they exert.

Credit: Josef Stuefer

Stable and healthy ecosystems, such as seagrass meadows, often yield in high biodiversity associated to these.

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[17] http://ec.europa.eu/environment/water/water-framework/index_en.html

[18] https://ec.europa.eu/maritimeaffairs/policy/maritime_spatial_planning_en

[19] https://ec.europa.eu/maritimeaffairs/sites/maritimeaffairs/files/swd-2017-128_en.pdf

INFOBOX 1.3

Biological observations needed under the EU's Marine Strategy Framework Directive (MSFD)

The first descriptor of MSFD's Good Environmental Status (GES) requires that biodiversity is maintained. This establishes the need for a reference state of biodiversity, and requires the state of biodiversity to be measured. Biodiversity in all EU waters must be above a given threshold, or action should be taken to improve the state of the descriptor. The EU scientific community does not have sufficient species identification expertise, and therefore, it will be important to invest in capacity building.

The second descriptor requires that non indigenous species do not affect ecosystems. This first requires the recognition of non-indigenous species among the array of indigenous species, calling for a thorough knowledge of global species diversity (non-indigenous species can come from areas distant from the ones in which they exert their impact). Then their effects on the functioning of the ecosystem must be assessed in order to determine the priority that should be given to their control. The actions carried out for the assessment of descriptor 1 (biodiversity) are conducive to identifying the agents of descriptor 2 (non-indigenous species).

The state of ecosystems can be impacted by direct extraction of natural resources, the most prominent being fisheries. Descriptor 3 requires that the population of commercial fish is healthy. Fish are a part of biodiversity, so the assessment of the health of their populations also falls under descriptor 1. Descriptor 3, however, calls for a special focus on commercial species, and on the impacts of fisheries.

Descriptor 4 passes from structure (biodiversity) to function, in the form of food webs. Species assemblages are required to be structured in balanced food webs. The presence of large top predators (e.g. sharks) is a sign of good condition in trophic webs. However, non-fished species can also play the role of top predators, for instance seals, dolphins and orcas. If predators are removed, they might be replaced by other species (for instance jellyfish replacing fish), and the state of food webs will be affected.

Although descriptors 5-11 focus primarily on reducing the prevalence of stressors, such as nutrients, litter, noise or alteration of hydrographical conditions, each is framed in terms of reducing harm to ecosystems. The stressors might be measured with standard methods (e.g. the presence of contaminants) but then it is required to assess the state of ecosystems based on the nature of their impacts. As such, it is necessary to monitor the state of ecosystems and their biological components to ensure compliance with the directive.

Legislative requirements for integrated observations and a regional approach

Informed decisions about priorities and interventions need to be guided by understanding natural change and the impacts of activities that can be managed. As such, the EU directives outlined above have underlined the need to establish observation systems to ensure the knowledge needed to support management for attaining and maintaining healthy marine ecosystems and the sustainable use of the resources and services they provide to society (Heip & McDonough, 2012).

The Regional Sea Conventions (RSCs) pre-date the MSFD and comprise a significant framework for regional cooperation in environmental monitoring and management. Europe's Regional Sea Conventions: The Baltic Marine Environment Protection Commission - Helsinki Commission (HELCOM[20]), the Convention for the Protection of the Marine Environment of the North-East Atlantic (Oslo-Paris Convention, OSPAR[21]), the Barcelona Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (UNEP/MAP[22]), and the Bucharest Convention on the Protection of the Black Sea Against Pollution – Black Sea Commission (Bucharest Convection[23]); are committed to achieving healthy oceans and have sustained monitoring programmes at regional level which will support several European policies and the growing demands for sustainable use of resources.

However, Member States' use of the outcomes of regional cooperation within their marine strategies varies. This has resulted in a lack of coherence among EU countries, even within the same marine region or sub-region. This problem is particularly acute in the Mediterranean and the Black Sea. Article 11 of the MSFD, for example, provides legally-binding requirements for Member States to establish and implement monitoring programmes for the ongoing assessment of the environmental status of marine waters. Such programmes are described in MSFD Annex 5, stating that they should be compatible within marine regions or sub-regions and that Member States sharing a marine region or sub-region should, in the interest of coherence and coordination, ensure that monitoring methods are consistent across the marine region or sub-region, to facilitate comparability of monitoring results. These requirements, however, have not been well met during the first phase of MSFD implementation (Elliott *et al.,* 2015).

ActionMed[24] demonstrated that although national monitoring plans exist in the Mediterranean, the absence of international coordination has resulted in a high degree of heterogeneity in their structure and coverage. To overcome this heterogeneity, a common list of elements to be monitored and the corresponding indicators should be agreed at sub-regional level, to ensure the feasibility of a Mediterranean GES assessment, taking advantage

[20] http://www.helcom.fi/

[21] https://www.ospar.org/

[22] http://web.unep.org/unepmap/

[23] http://www.blacksea-commission.org

[24] http://actionmed.eu/

of other monitoring programmes implemented in the region, such as those related to the Water Framework Directive, Common Fisheries Policy and MEDPOL[25] program, whose indicators have generated a comparatively high level of consensus among Mediterranean countries[26].

1.3 How mature are biological ocean observations compared to physical and biogeochemical observations?

Physical data are solicited by many economic and military sectors; therefore, more investment has been directed towards the implementation of the physical ocean observing system. The physical system infrastructure is often more automated - it needs less human intervention (e.g. satellites, underwater and autonomous systems, buoys, moorings). Satellites are costly to develop, but produce continuous data streams. Physical observations can be posted in real-time or with minimal time lag. This increases usability and attracts more investments into developing physical observation infrastructure.

Biogeochemical observations are needed to understand the role of nutrient, carbon and elemental cycling in the ocean and how these are changing due to human and environmental pressures and future trends in different climate change scenarios (e.g. carbon storage) and how the ocean is impacted by climate change (e.g. ocean acidification) or human activities (e.g. eutrophication, pollution). There are currently efforts to coordinate the biogeochemical observations, such as the International Ocean Carbon Coordination Project (IOCCP) for carbon-related observations; however, these are not as well advanced as physical observation.

Biological observations are often complex to measure. Whilst some automated sensors are now available, most biological measurements are taken by automated samplers or by obtaining water or sediment samples from the marine environment by a research vessel with post-sample processing at a coastal marine station or oceanographic laboratory – all of which require high input and capability from a skilled workforce. For these reasons, the price-tag per bit of information is greater than for physical data, although more automated cost-effective tools are being developed (see Section 4). Apart from the cost, biological observations need a significant amount of time to process and often interpret, which is an important barrier when it comes to operational practices (the time required to get the information from the sample is often greater than the time scale of the process being observed).

The dynamics of marine physics are understood from first principles, and most processes are well understood and parameterized. The physical system is quite accurately described by relatively few state variables (e.g. temperature, salinity and current) and primary equations with well-defined dynamics; therefore, the data-modelling infrastructure is consolidated and focused. Although coastal systems are complex and remain challenging to model, the physical state of the ocean can generally be predicted with acceptable certainty. As such, in physics we know which aspects of variability are important and which variables to focus on for observation. The ecosystem state in terms of biota is characterized by greater intrinsic complexity at a range of scales and by hierarchies of interacting components (individuals, populations and communities). In biology, the uncertainty about what to measure to give the best information about ecosystem state is much greater. There has been a tendency to quantify what is feasible to measure, e.g. size, abundance and distribution of tractable organisms, and we lack measurements of potentially more important variables which may be more difficult to measure, although recent progress is promising (see Section 1.4).

1.4 What is the way forward?

Given the need for better understanding of ocean and coastal ecosystems, the benefits they provide and the threats they are facing, there is a clear need for increased investment in biological observation systems. Having established a good level of understanding of the physical system, it is now imperative that we improve understanding of the biological elements of ocean ecosystems. Doing so requires extensive observational data. Existing data currently supporting biodiversity assessments vary at a range of spatial and temporal scales, often severely limiting our capacity to understand the intensity, drivers and consequences of biodiversity change, and to assess the effectiveness of management measures. The availability of technology to enable more cost-effective collection of larger volumes of biological data is improving, but investment is needed to ensure that the most effective approaches are deployed widely and in a coordinated fashion. Ultimately a programme is required which integrates observation of biological, physical and biogeochemical aspects of ocean ecosystems and establishes standardized approaches so that data can be shared, synthesized, analyzed and interpreted from a large scale, long term, whole-system perspective.

Ocean observation must be taken across disciplines, as physical forces induce biological and chemical effects, which in turn mediate other (sometimes severe) biological changes, in some cases feeding back into physical changes. Comprehensive observing systems must be interoperable to enable studies across different science domains and observing regimes. Multiple science communities must likewise interact to provide a coherent, integrated view of the results. The upcoming OceanObs'19[27] international conference in 2019 will help galvanizing the ocean observing communities and will chart the next decade of ocean observing by connecting observers with users.

A key step in developing such a balanced and integrated programme is the agreement of key variables on which to focus coordinated observation programmes.

[25] http://web.unep.org/unepmap/keywords/med-pol-programme

[26] http://www.devotes-project.eu/european-seas-keystone-species-catalogue-and-review-report/#KYCatalogue

[27] http://www.oceanobs19.net/

INFOBOX 1.4

An example of complementing existing ocean observations

FerryBox[28] is an automated measurement system for determining physical and biogeochemical variables in surface seawater. FerryBoxes are installed on board commercial vessels cruising along regularly scheduled routes (e.g. on ferries or liner shipping). FerryBox routes presently consist of commercial container and passenger ships that operate in key coastal regions including the Norwegian coast and fjords, Baltic Sea, North Sea, and parts of the German, French, Spanish, and Greek coastlines.

FerryBoxes offer high frequency data, in particular in areas which are used by the fishing and aquaculture industries. For example, Norwegian coastal and fjord waters are important spawning grounds for Atlantic cod but these areas also host more than 1000 finfish aquaculture sites that produce more than 1 million tons of salmon per year (about half of all global farmed salmon), much of which provides protein for other European countries. Both the fishery and aquaculture industry are susceptible to fluctuations in physical conditions (e.g. temperature, salinity, mixing), chemical conditions (e.g. nutrient concentrations, pH, contaminants), and biological conditions (e.g. harmful algal blooms, presence of fish and shellfish parasites/viruses). Poor characterization and understanding of the temporal and spatial scales at which these biological and physicochemical conditions change, in combination with uninformed management, could have significant negative effects on the fisheries and aquaculture operations. The high spatial and temporal frequency of data collected by FerryBox systems are providing real-time information for nearby aquaculture and fishing operations.

The FerryBox system is an ideal mean to provide long-term and high-frequency physical and biogeochemical data to support any biological observations in a specific area at significantly reduced cost compared to other approaches. In addition, FerryBox systems still have major opportunities for improvements in biological variables. The addition of advanced biological and chemical sensors could assist industries in identifying and warning of adverse conditions and mitigate potential negative impacts.

The concepts of Essential Biodiversity variables (EBVs), similar to Essential Ocean Variables (EOVs), have been proposed to facilitate the task of identifying key variables for marine biological observations (Miloslavich *et al.,* 2018, Navarro *et al.,* 2017). EOVs have been introduced by GOOS to rationalize data collection, facilitate data dissemination and maximize data utilization. The biological component of GOOS is still in a conceptual phase for many elements (phytoplankton, fish and marine turtles, birds and mammals for the global ocean and seagrass, macroalgal and mangrove communities for coastal domains) and in a pilot phase for others (zooplankton and live coral) (Palacz *et al.,* 2017). In contrast, the physical and biogeochemical components of GOOS are considered to be mature. EBVs have been introduced to promote sustained and operational monitoring of marine biodiversity by the Marine Biodiversity Observation Network, (MBON), which is part of the Group on Earth Observations Biodiversity Observation Network (GEO BON). MBON and the GOOS Biology & Ecosystems Panel (GOOS BioEco) have developed the implementation of biological EOVs and marine EBVs and increased the number of monitoring programmes that include these variables (Miloslavich *et al.,* 2018; Muller-Karger *et al.,* 2018). These initiatives and variables will be discussed in more detail in Section 4. In Europe, there is also recognition that the biological ocean observation component should be strengthened in tandem with a renewed effort to build a comprehensive, end-to-end, European Ocean Observing System[29] (EOOS). It is vital to bring together and connect the different marine and maritime stakeholders (from research to environmental monitoring and industry) collecting biological ocean observations to drive efficiency and cost-effectiveness (see Box 3.2).

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[28] https://www.ferrybox.com/

[29] http://www.eoos-ocean.eu/

2 What questions do biological observations need to address?

The ocean and seas are complex systems. Our lack of understanding of these systems precluded accurate predictions. Biological observations need to reflect clearly defined hypotheses about potential causes of change, including the combined impacts of local and global drivers, and to support the management of our impacts on the ocean.

The ocean and seas are undergoing rapid changes in response to intensifying human activities from local to global scales. There is a general consensus on the most pressing questions that need to be addressed by sustained biological observations to understand how these changes affect human wellbeing (Mason *et al.,* 2017; Fig. 2.1). There is the need to address the sustainability challenge and to link biodiversity with ecosystem services (Díaz *et al.,* 2018) through the transdisciplinary integration of natural, economic and social sciences (Rudd, 2014; Rivero & Villasante, 2016; Lacroix *et al.,* 2016; Mason *et al.,* 2017).

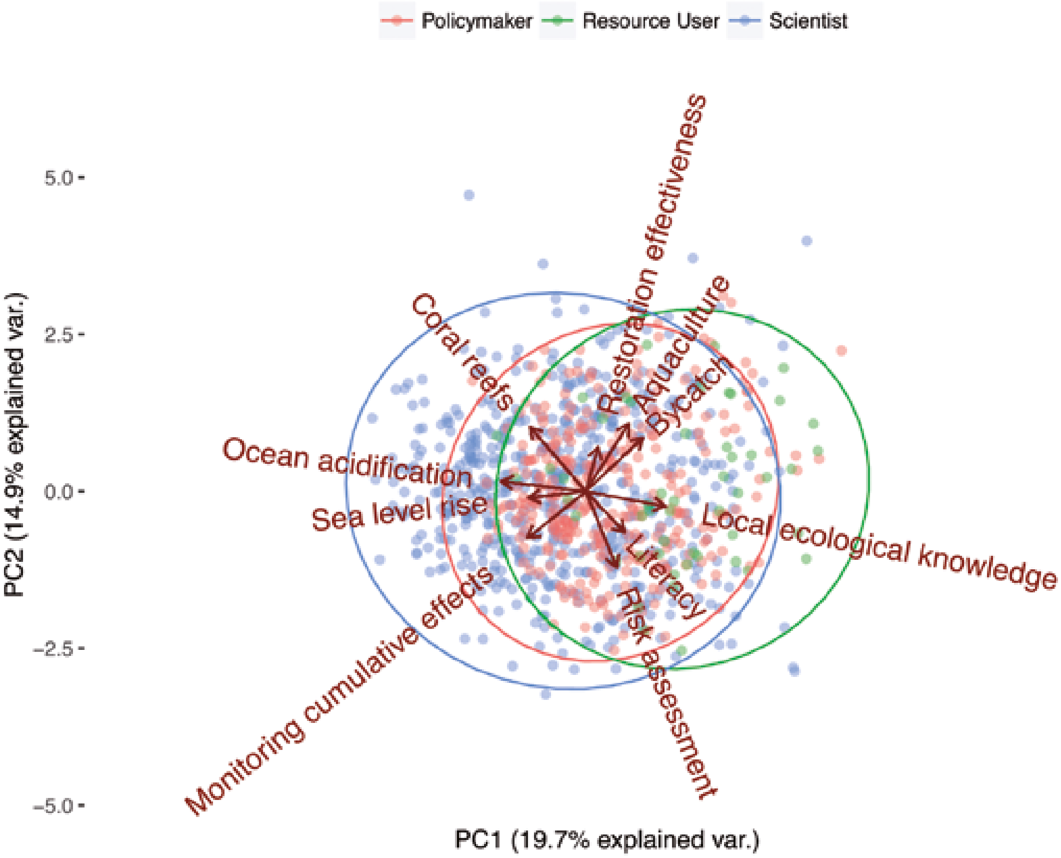


Figure 2.1 Results of a survey in the U.S. on ocean-research priorities identified by marine scientists. Using Principal Component Analysis (PCA), the datasets are displayed graphically as two principal components (PC1 and PC2) relating to the percentage of variance between stakeholder groups agreement where the maximum of variation was detected. Red arrows and red legends in the graph demonstrate large agreement among different stakeholder groups, along with some differences. While scientists tend to favour research questions about ocean acidification and marine protected areas, policy-makers prioritize questions about habitat restoration, bycatch and risk assessment; and fisheries resource users call for the inclusion of local ecological knowledge in policy-making. These results highlight the need to combine different types of knowledge in the co-design of solutions-oriented research, which may facilitate cross-sectoral collaboration. From Mason *et al.,* 2017.

Biological observations should reflect clearly defined hypotheses at local and regional scales. Constraining the spatial and temporal distribution of observations to address *a priori* defined questions will be needed unless technological advances enable the acquisition of biodiversity at high resolution and over large spatio-temporal extents (akin to satellite observations of the ocean surface). As this kind of data becomes increasingly available through observation networks and new methodologies (e.g. eDNA), a more systematic (less question-specific) approach to evaluating the status and trends of biodiversity at the global scale will be possible. GOOS, in its strategic mapping, recommends to prioritize areas where improved biological observations will transform our current understanding of the ocean.

At the global scale, the main questions that biological observations need to address are: the productivity of the ocean, regime shifts, population collapses and mass mortalities, resilience and recovery, and the consequences of biodiversity loss for ecosystem functioning and services in response to the cumulative impacts of multiple stressors including ocean warming, overfishing and acidification. More specific questions can be asked in relation to geomorphological, climatic, ecological and social issues that may vary at regional and local scales. Examples include the consequences of reduction of ice cover in polar seas, the impact of harmful algal blooms and coastal eutrophication on aquaculture and changes in aesthetic values of the marine environment in areas important for tourism and recreational activities.

Local and regional environmental drivers may mitigate or exacerbate the effects of global change eliciting contingent responses of biodiversity. For example, ocean warming may exacerbate the effects of eutrophication by enhancing microbial activity thereby precipitating a system into an anoxic state (Doney, 2010). Similarly, the effect of ocean acidification may be exacerbated (or alleviated) by low (or high) food availability for calcifying organisms (Kroeker *et al.,* 2016). Knowledge of these interactive environmental mosaics is key to understanding large-scale patterns of marine biodiversity originating from the interplay of multiple stressors.

At any spatial scale, ocean observations should reflect two distinct but intertwined time dimensions, one concerning the current status of marine biodiversity and ecosystem functioning and the other their trends in response to escalating human impacts. Knowledge of the current status is necessary to support spatial planning, to promote informed management of the multiple uses of marine resources and to provide a baseline against which change can be measured and interpreted. Evaluation of the current status

INFOBOX 2.1

Biological ocean observations are needed to understand our changing ocean

An integrated, sustained biological observing system is necessary to capture and forecast the variety of 'ecological surprises' that we may expect to detect in our changing ocean. Biological outbreaks such as mucilage from plants and microorganisms, jellyfish (Boero, 2013), coral bleaching events and harmful algal blooms are now recorded more frequently along our coasts and in the open ocean. Only in recent decades have biological outbreaks been recorded sufficiently frequently to be perceived as a problem, with the potential to cause severe impacts to fisheries, tourism, aquaculture and to threaten human health. Networks of biological observatories are needed to identify where these events occur, and their temporal and spatial evolution and then link these *a priori* to management actions and measures.

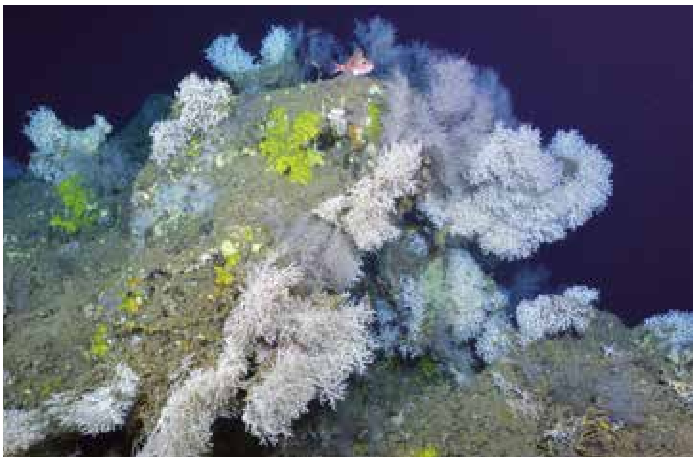
Viewed in a broader spatial and temporal context, spatial contingencies may reveal more complex structures, such as fronts, travelling waves, mosaics (patchiness) and trends. Distinguishing among these spatial structures and their temporal evolution may help to reveal the underlying processes and increase predictive capability, as is the case for epidemics, where spatio-temporal modelling allows for a more precise evaluation of the risk of infection and disease. Biological observations need to be performed sufficiently frequently in time and space to accurately describe the status and trends of marine biodiversity and to inform management on changes that directly affects the economy and society.

Credit: L. Benedetti-Cecchi

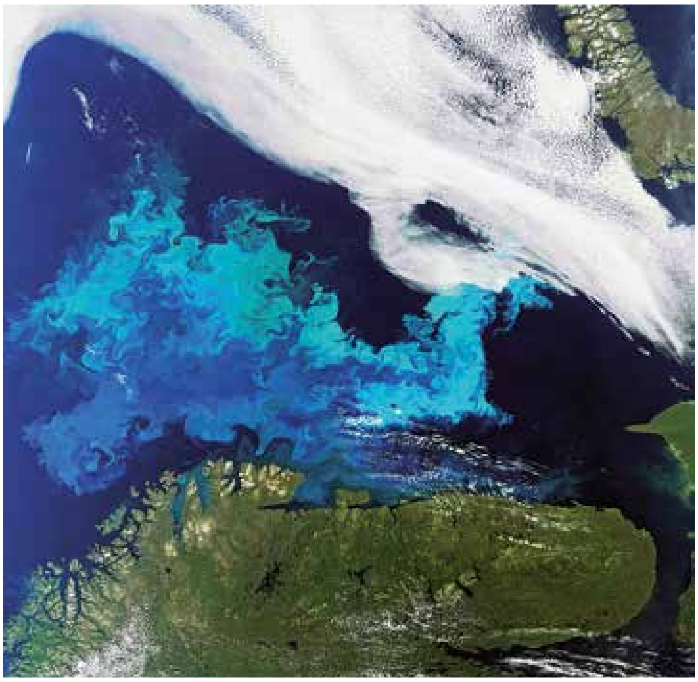
Outbreak of mucilages at Elba Island in the Tuscan Archipelago.

of marine biodiversity is required by the EU under the MSFD, which encourages the adoption of an integrated ecosystem approach for the assessment of good environmental status (GES). Having agreed on the goal to maintain a healthy ocean, in order to continue to societal goods and benefits from its ecosystem services (Turner & Schaafsma, 2015), biological observations need to address questions related to the descriptors and indicators of GES (Box 1.3). Many of these indicators are centered around biodiversity, which should be maintained at referenced conditions, minimizing impacts and securing balanced food webs and healthy commercial fish populations. Questions on good environmental status should also address the problems caused by increasing levels of eutrophication and the impacts of human activities on the seafloor and the ocean in general. Ideally, an appraisal of the current status of the ocean should allow mapping and distinguishing between heavily impacted and more pristine regions, polluted sites in need of reclamation versus areas which could safely host aquaculture operations, sites appropriate for marine protected areas or where restoration can be most effective, and areas where sustainable fisheries may be implemented (Borja *et al.,* 2016).

The questions that biological observations should address to fulfil the goals of GES are numerous and varied, and may change with increased understanding of the marine environment. For example, until a few years ago there was little awareness of the effects of plastic substances of different compositions and sizes (such as microplastics) on marine life, whereas the current evidence of their abundance in the sea has generated the impetus to monitor microplastics and to address their role as substratum for microbial life and their fate in food webs. The first implementation of the MSFD has also demonstrated that, in addition to the widespread lack of data in large areas of European seas, there are still many gaps in our understanding of the marine ecosystems which prevent a reliable assessment and an evaluation that is comparable among different European sea basins.


Credit: Ifremer/HROV

Cold water coral ecosystem, with a rockfish *(Helicolenus dactylopterus)* overhanging a white and black coral forest, during the Hybrid ROV Ariane expedition at a depth of 222 meter. Cold water corals ecosystems are endangered by ocean acidification.


Credit: European Space Agency - ESA

Most sustained biological observations are sea-surface based. In the picture a Phytoplankton bloom captured by the Envisat satellite.

Trends in biodiversity and ecosystem functioning occur at a hierarchy of temporal scales and a key question is how biological observations can be designed to capture these multiple levels of variability (Strong *et al.,* 2015). Long-term observations spanning multiple decades are needed to separate effects of global processes (e.g. ocean warming and acidification) and of sustained human activities (e.g. fisheries) from those of natural fluctuations in the physical environment (e.g. El Niño phenomenon). At the opposite end of the temporal spectrum, over time scales of months or a year, biological observations are needed to capture responses to sudden episodic events such as heatwaves and human hazards (e.g. oil spills) that can have long-lasting effects on marine life. At intermediate temporal scales (5-10 years), observations should quantify the response of ocean biodiversity to recurrent, albeit infrequent events such as hurricanes or tsunamis and, perhaps more importantly, to assess the recovery ability of ocean biodiversity from impacts occurring at any temporal scales (Elliott *et al.,* 2014).

Loss of certain species typically results in large-scale changes in biodiversity and ecosystem functioning, called regime shifts. Such regime shifts have been increasingly documented for exploited marine ecosystems globally, such as the North Atlantic Ocean (Beaugrand *et al.,* 2008), the North Sea (Reid *et al.,* 2001; Beaugrand and Ibanez, 2004) and various coastal systems, including coral reefs and macroalgal forests (Rocha *et al.,* 2014). Corals are increasingly threatened by global warming and ocean acidification and by local stressors such as eutrophication and overfishing. These stressors can drive coral reefs to collapse and lead to a switch towards seaweed-dominated assemblages (Graham *et al.,* 2015). Similarly, regime shifts from macroalgal forests to less productive and diversified alternative states dominated by turf-forming algae or barren habitats are increasingly documented worldwide (Strain *et al.,* 2014). The susceptibility of these systems to switch between alternative states underscores nonlinear responses to changing environmental conditions and tipping points (Tett *et al.,* 2013). Experimental studies have shown that the approach of these systems to a tipping point may be anticipated using appropriate indicators of loss of resistance and resilience (Benedetti-Cecchi *et al.,* 2015; Rindi *et al.,* 2017).

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[30] Models in the context of this document include both numeric and statistical modelling approaches. Please see the EMB Policy Brief Nº6 on Marine Ecosystem Modelling for further details.

In the choice of a relevant/valuable/important set of biological observations, the status assessment, detection of changes and documentation of impacts should not be the only goals. Sustained biological observations should aim at collecting the relevant information that will allow the identification of probable drivers and underpin research into the mechanisms underlying changes. As such, they should allow the development of models that enable the prediction of structural and functional changes in biodiversity under future scenarios and to provide tools and knowledge to assist informed management decisions. Thus, the challenge is to define a set of cost-effective observations that can be performed sufficiently frequently to capture changes in ocean biodiversity at multiple spatial and temporal scales and in a wide range of environmental conditions. EOVs and EBVs are promising in these respects (see Section 4).

Available biological data and currently used models may not be sufficient to fulfil the tasks above. Indeed, compared to the terrestrial environment, many aspects of marine ecosystems and the way they work and can react to multiple stressors are far less known. For example, although the wide majority of the ocean is constituted by deep waters, we are just starting to explore the genetic and functional diversity of microorganisms that dominate these waters and of their contribution to oceanic carbon cycling (Danovaro *et al.,* 2017). In addition to the difficult access to the ocean beyond a few metres from shore, our lack of a complete understanding of marine life depends on our scarce knowledge on microscopic organisms, and their role as major players in the ocean. The study of these organisms, through expeditions such as Tara Ocean[31] and networks for ocean microbial observation (Buttigieg *et al.,* 2018), is relatively recent, while the application of advanced molecular techniques in recent years has revealed a surprisingly high and largely unknown diversity (de Vargas *et al.,* 2015). Even in coastal habitats where most ecological research has been done, climate change and intensifying human activities continuously reshape marine biodiversity. Human activities along the coast benefit from the economic assets provided by the marine environment, and sustained biodiversity observations are necessary to assess the rapid changes induced by these activities. Hence, together with the development of a new generation of tools and sensors to collect biological data, there is an urgent need to promote scientific activities aimed at increasing our understanding of the fundamental mechanisms underlying life in the ocean and the complex interrelationships among its components both in the coastal zone and in the deep ocean. This requires that some observations are collected with reference to well-articulated questions and hypotheses and these must also drive technological development to promote automated observations globally. The connection between questions and hypotheses is key to ensure that newly generated data can be used to inform management decisions and to address societal needs related to the use and conservation of life in the ocean. Hypothesis-driven and policy-driven science will lead to targeted assessment.

Credit: Swedish Coast Guard

Blooms of cyanobacteria affect recreational use of the coast south of Stockholm, Sweden. Strong cyanobacteria accumulations are remarkable and may be odorous and toxic. Warnings based on observations are issued for the blooms to alert the population.

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[31] https://oceans.taraexpeditions.org/

3 Why do ocean observations need to be integrated across disciplines, regions and habitats?

Changes in marine biodiversity occur locally, regionally and globally. Biological observing programmes need flexibility to capture the relevant drivers operating at multiple spatial scales. This can only be achieved through the networking and integration of ongoing monitoring programmes, methodological standardization and appropriate policies of data integration and dissemination.

Many of the changes in marine ecosystems originate from long term processes or sustained perturbations and cannot be examined effectively with short term programmes. Many of them cross jurisdictional boundaries, so effective observation and intervention requires cooperation and integration across regional and national boundaries and habitats (e.g. offshore and onshore, benthic and pelagic) and disciplines. Biological ocean observation is very fragmented and, despite progress in storage and dissemination of digital information, there is still reluctance to share data within the scientific community and industry, and among national authorities. Programmes tend to be driven by scientific interest or local needs. It is thus essential to establish appropriate mechanisms to overcome these barriers and improve data integration and networking.

With the experience from other observing systems, and acknowledging the much more complex nature of biological observations, one can define a three-tier system according to the scale, requirements, needs and characteristics such as know-how, access, resolution and technology: Global, Regional and Local.

Credit: Gaynor Rosier-Marine Photobank

Many observation programmes still rely on volunteers, such as divers, to gather data.

3.1 Global scale issues

Almost none of global observation networks has sustained or secured funding for their activities (Borja *et al.*, 2016). In order to capture adequately the effects of global change on biodiversity, long term observations in key areas are required (generally involving many nations distributed across continents with a sustained long-term commitment towards observations, e.g. the World Ocean Assessment[32]). For the system to be "fit for purpose" with maximum efficiency, observations must be harmonized using standard protocols, techniques and appropriate platforms contributing to a global observatory network. This ensures interoperability and comparability, which are important characteristics of any observing system. One example of such a system is the international GOOS programme which includes key application areas for climate, operational services, and marine ecosystem health. The marine ecosystem health area, which is relevant to biological observations, is the least mature and requires an integrated holistic ecosystem approach. Existing global marine biological observation systems that have a proven track record are the SAHFOS Continuous Plankton Recorder (CPR)[33], the Ocean Tracking Networks (OTN)[34], the International Long Term Ecological Research Network (ILTER Network)[35], the Reef Life Survey (RLS)[36], the Marine Mammals Exploring the Ocean Pole to Pole (MEOP)[37] and the International Council for the Exploration of the Sea (ICES)[38], among others.

[32] http://www.worldoceanassessment.org/

[33] https://www.sahfos.ac.uk/services/the-continuous-plankton-recorder/

[34] http://oceantrackingnetwork.org/

[35] https://www.ilter.network/

[36] https://reeflifesurvey.com/

[37] http://www.meop.net/

[38] http://www.ices.dk/

- The CPR has collected zooplankton observations in a standardized way since 1931 and operates in the North-Atlantic, Southern seas, Australia, and the Pacific;
- The OTN collects observations on fish and cetacean's migration with acoustic telemetry and satellite tags in the Atlantic and Pacific coasts of Canada and U.S., and around Australia and South Africa;
- The ILTER Network includes more than 60 sites located in coastal and marine environments with a worldwide distribution. Many of these sites are historically important, with several decades of sustained observations of different marine ecosystems;
- The RLS coordinates the gathering of records of abundance of all conspicuous species observed on reefs gathered by divers, spanning all ocean basins;
- MEOP collects behavioural and standardized environmental data from marine mammals in Polar regions;
- ICES organizes the collection of standardized observation of planktonic and benthic communities and fish stocks in the Northern Atlantic.

The largest proportion of marine biological data available to scientists today is generated, however, by short-term monitoring or research activities (such as the length of a PhD programme), which are organized regionally or locally. The lack of coordination and standardization in sampling and identification techniques results in spatial and temporal gaps that makes global scale synthesis extremely difficult. For example, there are some quality assurance schemes such as the National Marine Biological Analytical Quality Control scheme in Europe[39] but these are not adopted throughout all areas.

3.2 Regional scale issues

Worldwide, there are a number of existing and emerging regional ocean observing programmes e.g. the U.S. Integrated Ocean Observing System (IOOS), the Australian Integrated Marine Observing System (IMOS) and the developing Canadian Integrated Ocean Observing System (CIOOS) (Bajona, 2017). The European Ocean Observation System (EOOS) is currently being developed as a framework to promote the alignment and coordinated of integrated observation systems at a European scale (see Box 3.2). The European Regional Sea basins, such as the Baltic or Mediterranean, or an oceanic region such as the North Atlantic, have distinct characteristics, and the experience from EuroGOOS[40] in the area of operational oceanography shows that regional observing networks (ROOS') are an effective way of organizing observations at regional basin level. In addition, the Regional Sea Conventions implement a regional approach for environmental assessments and ecosystem status (e.g. MSFD), providing an important platform for regional dialogue and priority setting (see Section 1.2 for details). Similar to those at the global scale, regional observing networks must be sustainable and adjustable to evolving observing requirements. These are the two most important characteristics, since sustained long time series are of paramount importance while new observing approaches are emerging every day as technology progresses, making it possible to measure new parameters and/or improve existing protocols.

INFOBOX 3.2

The U.S. Integrated Ocean Observing System (IOOS), the Australian Integrated Marine Observing System (IMOS) and the European Ocean Observing System (EOOS)

IOOS[41] is a national-regional partnership working to provide new tools and forecasts to improve safety, enhance the economy, and protect the environment. Integrated ocean information is available in near real time, as well as retrospectively. Its vision is to provide a fully integrated ocean observing system that enables the National Oceanic and Atmospheric Administration (NOAA) and its partners to provide service to the U.S. through improved ecosystem and climate understanding; sustained living marine resources; improved public health and safety; reduced impacts of natural hazards and environmental changes; and enhanced support for marine commerce and transportation.

Since 2006, IMOS[42] has been routinely operating a wide range of observing equipment throughout Australia's coastal and open ocean, making all of its data accessible to the marine and climate science community, other stakeholders and users, and international collaborators. IMOS is designed to be a fully-integrated, national system, observing at ocean-basin and regional scales, and covering physical, chemical and biological variables.

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[39] http://www.nmbaqcs.org/about/history-of-the-scheme/

[40] http://eurogoos.eu/

[41] https://ioos.noaa.gov/

[42] http://imos.org.au/

In Europe there are existing frameworks towards the coordination of specific platforms and sectors. The recognition of having an inclusive framework has led to a community call for EOOS. EOOS[43] is a framework to optimize Europe's existing ocean observing capability, adding value to existing efforts through connection, coordination and alignment of communities across disciplines and sectors and providing a central focal point for strategy, stakeholder engagement and innovation. A key focus of the EOOS framework is enhancing the alignment and coordination of *in situ* ocean observation collection. The geographical scope is global, with a focus on European capability and leadership both in European EEZs and beyond. Ultimately, EOOS will build on existing initiatives and advance Europe's capability in ocean observation both for European societal needs and as a leading contributor to the global efforts in ocean observing and international policies including the UN 2030 Agenda on Sustainable Development, marine biodiversity conservation and climate change agreements.

In its initial stages, EOOS coordination has been jointly led by EuroGOOS and the European Marine Board to connect the operational oceanographic community with the wider marine scientific community. Since 2016, the EOOS initiative has also been working to connect with more diverse stakeholders from environmental monitoring to fisheries and from blue economy industries to wider society (e.g. citizen science) through an Advisory Committee of wider stakeholders and stakeholder events e.g. Forum and Conference. In 2018, EOOS is developing a community-driven Strategy and Implementation Plan for 2018-2022. This will build and strengthen the community of European ocean observing stakeholders, break down institutional barriers, and enable sharing of data collection towards a more efficient and cost-effective system. The framework will also develop mechanisms for regular stakeholder dialogue to ensure co-design of future priorities and programmes, and that user needs are listened too.

This EMB foresight paper on biological ocean observations is a contribution to the early implementation of EOOS.

3.3 Local level issues

Most of the existing biological observing stations and platforms are operating at a local level (within a national sea area, or a given bay or stretch of coast within a national territory). These are characterized by high variability in terms of spatial and temporal resolution and quite often with infrequent and/or sporadic operation. Local problems require local, focused observation systems e.g. algal blooms in aquaculture regions, impact of pollution in and around harbours and estuaries, etc. (see Box 3.3 for another example) but much of this work is carried out by a developer during EIA (Environmental Impact Assessments) (Lonsdale *et al.*, 2017). Observation methods are usually specific to the needs for that specific area, either as variants of existing methods or completely new and locally developed. It is in these observatories that new observing methods are implemented and initially tested before being transferred to broader systems. Local observing requirements may dictate specific approaches and techniques, ensuring a good 'fit for purpose', but conformity to agreed standards both in terms of the quality of the observations and the data must be in place to ensure scalability and comparability.

INFOBOX 3.3

An example of a national monitoring programme

The Danish open marine waters lie in the transitional zone between the brackish Baltic Sea and the saline North Sea, with considerable changes in temperature and salinity due to changing wind and currents. The high population density and intensive exploitation of the countryside result in pollutant discharges, and commercial fisheries places pressure on the marine ecosystems. In addition, there are pressures from other marine activities such as shipping, sand and gravel extraction, and oil and gas extraction. The Danish National Monitoring and Assessment Programme for the Aquatic and Terrestrial Environments (NOVANA[44]), in the case of marine waters, focuses on three elements: a) Eutrophication, incl. physical conditions and modelling, b) Species and habitats, and c) Hazardous substances and monitoring of their biological effect. This monitoring programme is primarily motivated by a number of environmental problems such as oxygen deficiency, the occurrence of harmful algal blooms (HABs) or hazardous substances, a decline in submerged aquatic vegetation and coastal fish populations and changes in the biological structure of the fjords. These problems became apparent at the end of the 1970s and during the 1980s and 1990s, a number of research projects and monitoring activities showed that several of these problems were to some extent due to the input of pollutants such as nutrients and hazardous substances.

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[43] http://www.eoos-ocean.eu/

[44] http://mst.dk/natur-vand/overvaagning-af-vand-og-natur/

3.4 Working across geographical scales

To understand and manage global changes requires working across multiple geographical scales, which requires mechanisms for exchange of expertise, protocols and data between and within scales. These mechanisms would help to minimize problems such as the general lack of and uneven distribution of taxonomic expertise among institutions and nations (Heip & McDonough, 2012). It is important to define and operate appropriate mechanisms tailored to the needs and characteristics of each of the three scales as well as the links between them. Networking workshops for the definition of standards, inter-calibration exercises, labels of good practices and the exchange of staff are examples of such mechanisms. The EU FP7 project ASSEMBLE[45] and the follow-on ASSEMBLE plus[46] are a good example of such a network.

An important barrier that must be overcome at all three scales is data collation and exchange. Acknowledging the great effort needed to produce biological data, appropriate actions to illustrate the added value of sharing data both at personal and at community level are required. In addition, the rapid delivery of data in a consistent and commonly agreed manner (common protocols) with the same quality criteria, enhance the evolution of the observing system. Shared, distributed step-by-step protocols facilitate standardization. The use of common data portals and infrastructures is an essential step towards integration within and across scales (see Box 3.4). It is emphasized that any data added into databases for comparisons with elsewhere or with other times needs to be rigorously quality controlled (Gray & Elliott, 2009).

Modelling also requires and drives integration of data and should help to prioritize observations and so improve efficiency. Modelling capabilities differ depending on whether local, regional or global issues are considered, and this influences how well the direction and magnitude of change in the physical environment, the ocean productivity and ecosystem dynamics can be represented. Further expansion of models and closer coupling of models with observations is a priority, considering that it is through models (anchored in observations) that an improved understanding of the dynamic relationships between ocean circulation and biogeochemical and biological processes can be achieved. Marine ecosystem models are advancing to include a wider array of ecosystem components and interactions, including human activity. This, in combination with the drive for more comprehensive, multidisciplinary observations and advancements in artificial intelligence, machine learning and cloud computing may also allow improved assessments of the reliability of model forecasts and predictions (EMB Policy Brief N°6 on Marine Ecosystem Modelling).

Credit: Leontien De Wulf - VLIZ

The promotion of standards in gathering of data and lab protocols could help management to better understand the ecosystem.

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

[46] http://www.assembleplus.eu/

INFOBOX 3.4

Examples of data initiatives and research infrastructures related to biological ocean observations

The European Marine Observation and Data Network (EMODnet)[47] is a data system financed by the European Commission Directorate-General for Maritime Affairs and Fisheries (DG MARE) to strengthen the blue economy. EMODnet reuses data from past research projects and existing data collection networks and infrastructures to calculate ready-to-use data products on biological, physical and chemical parameters, geology, bathymetry, seabed habitats, and human activities. The EMODnet biology data portal provides free access to data on temporal and spatial distribution of marine species and species traits from all European regional seas.

The Pan-European Infrastructure for Ocean and Marine Data Management (SeaDataNet)[48] is a distributed Marine Data Infrastructure for the management of large and diverse sets of data deriving from *in situ* observations of the seas and ocean. The on-line access to *in situ* data, meta-data and products is provided through a unique portal interconnecting the interoperable node platforms constituted by the SeaDataNet data centres.

The European Ocean Biodiversity Information System (EurOBIS)[49], a node of the international Ocean Biogeographic Information System (OBIS), has collected more than 800 datasets from past projects in 157 institutes and provided more than 2,000,000 marine species occurrence records from all European seas and the East Atlantic. All records are standardized to WoRMS, quality controlled, integrated and shared with EMODnet, OBIS and the Global Biodiversity Information Facility (GBIF) (Vandepitte *et al.*, 2015).

The World Register of Marine Species (WoRMS)[50] is an authoritative list of names, including synonyms of all published marine species. The content is assembled by more than 300 taxonomic experts and other marine biological databases. The register provides more than 200,000 species descriptions, with valuable information for the quality control and analysis of observation data: accepted name, known synonyms, taxonomy, original species descriptions and trait information (Vandepitte *et al.*, 2015). WoRMS is the marine biology standard for major data networks such as EMODnet and OBIS, and used by several data infrastructures such as GBIF and the European Marine Biological Research Centre (EMBRC-ERIC).

The International Council for the Exploration of the Sea (ICES)[51] is a global organisation that develops science and advice to support the sustainable use for the oceans. ICES has a well-established Data Centre, which manages a number of large datasets related to the marine environment. ICES data products are publically available, and the ICES Data Centre provides specific marine data services to ICES member countries, expert groups, world data centers, regional seas conventions (HELCOM and OSPAR), the European Environment Agency (EEA), and various other European projects and biodiversity portals.

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[47] http://www.emodnet.eu/

[48] https://www.seadatanet.org/

[49] http://www.eurobis.org/

[50] http://www.marinespecies.org/

[51] http://ices.dk/

INFRASTRUCTURES

The European Multidisciplinary Seafloor and water column Observatory (EMSO-ERIC)[52] is a distributed research infrastructure consisting of fixed seafloor and water column observatory nodes for deep ocean observations. EMSO observatories are deployed at key sites around Europe and have long-term, high-resolution, (near)-real-time capabilities to address environmental processes such as climate change, natural hazards and marine ecosystem changes.

LifeWatch-ERIC[53], is the e-Science European Infrastructure for Biodiversity and Ecosystem Research. Several components of importance for European marine biology observation have been constructed by LifeWatch-ERIC, such as the LifeWatch taxonomic backbone, the European Tracking Network (ETN), and LifeWatch marine observatories.

JERICO-NEXT[54], the successor of the project JERICO, an Integrated Infrastructure Initiative (I3), improves and innovates cooperation of European coastal observatories and develops high resolution monitoring strategies and cooperates with other European initiatives such as ESFRI, EMODnet and EMBRC. JERICO and JERICO-NEXT have also achieved technological development for observations (including biological observations, especially in the field of imagery).

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[52] http://emso.eu/

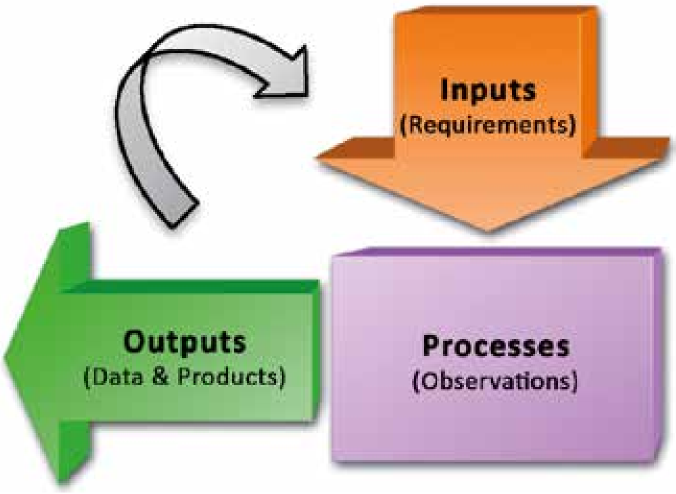
[53] https://www.lifewatch.eu/

[54] http://www.jerico-ri.eu/

4 How should biological observations be done?

Implementing a sustained and standardized biological observing system requires the identification of key variables to inform on the status and trends of marine biodiversity. Two complementary frameworks are of note: Essential Ocean Variables (EOVs) and Essential Biodiversity Variables (EBVs). Feasibility, sensitivity, scientific and social relevance are the leading principles used to prioritize variables in these frameworks. However, EOVs and EBVs are a priorities list only and additional biological variables should be considered as needed.

All ocean and environmental protection agencies recognize the importance of undertaking concerted actions aimed at quantifying changes in marine ecosystems, with the ultimate goal of maintaining a healthy ocean and seas. The Integrated Framework for Sustained Ocean Observing (FOO[55], Lindstrom *et al.*, 2012) identified key priorities to harmonize activities, goals and procedures among existing observing communities and to establish an integrated and sustained global observing system. The FOO system is based on three pillars (Fig. 4.1): requirements (information needed to address a specific scientific or societal question, or inputs); observation elements (technology and networks applied to data collection and collation, or processes), and information products (synthesis of observations to provide services to scientific and /or societal issues, or outputs). A key element is the Feedback Loop, allowing for continuous improvement of the overall system. The requirements for biological ocean observations have been considered above in the preceding sections. This section focuses on the variety of observation elements and information products.



Credit: Task Team for an Integrated Framework for Sustained Ocean Observing, UNESCO 2012

Figure 4.1 Simplified ocean observation Systems Model based on the Integrated Framework for Sustained Ocean Observing (FOO).

4.1 Essential Ocean Variables

Inspired by the positive impact that the definition of Essential Climate Variables (ECVs) had in climate science, the FOO suggested the organization of ocean monitoring activities around Essential Ocean Variables (EOVs), to be defined by panels of experts. To this aim, the IOC-UNESCO Global Ocean Observing System (GOOS) established three panels: Physics and Climate, Biogeochemistry, and Biology and Ecosystems. The first two panels focus on abiotic variables and capitalize on existing technology that allows automated sampling (e.g. satellites and remote sensing in general). The Biology and Ecosystems (BioEco) panel was established in 2015 with the aim to prioritize biological EOVs.

INFOBOX 4.1

The GOOS Biology and Ecosystems Panel

The Global Ocean Observing System (GOOS) was established in 1991 under the auspices of the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO). Its Biology and Ecosystems Panel (GOOS BioEco[56] panel) aims to develop and coordinate efforts in the implementation of a sustained and targeted global ocean observing system driven by societal needs to include biological and ecological Essential Ocean Variables (EOVs) to answer relevant scientific and societal questions, and support critical policy, development, and management decisions on ocean and coastal resource sustainability and health.

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[55] http://goosocean.org/index.php?option=com_content&view=article&id=18&Itemid=113

[56] http://goosocean.org/index.php?option=com_content&view=article&id=79&Itemid=273


Credit: SAMS

Scientist assessing the percentage cover of a species of high shore seaweed, *Pelvetia canaliculata*, in the UK. Many biological ocean observations are conducted manually and cannot yet rely on automated systems.

EOVs allow the organization of ocean monitoring activities around a set of standardized procedures and promote the development of a sustained and coordinated global observing program. This standardization is essential to guarantee comparable data and to harmonize national and international reporting obligations. EOVs provide a scalable and cost-effective approach that will facilitate the participation of developing countries, ensuring full coverage of biological ocean observing across the globe. According to the readiness level for the implementation of a global ocean observing system, biological EOVs are currently at low or intermediate level (conceptual or pilot phases).

4.1.1 Biological EOVs

Limited availability of high-tech approaches for automated measurements has hindered sustained, large-scale monitoring of biological variables, especially compared to physical and biogeochemical observations. To facilitate the integration of biological observing systems in coordinated monitoring networks, the GOOS BioEco panel prioritized a set of biological EOVs on the basis of three criteria as defined by the FOO: impact, scalability (or feasibility) and social relevance (Miloslavich *et al.,* 2018; Constable *et al.,* 2016[57]). Impact relates to the ability of the EOV to signal changes in ocean status and trends in response to human activities and relevance to the needs of international conventions of ocean conservation. Scalability is assessed in terms of the spatial and temporal scales at which variables have been examined in biological observing programmes. Scalability depends on costs, available technology and human capabilities and implies that EOVs can be implemented globally with existing technology and knowledge (Fig. 4.2). Social relevance requires that EOVs must have direct connection with services that lead to societal goods and benefits which ocean biodiversity provides to humanity and must be able to inform policy decisions.

Eight biological EOVs have been identified so far (Annex 2). This is not an exhaustive list and should be regarded as the minimum set of candidate variables needed to implement a global observing system of biological status and trends in a changing ocean (Miloslavich *et al.,* 2018). Each EOV is further characterized by a set of sub-variables, derived products and supporting variables. Sub-variables are quantities needed to calculate the desired EOV. Derived products are aggregated outputs derived from the EOV and supporting variables are further quantities needed to characterize the environmental context of the EOV. The EOVs and sub-variables are similar to indicators within the context of the MSFD but this leads to confusion unless those sub-variables are targets against which monitoring can be judged. Many sub-variables correspond to the Essential Biodiversity Variables (EBVs) identified by the Group on Earth Observations Biodiversity Observation Network (GEO BON) (Pereira *et al.,* 2013; see next section). Linking ocean EOVs and EBVs is essential to harmonize observations across the global ocean system and to assess progress towards the achievement of the United Nations (UN) Sustainable Development Goal (SDG) 14 (Reynolds *et al.,* 2018). It is now recognized that EBVs are sub-variables of EOVs (Muller-Karger *et al.,* 2018). The complete list of EOVs along with their specification sheets is available on the GOOS website[58].

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[57] This study is specific to the Southern Ocean and under the umbrella of SOOS, the Southern Ocean Observing System.

[58] http://www.goosocean.org/index.php?option=com_content&view=article&id=14&Itemid=114

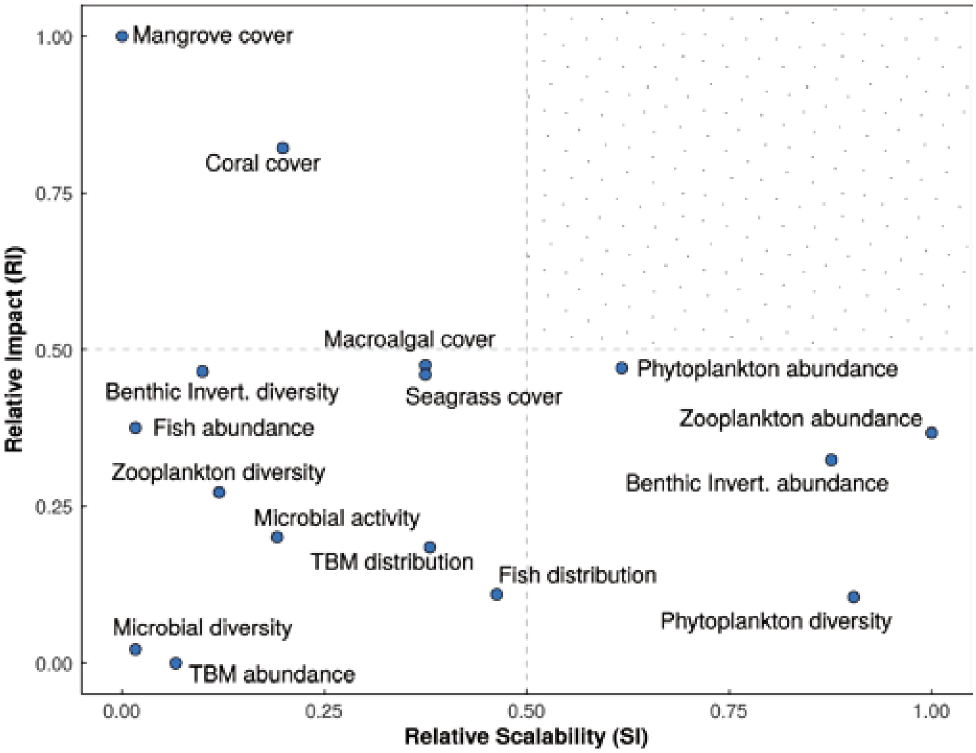

Figure 4.2 Relative impact and scalability of candidate EOVs. Impact reflects the extent to which a variable has been used to address societal needs (e.g. biodiversity conservation) and anthropogenic stressors in the literature. Scalability was assessed with reference to the spatial and temporal scales at which main ocean observation programmes operate. From Miloslavich *et al.*, 2018. *TBM= sea turtles, seabirds and marine mammals.*

The selected EOVs are broad in scope, build on a long history of ocean observations and focus on key components of benthic and pelagic environments. Corals, mangroves, macroalgal canopies, shellfish and reef-building worms are foundation (eco-engineer) species, contributing important functions and services to coastal ecosystems. Phytoplankton and zooplankton dominate the pelagic environment. The biomass and diversity of planktonic organisms will address changes in the vast open ocean, in addition to integrating coastal benthic EOVs. Addressing the ocean productivity, phytoplankton and zooplankton EOVs inform on carbon and nutrient cycling, storage and export, contributing to the definition of key biogeochemical indicators, such as dissolved organic carbon, particulate matter, oxygen, nutrients and ocean colour. Fish, sea turtles, sea birds and mammals extend EOVs to apex consumers in ocean food webs, broadening the assessment of the state and trends in the ocean's life to trophic aspects. The biomass and diversity of microbes are emerging biological EOVs due to the relevance of these organisms on biogeochemical cycles and ecosystem function. Finally, the biomass and distribution of benthic invertebrates are emerging EOVs due to the role of these ecosystem components in benthic-pelagic coupling and their major importance in providing ecosystem services (e.g. food production, carbon sequestration and sediment-water exchange).

Credit: European Marine Board

Internationally agreed variables can standardize data gathering methods and allow comparison of different ecosystems around the world.

4.2 Essential Biodiversity Variables

Assessing changes in biodiversity is difficult, in part because biodiversity itself is a complex concept embracing variation at multiple scales and organizational levels, from genes to species and ecosystems (Strong *et al.,* 2015). Different measures of biodiversity derived at different scales might tell different and potentially contradictory stories about the magnitude and direction of change. Existing data supporting biodiversity assessments vary at spatial and temporal scales and also thematically (e.g. taxons, realms) (Navarro *et al.,* 2017). This limits our ability to identify the drivers of biodiversity change and to implement adequate management strategies to mitigate their impact. To improve this, the Group on Earth Observations Biodiversity Observation Network (GEO BON) was established in 2008 as a global initiative to improve the acquisition, coordination and delivery of biodiversity observations and related analytical services to end users such as decision-makers and the scientific community. Originally, this initiative addressed all biodiversity and included a working group that dealt specifically with the marine ecosystem changes. Ten years later, GEO BON has developed a globally coordinated strategy for the monitoring of biodiversity change based on two fundamental components: a framework based on Essential Biodiversity Variables (EBVs) (Figure 4.3, Pereira *et al.,* 2013) and a system of coordinated Biodiversity Observation Networks that includes the Marine Biodiversity Observation Network (MBON) for promoting sustained and operational monitoring of marine biodiversity (Navarro *et al.,* 2017). As a step to defining such programmes, a book on current methods and networks was published (Walters & Scholes, 2017) including a chapter on collecting and managing marine biodiversity data (Costello *et al.,* 2017).

Credit: Thierry Le Bec - UBO

Sampling of eelgrass *(Zostera (Zostera) marina)* in the Bay of Brest (France).

INFOBOX 4.2 The GEO BON Marine Biodiversity Observation Network

MBON
Marine Biodiversity
Observation Network

The Marine Biodiversity Observation Network (MBON[59]) of the Group on Earth Observations Biodiversity Observation Network (GEO BON) evolved from GEO BON's Working Group on "Marine Ecosystem Change" and is envisioned as the key biodiversity pillar of GEO and GEO BON for the marine realm. The MBON aims to help coordinate individual monitoring programs and existing networks focused on local, regional and thematic aspects of marine biology and biodiversity and facilitate the sharing of data, experiences, and protocols to understand species and the status and trends of ecosystems and their services and support critical policy, development, and management decisions on ocean and coastal resource sustainability and health.

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[59] http://www.marinebon.org/

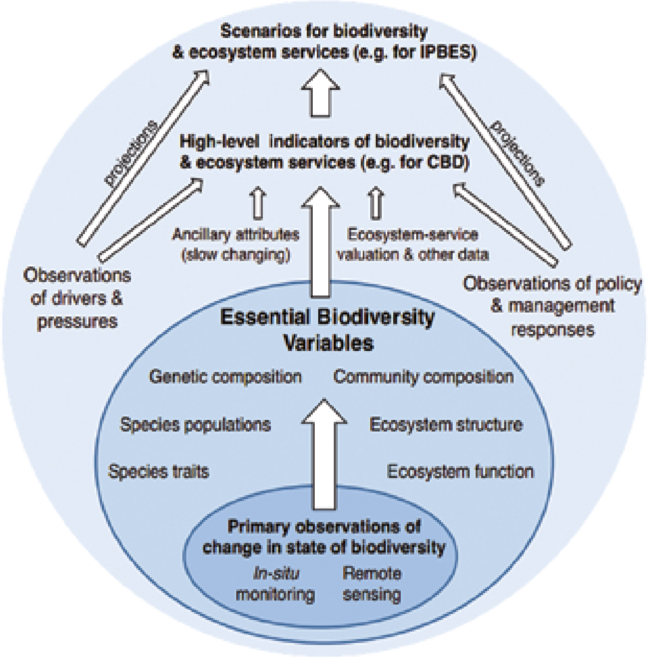
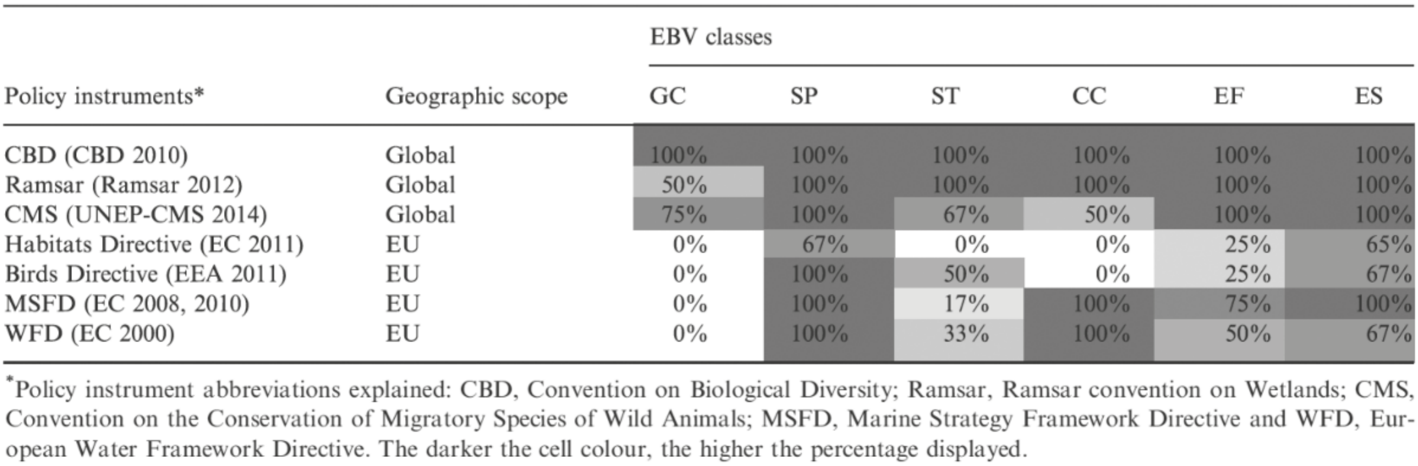


Figure 4.3 Relationships between biodiversity observations, Essential Biodiversity Variables and reporting for responding to different policy requirements. From Pereira *et al.*, 2013.

EBVs are a set of complementary biological state variables needed to detect biodiversity change. GEO BON proposed a list of 22 candidate EBVs (Annex 3) within six organization levels: “genetic composition”, “species populations”, “species traits”, “community composition”, “ecosystem structure”, and “ecosystem function”, which aim to be valid irrespective of considered ecosystems (Pereira *et al.*, 2013). This set of candidate EBVs aims to account for the full complexity of ecosystem biological components, but with less consideration for the operational needs. The operationalization of EBVs is being addressed globally (e.g. Proença *et al.*, 2017; Schmeller *et al.*, 2017), nationally (e.g. Turak *et al.*, 2017), using satellites (e.g. Skidmore *et al.*, 2015), but there is still a long way to go to have an agreed set of variables that can be proposed to monitoring programmes for large scale long-term observations in the ocean (for current status see Navarro *et al.*, 2017).

To test the usability of the EBV framework for policy makers, Geijzendorffer *et al.*, (2016) determined the fit of the different EBV classes to the biodiversity data requirements for reporting under seven marine relevant global and EU biodiversity policy instruments. For each of the selected instruments, biodiversity reporting needs were identified and linked to specific EBVs. Results for each policy instrument were summarized as the percentage of EBVs needed for reporting per EBV class and per policy instrument (Table 4.1). They found that the biodiversity indicators used did not incorporate EBV classes equally. While EBV classes, such as “species populations”, were well represented, in current indicators, others such as “genetic composition”, were almost absent. Some important biodiversity facets are not well covered by the current set of indicators, due to gaps in primary data. The EBV framework could become an important tool to balance the different types of data and ensure all data needed are collected, by promoting feasible and cost efficient approaches. The indicator catalogue compiled by Teixeira *et al.*, (2016) could be combined with the EBV approach to remedy the deficiencies in the latter approach.



		EBV classes					
Policy instruments*	Geographic scope	GC	SP	ST	CC	EF	ES
CBD (CBD 2010)	Global	100%	100%	100%	100%	100%	100%
Ramsar (Ramsar 2012)	Global	50%	100%	100%	100%	100%	100%
CMS (UNEP-CMS 2014)	Global	75%	100%	67%	50%	100%	100%
Habitats Directive (EC 2011)	EU	0%	67%	0%	0%	25%	65%
Birds Directive (EEA 2011)	EU	0%	100%	50%	0%	25%	67%
MSFD (EC 2008, 2010)	EU	0%	100%	17%	100%	75%	100%
WFD (EC 2000)	EU	0%	100%	33%	100%	50%	67%

*Policy instrument abbreviations explained: CBD, Convention on Biological Diversity; Ramsar, Ramsar convention on Wetlands; CMS, Convention on the Conservation of Migratory Species of Wild Animals; MSFD, Marine Strategy Framework Directive and WFD, European Water Framework Directive. The darker the cell colour, the higher the percentage displayed.

Table 4.1 Biodiversity information reporting requirements of selected biodiversity policy instruments, expressed as the percentage of EBVs required per EBV class. The EBV classes are Genetic Composition (GC), Species Populations (SP), Species Traits (ST), Community Composition (CC), Ecosystem Function (EF) and Ecosystem Structure (ES). From Geijzendorffer *et al.*, 2016.

INFOBOX 4.3

The agreement to coordinate a global marine biodiversity observing system

The Marine Biodiversity Observation Network (MBON) from Group on Earth Observations Biodiversity Observation Network (GEO BON[60]); the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO[61]) Global Ocean Observing System Biology & Ecosystems Panel (GOOS BioEco Panel), and the Ocean Biogeographic Information System (OBIS[62]) signed, in 2016, an agreement[63] to work together to enhance existing biological observation scopes and capacities, to implement best practices and international standards, and to encourage open access and data sharing. Their aim is to enhance global capacity for marine biological and ecosystem observations in the long term and to integrate it with existing and new marine observation programmes for physical and chemical variables that are essential to understand biodiversity changes. They also plan to develop and streamline the implementation of biological EOVs and marine EBVs and to increase the number of monitoring programmes that include these variables. The concepts and approaches for both marine EBVs and biological EOVs are evolving - e.g. biological taxa relevant for ecosystem functioning such as microbial biomass and diversity or benthic invertebrate abundance and distribution, are recognized as EBVs and considered as emergent biological EOVs and will be developed soon (Muller-Karger *et al.,* 2018).

There is still a clear challenge in reaching a threshold between overall scientific relevance, the needs for (EU) legislation without compromising the interoperability at global level, and the feasibility when defining the variables to be monitored. Thus, discussions and refinement of the two sets of essential variables are continuing. The current discussion on the development of the European Ocean Observation System (EOOS) is a very good opportunity to promote an integrated ocean observation system based on EOVs and EBVs in Europe. Even though these variables are designed to be global, engaging regional systems such as EOOS will be key to ensuring progress and maturation.

4.3 Monitoring and attribution of causality

Biological EOVs and marine EBVs are not new, but build on a long history of biological observations in the ocean. Most of them have been measured for decades worldwide and the availability of historical records is a key strength of the selected EOVs/EBVs. This wealth of data indicates their sensitivity to global change and their inherent natural variability, which should not overwhelm the anthropogenic signal they are expected to capture. These considerations can be addressed formally using historical data to define appropriate sampling designs with the necessary statistical power to detect ecologically, economically and socially relevant changes. Such a definition of a statistically-robust sampling design requires the threshold/trigger/reference value to be agreed in advance of the monitoring, i.e. to determine for each variable the level of unacceptable change and the inherent variability and then monitor to detect such a change over and above natural variability. If the accepted level of change is not defined then the monitoring will merely be surveillance, i.e. *a posteriori* trends will be detected and management measures agreed afterwards.

Deciding where to allocate sampling effort, in other words when and where to intensify observations, is important in the definition of any sampling design. A better understanding of natural fluctuations in selected EOVs/EBVs will assist with a judicious allocation of sampling effort. This calibration procedure will benefit from systematic comparison of EOVs/EBVs in space and time. A better understanding of temporal patterns of variation of EOVs/EBVs, how these patterns change regionally, as well as the underlying drivers, will be key to probing the value of EOVs/EBVs for global ocean observing. But it is emphasized that all of this requires a clear view of what change is required to be detected. This has to be based on sound cause-effect hypotheses. It should always be borne in mind that field surveillance may only provide circumstantial evidence of causality and so the approach may need to be supported by experimental and/or modelling approaches.

The broad scales addressed by EOVs/EBVs and the availability of historical records will help to facilitate the attribution of causality, which requires comparisons with appropriate benchmarks including both spatial and temporal reference data. Model- and design-based approaches are both suitable for this purpose. Models generating predictions under different pressure scenarios may suggest plausible causes behind observed patterns in EOVs/EBVs. Design-based approaches, such as Before-After/Control-Impact paired series (BACI) designs and their evolution (beyond-BACI designs; Underwood, 1994; Gray & Elliott, 2009), use well established statistical principles to tease apart signal from noise through comparisons of reference and disturbed conditions or across perturbation gradients. A wise use of EOVs/EBVs should build on these principles and requires placing monitoring activities in a hypothesis-testing framework. For example, spatial contrasts along a latitudinal gradient and comparisons with historical data enabled the attribution of a 100-km range contraction of macroalgal forests along the western coast of Australia due to the 2016 marine heatwave, which was consistent with a hypothesis of increasing tropicalization of the region (Wernberg *et al.,* 2016).

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[60] https://geobon.org/

[61] http://www.ioc-unesco.org/

[62] http://iobis.org/

[63] hhttp://iobis.org/documents/GOOS-BioEco-OBIS-GEOBON-MBON_collaboration_SIGNED.pdf

New variables and measurements are needed in the near future to have a better understanding of the marine ecosystems. Scientist at the Centro Oceanográfico de Canarias, IEO.

4.4 Additional variables

It is important to recognize that the present list of EOVs and EBVs is not an exhaustive list of relevant variables to track changes in ocean biodiversity. Additional variables may be necessary in some contexts or may become relevant under novel environmental conditions. For example, environmental monitoring for national or European assessments (e.g. for MSFD) may include wider variables that are not EOVs / EBVs and yet crucial to assessing good environmental status in a particular sea or ocean basin, or of high interest to a specific stakeholder group e.g. industry. In addition, new variables and measurements may be needed to evaluate the impacts of intensifying and more frequent marine heatwaves on biodiversity and ecosystem services. Biodiversity variables that have not yet been formalized as EOVs, but that are clearly important for biological ocean observations, include (but are not limited to) microbe biomass and diversity, and benthic invertebrate abundance and distribution. Despite this, it is emphasized that certain components (such as microbes) may have such a large inherent variability that it would not be able to detect anthropogenic change against the background variability. These examples illustrate the need for a tight collaboration between marine biodiversity researchers and the wider ocean observation communities and a flexible framework to adapt biological ocean observations to the different needs that may emerge at local, regional and global scales, a position that is strongly supported in this Future Science Brief.

4.5 Ocean observation elements: technology and networks needed to collect and collate data

Infrastructure is the foundation of the ocean observing system. Key observation infrastructure elements include the technology (observing platforms to sensors and samplers) and networks used to collect ocean observation data on a routine basis (Navigating the Future IV, European Marine Board 2013). The marine science community currently utilizes a wide array of biological ocean observation infrastructures, tools and techniques. Many existing observing networks are already moving towards common standards for data collection and dissemination to maximize the utility of data from biological observation.

In addition, technological evolution today is providing us with promising tools to observe and monitor the ocean. Some research labs and international initiatives are bridging the gap between marine science and engineering to improve biological ocean observation technology, including automated, miniaturized sensors that will make large scale and long-term biological ocean observation possible. The Partnership for Observation of the Global Oceans (POGO[64]), a forum for leaders of major oceanographic institutions around the world, has set up a Task Force on Biological Observations with a specific focus on emerging technologies. The increasing capability for routine, biological ocean observations e.g. on automated platforms such as ARGO floats[65], may also raise ethical considerations, for example on sharing of data on biological resources within the Exclusive Economic Zone (EEZ) of a particular nation. This is an emerging area and highlights the need for dialogue across stakeholder communities.

This section is not intended as a comprehensive review of the state-of the-art of biological ocean observation elements, but to provide examples of some networks and technologies relevant for biological ocean observation in Europe.

Platforms

Platforms range from research vessels to autonomous observing and monitoring systems and land-based infrastructures e.g. marine stations. Combining observation from different platforms increases the range of spatial and temporal scales that can be covered and resolved (Dickey, 1993). This improves the detection of ecosystem changes, such as short-term processes (e.g. Thyssen *et al.*, 2015), long-term trends (e.g. Behrenfeld *et al.*, 2006), regime shifts (e.g. Dinniman *et al.*, 2012; Rocha *et al.*, 2014), alterations in phenology (e.g. Edwards & Richardson, 2004), or displacement of biogeographic boundaries (e.g. Beaugrand *et al.*, 2002). It also facilitates the development of ecosystem models, which require nesting diverse spatial domains (i.e. using a coastal model coupled to an oceanic model) and integration of processes occurring at a wide range of interacting scales (i.e. resolution of turbulence and mesoscale processes). The combination of platforms is also necessary to validate new tools (e.g. sensors, imaging technologies, etc.). Examples include the estimation of phytoplankton biomass subdivided into functional groups based on *in situ* measurements of water column pigment concentration by continuous underway or moored platforms, to be validated through measurements obtained from remote optical sensors mounted on satellites or drones (e.g. Nair *et al.*, 2008). Another example is the estimation of biomass and distribution of seagrass through acoustic (multi-beam

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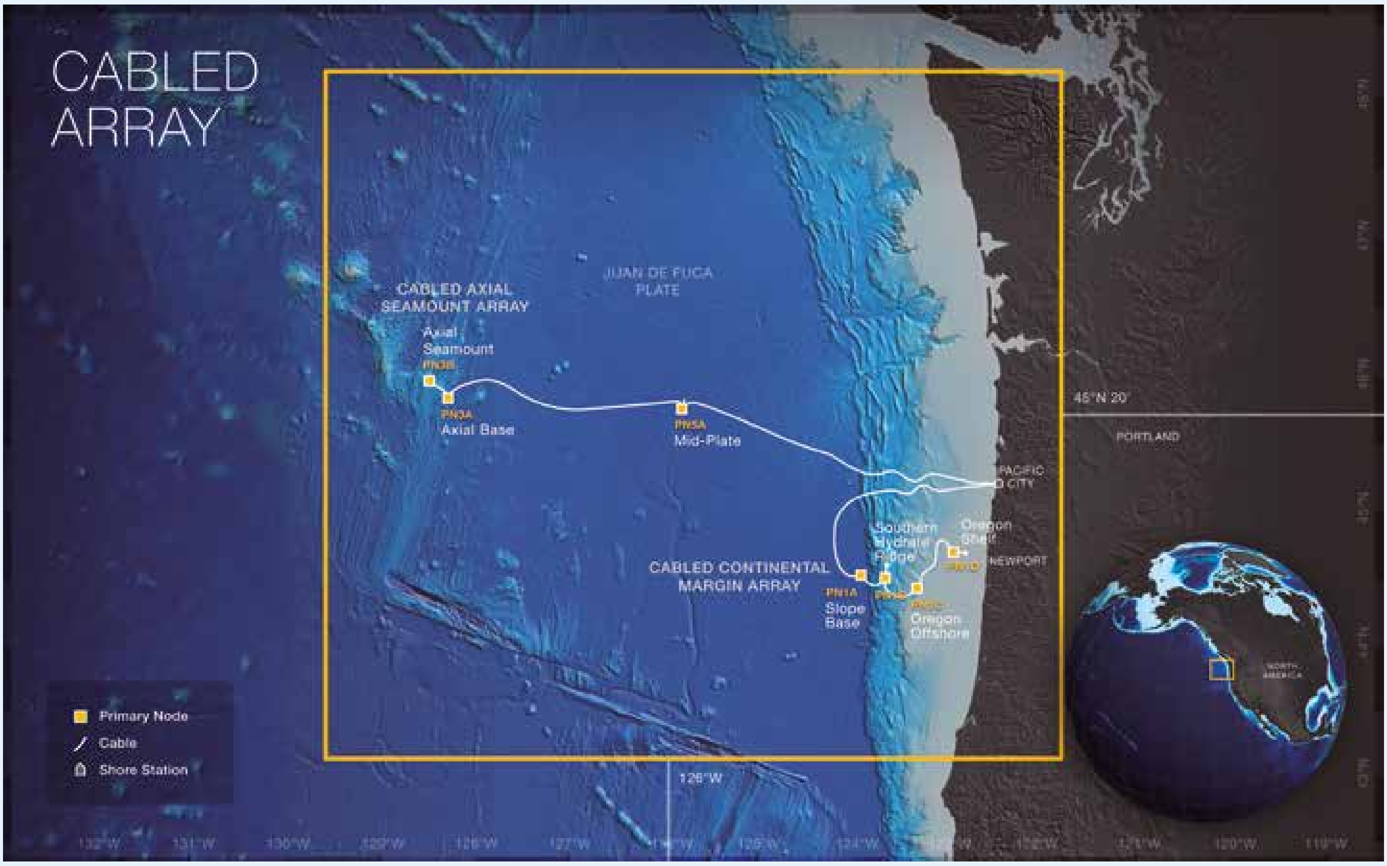
[64] http://www.ocean-partners.org/

[65] http://www.argo.ucsd.edu/

INFOBOX 4.4

Digital Ocean Infrastructures

Progress with ocean cyber-infrastructure is fostering the implementation of observatory networks devoted to real-time sampling of ocean variables. The North East Pacific Time-integrated Undersea Networked Experiments (NEPTUNE) is a project that makes extensive use of ocean cyber-infrastructure to widen the scope of observations. In NEPTUNE (now called the U.S. Cabled Array), about 900 km of sea cables deployed on the sea bottom carry many different types of sensors to record changes in a variety of physical and biogeochemical variables. It has been operational since 2014. The NEPTUNE experiment has been duplicated in Canada and a similar experiment has been implemented in Europe: the European Multidisciplinary Seafloor and water-column Observatory (EMSO). These digital ocean infrastructures allow continuous monitoring of ocean variables and will increase our ability to anticipate significant events such as super-storms, eruptions, tsunamis and earthquakes. Biological observations, however, are not yet fully integrated into these observatory networks, highlighting an important technological gap. The development of sensors that allow real-time evaluation of biological variables, including characterization of biodiversity on the sea floor and in the water column, is a formidable innovation challenge. As biological sensors become increasing available, the prospect of a fully integrated ocean observing infrastructure becomes more realistic.



Cabled Array (formally NEPTUNE) site map off the North Pacific coast of the U.S.

Credit: U.S. National Science Foundation's Ocean Observatories Initiative

echosounding) and imaging technologies mounted on vessels or gliders, to be validated through traditional diving sampling methods (e.g. Wilson *et al.*, 2012).

Biologging

An increasing amount of information about marine animals from all the major taxa of top predators, including fish, reptiles, birds and mammals, is collected today using biologging devices (Bograd *et al.*, 2010). Such devices have been used for a long time to investigate the behaviour and physiology of free ranging animals (e.g. Hunter *et al.*, 2003; Meir *et al.*, 2008; Cermeño *et al.*, 2015; Weimerskirch *et al.*, 2015), the behavioural ecology and population structure of top predators (e.g. Baird *et al.*, 2010; Russell *et al.*, 2015) and, more recently, to collect environmental data on the appropriate scales and accuracies to support in depth ecological studies (e.g. Biuw *et al.*, 2007; Hindell *et al.*, 2016) and environmental applications (e.g. Mallett *et al.*, 2018; Pellichero *et al.*, 2018). Over the last decade, biologging has been an invaluable tool to integrate information about higher trophic levels into observing systems (Boehme *et al.*,

2010) and utilizing larger marine animals as platforms of opportunity enables the collection of detailed concurrent environmental, biogeochemical and biological information. Combining biologging information with other data sources enables the observing system to address specific questions e.g. the anthropogenic impact on top predators, closing a gap between resources and requirements (e.g. Johnston *et al.*, 2014; Hastie *et al.*, 2016).


Credit: Decleer Misjel - VLIZ

A Herring Gull, tagged under the LifeWatch programme.

Citizen Science

Citizen Science is the collaboration between scientists and the general public as volunteers to gather data relating to the natural world and/or collaborate in the data analysis. Citizen Science has an important role to play in ocean observations. It would be impossible for scientists alone to gather sufficient data to generate a comprehensive understanding of all marine systems, especially given the increasing urgency for scientific knowledge to assess the effects of human activities. Working together with a large number of interested volunteers does not only increase the amount of information acquired, but can make marine environments, sometimes apparently remote and unconnected, more accessible to the general public, promoting the principles of Ocean Literacy. Citizen Science projects can observe and gather data from marine and coastal flora and fauna, marine pollution or beach litter, status of local ecosystems, fishing, water properties and other physical features (European Marine Board Policy Brief 5 (2017)). Some programmes have already yielded excellent science (e.g. the Secchi Disk Seafarers (Seafarers *et al.*, 2017), the Reef Life Survey, (Edgar *et al.*, 2014), the evaluation of jellyfish presence in the Mediterranean Sea over the long term (Boero *et al.*, 2016), etc.), which has resulted in a number of high profile global insights (Stuart-Smith *et al.*, 2013); (Edgar *et al.*, 2014). The European Marine Board Position Paper 23 "Advancing Citizen Science for Coastal and Ocean Research" highlights how to make a Marine Citizen Science project scientifically based, reliable and successful (García-Soto *et al.*, 2017) and also provides an overview of some

INFOBOX 4.5

Taxonomy: the foundation of biological observations

Taxonomy is the science of naming, describing and classifying organisms and includes all plants, animals and microorganisms of the world. Using morphological, behavioural, genetic and biochemical observations, taxonomists identify, describe and arrange species into classifications, including those that are new to science (CBD, 2007). The longest running biological observations and time-series programs are therefore taxonomy-based.


Credit: Mieke Sterken - VLIZ

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. In addition, the discovery in the natural environment of a high number of genes not corresponding to any known taxa has highlighted the gaps in our knowledge of marine biodiversity (De Vargas *et al.*, 2015), highlighting the need for more detailed and joint molecular and taxonomic studies to enable the exploitation of the ever growing availability of metabarcoding 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 (Navigating the Future IV, European Marine Board 2013). 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 (Heip & McDonough, 2012).

Incentives should be provided to maintain existing classical taxonomic expertise and to support the education and training of young scientists in taxonomy; and in the process, enhance the taxonomic component of marine ecological research (Heip & McDonough, 2012).


Credit: Leoni Adams, Ocean Observatories Initiative

Coastal survey conducted by the Citizen Science project CoCoast.

of the many Marine Citizen Science projects already running in Europe.

Marine stations

Long-term biological observations are maintained by several marine stations throughout Europe. Most focus mainly on plankton, which provides a proxy for the state of marine biodiversity. The definition of a European strategy of long term time series, based on these local observation systems, extended to other components of biodiversity (nekton and benthos), would be a great contribution to the maturation of current observing systems. However, it is of concern that several marine stations linked to universities have been closed in recent years and there is a reduction in the importance given to classical techniques such as taxonomy (Drew, 2011).

Marine Protected Areas

The protection of marine biodiversity is the first aim of Marine Protected Areas (MPAs), from nationally designated MPAs to the Sites of Community Importance of the Natura 2000 Network. Detailed biodiversity inventories are currently not available for most of these sites which are generally well preserved and rich in species. MPAs represent a good opportunity to start all-species inventories that will become benchmarks for the evaluation of the state of biodiversity.

Fisheries and aquaculture programmes

As main providers of food from the marine environment, fisheries and aquaculture activities undertake observation programmes (e.g. catch composition, species distribution and abundances) and are an important source of information regarding nekton and benthos in some instances (e.g. ICES databases). The data gathered is provided to government agencies (e.g. long-term datasets on pathogens), and seldom used by other scientific programmes (e.g. trend analysis and water quality indicators).

Other industries present in the marine environment, such as aggregate, oil and gas extractors, offshore wind farms, infrastructure developers, etc.; also gather marine data during Environmental Impact Assessments and monitoring required as the condition of a license to operate. A challenge remains to collate their data for wider use. Initiatives such as SeaDataNet and EMODnet (see box 3.4) are facilitating the publishing of industry data as open data, to contribute to future applications for society.

Merging these operating networks and programmes that already have personnel and infrastructures is a sensible strategy. Fostering these initiatives will require appropriate budget, but they provide a solid basis that is worthy of consideration to further strengthen observing capacity of marine biodiversity globally.

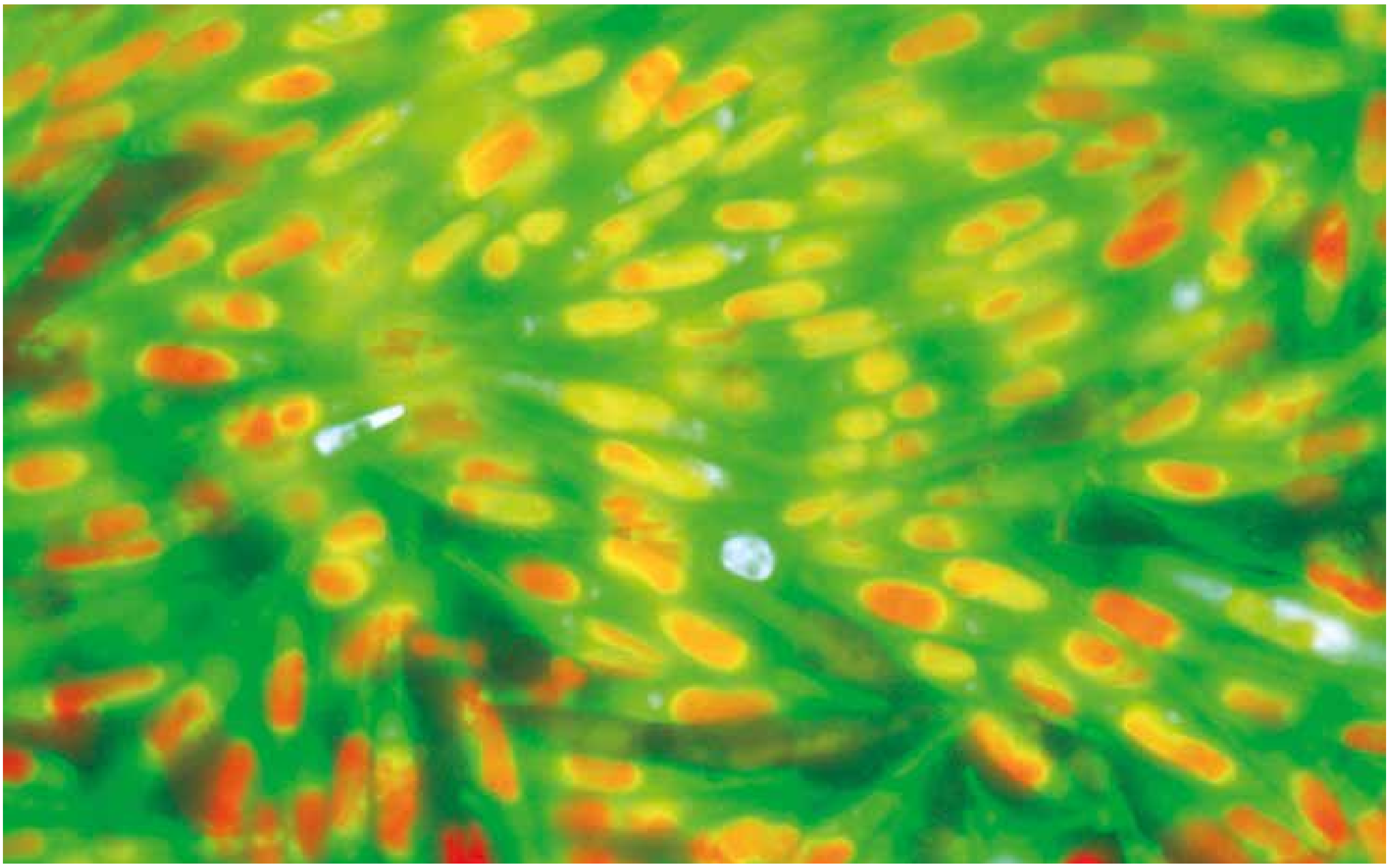
4.5.1 Implementation of new technological advances in biological ocean observing systems

Emerging areas of biological ocean observing technology includes sampling tools to measure molecular genetics ('-omic' tools), imaging and optics techniques and hydro-acoustic (both active – echosounder and sonar, or passive – hydrophone) approaches. In addition, the development of sensors to allow automated monitoring of marine biodiversity that make broad-scale observations more feasible in different marine habitats, are key for a purely integrated global biological observing system of seas and ocean. There is also a drive towards miniaturization of sensors, including those for biogeochemical and biological variables. The application of these technologies, in association with available platforms (e.g. unmanned vehicles, moorings, marine mammals and gliders) provide a growing amount of biological information since the techniques and programmes dramatically increase spatio-temporal resolution and organization levels (individual, population or functional group). They also reduce the time between sampling and data supply, increase the relevance of the ecosystem information they provide and the cost effectiveness of the monitoring programme. The application of these new technologies provides new insights into ecosystem function, dynamics and diversity.

Omic tools

These include a set of techniques suitable for the detection and quantification of genomes (DNA; genomics), transcriptomes (mRNA; transcriptomics), proteins (proteomics) and metabolites (metabolomics) relevant to the structure, function and dynamics of organisms. The prefix meta- ("beyond") is used when -omic technologies are applied to the analysis of environmental samples, used to characterize ecological communities (metagenomics, metatranscriptomics and metaproteomics (Marchesi & Ravel, 2015; Gilbert & Dupont, 2011)).

DNA sequencing methods can be applied to either single-gene surveys, in which single-genes (usually characteristic gene targets) are amplified through the polymerase chain reaction (PCR), or from random "shotgun" studies (sequencing to get largely unbiased samples of all genes from all the members of the sampled communities), in which the total DNA from a sample is sequenced to obtain a profile of all genes within the community



Credit: Jean-Paul Cadoret / Antoine Carlier, Ifremer

Phaeodactylum tricornutum, a phytoplankton species, is the second diatom for which a whole genome sequence has been generated.

(Gilbert & Dupont, 2011). Not defined as an omic technique *per se*, DNA barcoding is based on sequencing of short genetic sequences that are known to belong to a given species. This technique can be useful to identify cryptic species, which seem widespread in marine ecosystems, link different life stages and detect invasive species (Trivedi *et al.*, 2016). DNA barcoding complements and expands traditional taxonomic methods for individual species identification, by reducing processing time and increasing resolution when applied to cryptic and sibling species or when it is necessary to distinguish between strains of a given species, such as in harmful algal bloom (HAB) monitoring programmes (e.g. Eckford-Soper *et al.*, 2013).

The assessment of diversity is one of the main goals of biological monitoring programmes. At this early stage of the field, the application of environmental DNA (eDNA) barcoding (metabarcoding) techniques (see box 4.6) to assess taxonomic diversity, identify species present and trace non-indigenous species (e.g. Zaiko *et al.*, 2016) needs to be used alongside traditional taxonomy. In addition, the gaps in reference databases, caused by the lack of genetic information for many known species, mainly marine invertebrates, may strongly limit the possibility to identify and label the sequences found in the eDNA. Finally, metabarcoding potentially provides information on the relative (qualitative) abundance of genes (OTU, Operational Taxonomic Units) but not about absolute abundance or biomass, which is needed to assess biodiversity and still need to be assessed by traditional techniques, for instance: microscopy (e.g. phytoplankton), macro-photography (benthic invertebrates), visual inspection (marine mammals and birds) and acoustics (pelagic fishes), and/or state-of-the-art imaging and flow-cytometry.

The application of multi-omic approaches, which combine sequencing techniques and mass spectrometry, has great potential to reveal ecosystem function. While metabarcoding can elucidate the taxonomic diversity with a very high resolution, metatranscriptomics and metaproteomics shed light on the specific functions that are activated under certain environmental conditions. The realization of this potential is, however, constrained by computational and analytical bottlenecks imposed by the vast amount of biological data generated by omic approaches (of the order of terabytes per sample) and, more importantly, the need for robust interpretative frameworks based on ecological principles (Hanh *et al.*, 2016). As an example of the application of a multi-omic approach in relation to monitoring of HAB species, omic tools can be applied to: assess phylogenetic relationships among HAB taxa; differentiate between toxin and non-toxic cryptic species and strains; identify the genes and metabolic pathways involved with the production of toxins and other allelopathic metabolites; and develop biosensors for the *in situ* detection of micro-algae toxins (Anderson *et al.*, 2012).

INFOBOX 4.6

Environmental DNA (eDNA)

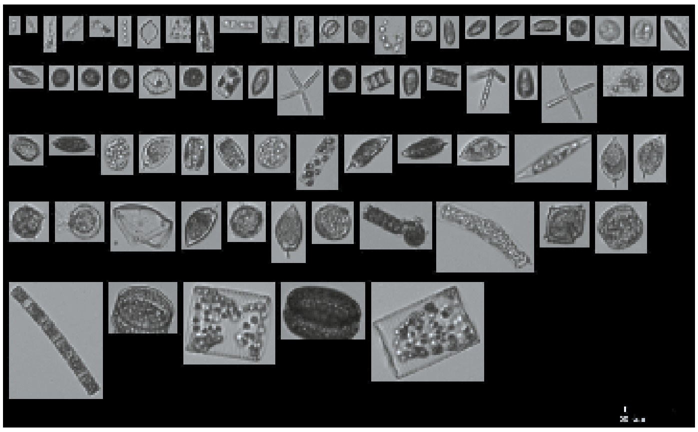
Environmental DNA refers to nucleic acid material that is extracted directly from environmental samples, with no obvious evidence of the presence of the organisms to which that material belongs. DNA from environmental samples can derive from fragments, tissues, gametes or free nucleic acid material of large organisms, which release this material into the environment. Hence in the marine environment jellyfish, fish and even mammals can be traced through the High Throughput Sequencing (HTS) metabarcoding analyses of eDNA obtained by filtering a few liters of seawater. The analysis of eDNA from filtered aquatic samples was initially conceived and applied to the study of microorganisms such as whole bacteria, archaea or eukaryotic unicells (algae, ciliates, other protists) or microscopic metazoans, which are collected on filters.

While eDNA analysis can also occur via selective molecular techniques (such as quantitative real-time PCR or qPCR) that enable the detection and quantification of individual species (allowing the quantification of microorganisms and activities), HTS of bulk eDNA material (metagenomics) or of selected marker DNA fragments used for species identification (metabarcoding) is the most frequently-used technique. World-wide scale metagenomics and metabarcoding analyses (e.g. through the Sorcerer, Tara Ocean and Malaspina cruises) have contributed extraordinary insights into the diversity and distribution of marine microorganisms.

Calibration of targeted eDNA tools for the assessment and quantification of specific species can extend the limits of how these tools might be used on animals in marine environments (Jungbluth *et al.*, 2013; Minamoto *et al.*, 2017). These tools allow the recovery of in-depth information on rare organisms that are difficult to recover by DNA sequencing. Targeted eDNA approaches are likely restricted to certain organisms, and field evaluation relative to traditional approaches is still required. Recombinase Polymerase Amplification (RPA) has advanced in recent years as a promising complementary technique with increased amenability to automation.

Imaging and optical techniques

Imaging systems enable visual records from physically observable properties of a given subject. The basic elements of an imaging system are: the observable properties, determined by the electromagnetic or mechanical (acoustic) energy emitted, reflected or absorbed by the subject; the sensor to capture this energy; and the processor and algorithms which transform the signal to render a digital image. Optical imaging systems can be classified as either 'active' or 'passive' depending on whether the imager generates the light or not (Jaffe *et al.*, 2001). Examples of passive optical imaging include underwater photography using ambient light, for instance to quantify the degree of coral bleaching (Chow *et al.*, 2016) and spectral reflectance data acquired by spectroradiometers mounted on satellites, aircrafts or drones. Spectroradiometers have been successfully applied to monitor physical (e.g. Sea Surface Temperature (SST), Le Traon *et al.*, (2015)), chemical (e.g. oil slicks, De Carolis & Pasquariello (2014)), biogeochemical (e.g. coloured Dissolved Organic Material (DOM), (Beltrán-Abaunza, *et al.*, (2014)) or biological (e.g. biomass of phytoplankton functional groups, Sathyendranath *et al.*, 2014)) properties of the upper ocean (Robinson *et al.*, 2008).


Credit: Sofie Vranken - VLIZ

Visualization of phytoplankton using FlowCAM.

Active optical systems include those measuring bulk optical properties, such as multi-spectral fluorescence, absorption/variable fluorescence or modulated/ pulsed light-source, which measure photosynthetic efficiency (light/ laser detection and ranging – LIDAR/ LADAR respectively), macro-photography and *in situ* (or in lab) micro-photography (Jaffe, 2015), alone or combined with (scanning) flow cytometry. Fluorescence can also be combined with cell characteristics such as electrical impedance (Benazzi *et al.*, 2008; Davis and McGillicuddy, 2006), to increase taxonomic resolution.

The past decade has witnessed a step change in our ability to image objects underwater due to advances in electronics and sensing technology coupled with signal and image processing and new approaches to measure rates of phytoplankton photosynthesis (Silsbe *et al.*, 2015, Lawrenz *et al.*, 2013). Figure 4.4 gives an example of the spatial pattern in primary production obtained using automated active fluorescence techniques, combined with automated scanning-flow cytometry as part of the new developments within JERICO-NEXT (Aardema *et al.*, 2018).

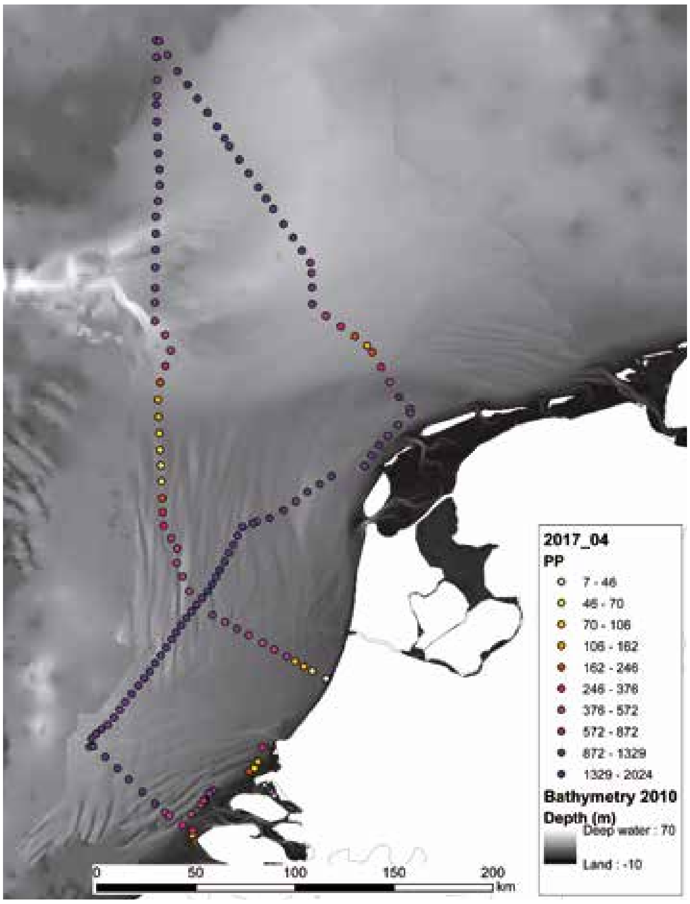
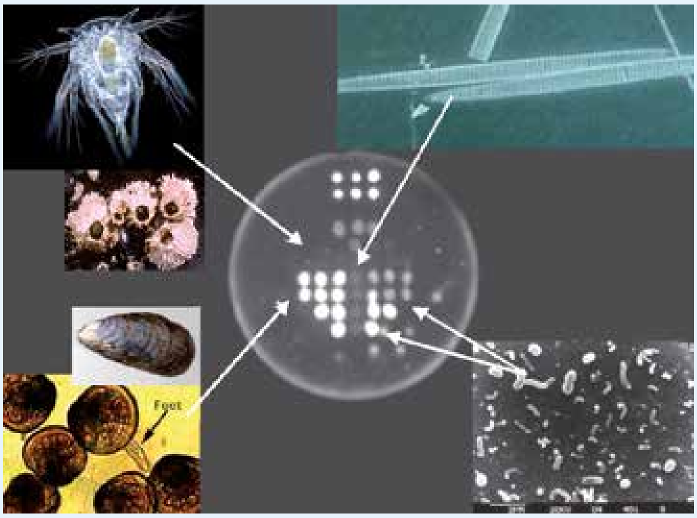


Figure 4.4 Primary production based on automated Fast Repetition Rate Fluorometry, using the water inlet of the ship (RV Zirfaea), so the estimates of the daily water column productivity (mg C/m^2/day) are based on samples taken at a fixed (subsurface) depth. From Aardema *et al.*, (2018).

For instance, underwater video and macro-photography have been applied to map seagrass meadows (Rende *et al.*, 2015), to assess the ecological quality of benthic habitats (Romero-Ramirez *et al.*, 2013), to monitor functional changes in animal activity and behaviour (Romero-Ramirez *et al.*, 2016; Weaver and Huvenne, 2014), or to assess coastal marine biodiversity (Mallet *et al.*, 2014). But most advances consist of the development of automated sampling devices to image plankton organisms of different size, from pico- to macro-plankton (from microns to millimetres), *in* or *ex situ* (Benfield *et al.*, 2007). Combinations of these techniques (micro-photography and fluorescence sensors, microphotography and flow cytometry) can provide ancillary information from the imaged plankton, such as intracellular fluorescence (e.g. Álvarez *et al.*, 2017). Given the key role of plankton in biogeochemical cycles and food-web structure and its rapid response to environmental change, plankton-based indices have been proposed as surveillance indicators to assess ecosystem health and to disentangle the effect of natural variability and anthropogenic drivers (McQuatters-Gollop *et al.*, 2017; Bedford *et al.*, 2018; Buttigieg *et al.*, 2018). Automated imaging devices have been advocated as appropriate tools to increase our understanding of plankton dynamics. These techniques offer several advantages compared to traditional microscopy methods: they (i) reduce the processing time allowing the analysis of a larger number of samples and the evaluation of a wider range of spatial and temporal scales of plankton distribution and dynamics (Romagnan *et al.*, 2015); (ii) allow the quantification of individual traits (e.g. size and shape) from which robust estimates of carbon biomass can be derived (e.g. Álvarez *et al.*, 2016); (iii) integrate information at different organization levels (individuals, populations, functional groups, communities) allowing the estimation of derived variables such as size spectra and biomass and production per size-class (Vandromme *et al.*, 2014); and (iv) facilitate the standardization of methods and adoption of common protocols for taxonomic identification, for instance through collaborative tools for image annotation (e.g. EcoTaxa – Picheral *et al.*, 2015). Some disadvantages of the automated technologies are the relatively high cost of manufacturing, maintenance and operation, although some affordable solutions have been proposed (Orth *et al.*, 2018), and some prototype devices have not been completely validated (e.g. Karlson *et al.*, 2017). As with omics tools, automated imaging methods need to be applied in combination with traditional approaches that provide a necessary benchmark to study plankton distribution and diversity.

INFOBOX 4.7

Environmental Sample Processor (ESP)

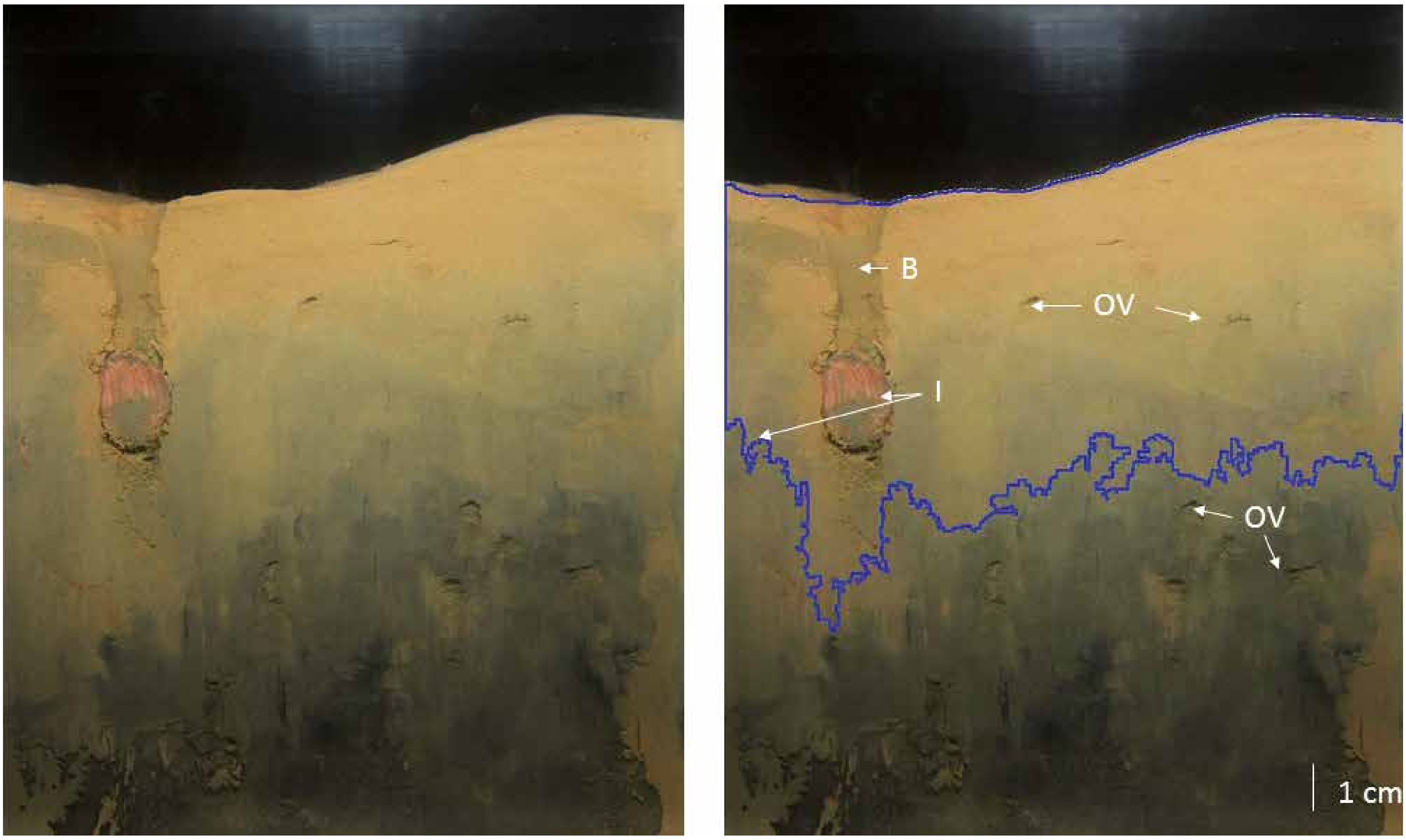


Montage showing an array from the first-generation Environmental Sample Processor (center) surrounded by some of the organisms that can be detected using probes in the array.

Credit: Monterey Bay Aquarium Research Institute - MBARI

Because of the difficult access and prevalence of largely unexplored microbial life, the deep sea has always presented obstacles to human knowledge on the functioning of marine ecosystems. The real challenge of collecting samples, enumerating and identifying microorganisms and their functions, is being overcome by the introduction of new devices based on imaging (see main text) or of even more sophisticated DNA, RNA and protein detection systems.

The Environmental Sample Processor (ESP), developed at the Monterey Bay Research Institute[66], is an *in situ* robotic device that autonomously collects and analyses sea water samples detecting organisms and/or toxins. Samples can either be preserved and archived for delayed analyses in the lab or directly analyzed with molecular technology to produce near real-time biological data. The instrument has been used to detect and quantify the presence and activity of the toxic diatom *Pseudo-nitzschia* (Bowers *et al.*, 2016), its toxin domoic acid (Doucette *et al.*, 2009); and in several other studies targeting different microorganisms. It has been deployed in combination with other autonomous or remote sensors on ocean moorings and in the deep sea (McQuillan & Robidart, 2017; Scholin *et al.*, 2017). The ESP is dependent on targeted analytics and therefore is best used for previously characterized organisms / sequences.



Sediment Profile Image collected in the West Wironde Mud Patch during the JERICO-NEXT project. The original image is on the left and the same image processed with a dedicated semi-automated image analysis software. The analysis of sediment Profile Images can be used to infer sound assessments of the ecological quality of benthic habitats. The two blue lines are the sediment-water interface (top) and the apparent redox Potential Discontinuity (bottom). B: Burrow, I: Infauna, OV: Oxic void.

Credit: Alicia Romero-Ramirez and Antoine Grémare

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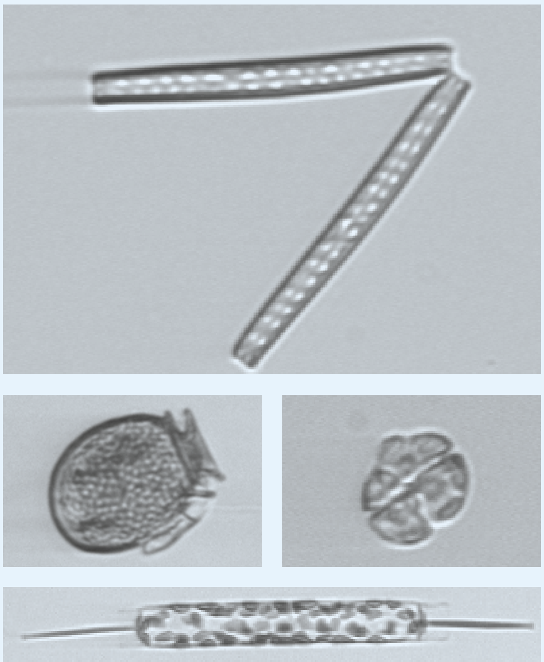
[66] https://www.mbari.org/

INFOBOX 4.8

Imaging Flow Cytobot (IFCB)



Images of phytoplankton species obtained with IFCB.

Credit: Lisa Campbell - MBARI

The IFCB is a submersible instrument that combines flow cytometric and video technology to capture high resolution images of suspended particles (10 - 150 µm). Samples are collected approximately every 20 minutes and chlorophyll fluorescence is used to trigger image acquisition. Image files are transmitted to shore and can be viewed via a dashboard (website).

Automated processing and machine-learning technology enables near real-time reporting of phytoplankton abundance at the genus, functional group or even species level (Olson & Sosik, 2007).

Analysis of IFCB time series can also detect harmful algal blooms (Campbell *et al.,* 2010), identify species interactions (symbiosis, parasites, predation), life cycle stages, as well as the variability and diversity of the phytoplankton community including changing phenology due to climate change (Hunter-Cevera *et al.,* 2016).

Multidisciplinarity and data integration

Despite the specificities of each biological component, observations need to be combined in a comprehensive and multi-disciplinary way, to seek synergies among platforms (vessels, moorings, gliders, remote sensing), technologies (imaging, acoustic, genetic), databases (integrate disparate data types and resolutions) and networks (inter-connection of data centres), and to envision technologies to facilitate and automate biological observations (Palacz *et al.,* 2017). The capacity for integrating disparate data will be challenged as new technologies are implemented (e.g. collection of images from imaging systems or acoustic spectra of targets from broad-band echo-sounders). An activity that can be considered part of the data integration process is the recovery of historical data through digitalization of ancient data reports and collections. These historical data provide important information to establish baselines and reference conditions, if the temporal dynamics (e.g. natural oscillation) of the considered parameters are fully understood. Data recovery has also been the focus of OBIS through data archaeology, such as historical data on fisheries and other related marine data being retrieved by its Oceans Past Initiative (OPI[67]) (Schwerdtner Máñez *et al.,* 2014).

The cultural revolution of free and open data sharing that has been achieved for most platforms measuring open ocean physical variables is not universal to biogeochemical and biological variables, and to certain areas under national jurisdiction. Additionally, integrating multidisciplinary data is a difficult task. Physical, chemical and biological data are maintained in different repositories that are seldom integrated. The OBIS-ENV-DATA[68] project has designed a possible data schema standard to capture and exchange both complex biological and abiotic environmental data (De Pooter *et al.,* 2017). EurOBIS and EMODnet biology store and exchange complex, multidisciplinary data types, such as benthic ecosystem samples: species composition, nutrient concentrations, sediment granularity or sediment profile images. The application of the OBIS-ENV standards in acoustic telemetry, bird GPS tracking, flow cytometry, metagenomics and plankton imagery is in full development.

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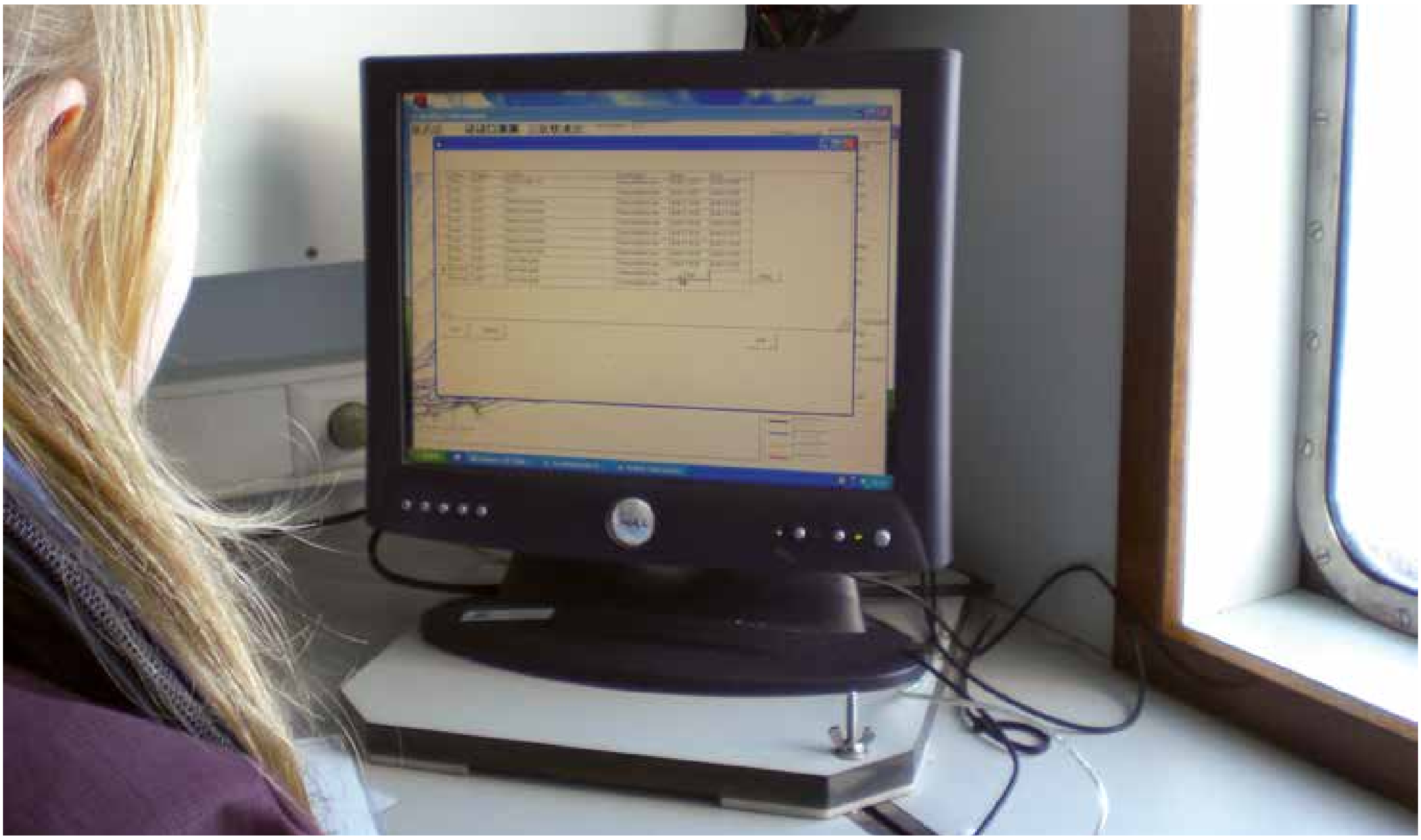
[67] http://oceanspast.org/

[68] http://www.iobis.org/2017/01/12/obisenvdata/



Credit: Angel Muniz Piniella

Digitalization of ancient data reports and collections could provide useful information about former marine conditions.

In both the Integrated Ocean Observing System (IOOS) and the Integrated Marine Observing System (IMOS) (see Box 3.2), the emphasis is clearly on the acquisition of automatically and high-frequency measured data that can be processed and used (e.g. for data assimilation) in near real-time. This is well suited for geophysical data because of the co-existence of automated sensors and of efficient models. This approach has proven efficient for the open ocean but is likely to show limitation in the coastal ocean due to the importance of biological components, processes and spatio-temporal complexity. It is essential to include biological variables, which raises the issue of how the acquisition of biological and geophysical variables should be harmonized.

We can envisage two ways forward: (1) the achievement of a large variety of small-scale (spatial and temporal) projects (e.g. Hawaiian IOOS reef fish project, and JERICO-NEXT Joint Research Activity Projects) in which the synoptic acquisition of biological, biogeochemical and geophysical data will allow practical experience regarding such coupling to be gained, and (2) larger projects extending over longer time periods (e.g. IMOS Plankton 2015 project) or extending sustained programmes (e.g. Copernicus[69]) and tackling more general scientific questions. The second option needs to acknowledge the extreme difficulty in achieving: (1) synoptic biological observations at a system of systems level, and (2) a coupled analysis between biological, biogeochemical and geophysical data at such a scale. These two approaches will indeed prove highly complementary and it is recommended that they should continue to coexist based on the purpose (e.g. global vs. regional or even local) and the location (e.g. open vs. coastal ocean) of considered monitoring. Clearly small-scale projects have the potential to explore alternative strategies and approaches for cost-efficient data acquisition and provide new views on how to develop sustained programmes.

4.5.2 How to harmonize data collection, acquisition, modelling and data analysis procedures?

A more universal uptake of autonomous samplers and sensors is required in order to provide large-scale synoptic biological datasets to integrate with biogeochemical and physical datasets. The development of robust, miniaturized, user-friendly and low-cost deployable sensors and samplers reduces the need for ship operations, saving time and costs, and will significantly increase data spatial coverage by ensuring wide uptake and sustainable use by diverse economies.

Irrespective of the absolute necessity or not of integrating observation at the level of a whole system of systems, there is a clear need to implement best practices in data acquisition. In IOOS this is a federative effort achieved through interactions with the Alliance for Coastal Technologies (ACT).

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[69] http://marine.copernicus.eu/

INFOBOX 4.9

Some demonstration themes to be addressed through a multidisciplinary approach

1. Plankton community changes

The plankton community makes up the base of the marine food web and plays a central role in global biogeochemical cycles, providing important ecosystem services such as fixing carbon, and as food to commercial fish. Marine ecosystems are changing, e.g. in terms of warming surface water, increasing CO_2 concentration and eutrophication, and plankton communities, due to their relatively high growth rates, respond rapidly to changes with significant fluctuations in population sizes and community structure. Any change in the plankton community structure may cause indirect effects on the cycling of organic matter (e.g. biological carbon pump and trophic transfer). Given the significant limitations in terms of spatial coverage (too costly to cover big areas) and available technology (automated biological measurements are at an early stage), effective synergies must be sought and efforts must be concentrated on "hot spot" areas (Palacz *et al.,* 2017).

2. Open ocean, shelf and coastal ocean interactions

Coastal regions are highly dynamic, with strong spatial and temporal variability driven by local terrestrial influences at the land-shore boundary, coastal zone meteorology, tides, and, equally important, by forcing at the shelf/open-ocean boundary. They are central to the connectivity between catchments, estuaries and the open sea. The exchange at the ocean boundary, and shelf edge dynamics have immediate impacts on ecosystem function and productivity on weekly to seasonal time scales but can also drive multi-decadal changes in ecosystem structure through effects on habitat ranges and biodiversity. It is axiomatic that the ecology cannot be interpreted and understood unless there is a good understanding of the physico-chemical forcing variables. High-frequency spatial and temporal data is required to quantify these exchange mechanisms and identify their impact on shelf/slope biogeochemistry and biology. However, traditional shipboard sampling cannot provide sufficient spatial and temporal resolution to fully examine and quantify these processes and thus obtaining reliable budgets for carbon, heat, salt, and other properties on continental shelves relies on remote sampling, satellite measurements, etc. (Palacz *et al.,* 2017).

3. Benthic communities

Marine benthos comprises of organisms that live on the sea floor (Gray & Elliott, 2009). Most are attached to the substratum (sessile organisms) or have low mobility and as such they often cannot escape from adverse environmental conditions, thereby integrating environmental changes. In addition, given that almost every activity in the sea has the ability to adversely affect the bed sediments/substratum then the benthos will reflect those changes. In particular, intertidal and shallow subtidal habitats are easily accessible and include species rich communities with relatively short-lived individuals that respond quickly to environmental change. Thus, benthic communities are especially suited for long-term comparative investigations because they can be easily observed, have fast dynamics and integrate the effects of environmental change over time. These characteristics have promoted the use of benthic communities in biomonitoring programmes since the 1970s (Gray & Elliott, 2009).

There is a wide range of sizes within benthic communities, from microscopic (e.g. biofilms and microalgae) to macroscopic fauna and flora. However, many benthic communities are organized around habitat forming (foundation) species: large organisms that provide habitat and shelter to many other species, thus playing a disproportionate role in maintaining biodiversity. Examples of such habitats include seagrasses, macroalgal forests and animal forests (e.g. sea fans). Foundation species fulfil the role of ecological indicators for many other organisms, since loss of the habitat-forming species will cause a drastic change in the whole community.

Benthic communities, among others, are increasingly exposed to multiple and potentially interacting stressors, from local disturbances to global change. A key challenge is to distinguish the effects of anthropogenic disturbances from natural variation (i.e. the signal to noise ratio). Methods have been developed to assess anthropogenic impacts in naturally fluctuating environments, including Before-After, Control-Impact paired series (BACI) designs and their evolution (beyond-BACI designs) (Underwood, 1994). These methods require sustained observations of well-understood marine benthic communities across a wide range of scales in space and time, so their utility may increase with the implementation of integrated, multi-scale biological observing systems.

Credit: VLIZ

With modern technologies, such as remotely operated underwater vehicles (ROV), data gathering from underwater ecosystems has become easier, but these data require high input and capability from a skilled workforce.

This certainly constitutes a good model that should be further developed and could lead to the attribution of a label of good practices and implementation that would promote the harmonization and coordination of data acquisition among regional observation systems.

The analysis of this rich amount of information requires the application of numerical techniques that allow us to manage and interpret complex and voluminous datasets. 'Big Data' is used in other scientific disciplines, such as astrophysics, economics, and material sciences, and marine science can learn from their approaches. The benefits of using 'Big Data' are many, and include advancements in scientific understanding at larger scales and higher resolution, applications to improving environmental management and policy, and public engagement. There is an opportunity to bridge gaps between disciplines with similar techniques, such as atmospheric or terrestrial sciences. However, the application of 'Big Data' presents some particular challenges, which are common to all scientific disciplines, such as the need to develop new analysis methods (Durden *et al.,* 2017). There are a variety of numerical techniques and tools able to cope with what can become a 'Big Data' problem, the three Vs of 'Big Data': volume, variety and velocity (Russom, 2011); large datasets, with an ample range of formats and representations, and data produced and feeding the dataset at a high rate, such as predictive analytics, data mining, statistics and artificial intelligence (AI) methods. The ability to store and exchange data in a standardized way is an essential requirement to build the data processing e-infrastructure needed for 'Big Data' analysis. LifeWatch, JERICO-NEXT, ASSEMBLE plus[70] and EGI Engage[71] projects are working towards such an e-infrastructure.

Models

Modelling plays a key role to address scientific questions related to functioning and dynamics of the ocean system. Close coupling between models and observations is a priority since the latter are necessary to initialize, tune and/or validate the former. Additionally, modelling is important in the delivery of services to end-users. Assimilation of biological data into models could improve model prognosis and simulation under changing scenarios. Process-based models subject to data assimilation also provide interpolation between observations and potentially allow for intelligent data fusion between different data sources. Model requirements in terms of biological state variables, process and scales need to be taken into consideration in the design of sampling networks. The definition and parameterization of the functional forms that describe the interaction between system components require additional information from experimental and process-oriented studies. Conversely, models enable spatial and temporal optimization of observational networks to maximize the information gain from a given observation effort. Cost-wise, operating models, compared to *in situ* work, is cheap and the potential exists today for improving the effect of observational efforts by pre- and post-application of models.

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[70] http://www.assembleplus.eu/

[71] https://www.egi.eu/about/egi-engage/

The coupling of geophysical models with biological (food web or trait-based) and biogeochemical models is clearly a key issue to implement a sustained, integrated ocean observing system.

This process is happening to some extent with food-web models (Serpetti *et al.,* 2017), and is described in more detail in the upcoming EMB Policy Brief N°6 on Marine Ecosystem Modelling. The creation of a dedicated international task force should thus quickly become a priority.

4.6 Information products: outputs from the observing system

The outputs from the observing system must ultimately be able to support advice to policy makers, scientists, stakeholders and the general public on topics related to the main thematic areas that guide the implementation of observing systems: climate, real-time-services, and ocean health and sustainable exploitation of the marine ecosystems. This requires a downstream community dedicated to timely data post-processing, data valuation, documentation and dissemination and the implementation of mapping and decision support tools to translate data into knowledge and to support informed environmental policies (Sumaila & Cisneros-Montemayor, 2010). For instance, the EMODnet Use Cases[72] demonstrate the value of ready-to-use data to the public sector, private sector, scientific research community and society. In addition to public interests, economic stakeholders (e.g. sectors such as fisheries, aquaculture, shipping and mining) should benefit from observing systems to promote sustainable and rational exploitation of the marine environment and reduce the carbon footprint of maritime operations. The first users are scientists, employed in either public research, governmental organizations or private companies. These first users solicit user-friendly data archives, which are open, sustained, interoperable (both within and between disciplines) and well-documented, where data are validated and observational errors and biases are assessed. Aside from being users, scientists are also producers of information that is needed to interpret the data, transforming them into knowledge, stimulating new kinds of observations and driving technological development.

One way to support Ecosystem Based Management (EBM) measures at local and regional scales in order to inform policy makers, stakeholders and the general public, is through Integrated Ecosystem Assessment (IEA) (Borja *et al.,* 2016). IEA makes explicit links between the natural environmental variability, human activities and ecosystem status to assess the scale of impact and recovery from the diverse natural and anthropogenic drivers, allowing targeted management and the adoption of mitigation measurements. The IEA is generally based on a combination of numerical tools for data analysis and representation, such as Integrated Trend Analysis (Möllmann *et al.,* 2013), Bayesian Networks (Cook *et al.,* 2015; Gagne *et al.,* 2018) and Spatial Modelling (Coll *et al.,* 2016), which use as basic input data the quantitative information collected through harmonized ecosystem monitoring programmes. In those cases where quantitative data are unavailable, it is still possible to evaluate linkages between activities, pressures and ecosystem state by building on semi-quantitative and expert judgment methods (e.g. ODEMM[73] approach).

Additionally, ocean observation outputs play a crucial role in promoting an ocean-literate society that feels connected to, and identifies with, the global ocean. Biological observations can have a significant economic impact, in terms of sustainable fisheries and tourism revenues. Ocean observations connect people with the ocean. It allows them to engage with vast and remote locations, e.g. through automated video, actively participating in Citizen Science data collection, or learning about the ocean through science communication and media outlets. Preparing the general public 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 more aware of the need to sustainably manage vitally important marine ecosystems (Navigating the Future IV, European Marine Board 2013).

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[72] http://www.emodnet.eu/use-cases?field_portal_taxonomy_tid=23

[73] http://odemm.com/content/home

5

Summary and recommendations

A strategic vision is needed to provide the necessary long-term support for an integrated ocean observing system. Policy makers, innovators and scientists need to cooperate to identify the key steps for implementing such a vision. Enhancing biological ocean observing capacity will strengthen European marine biodiversity conservation and ensure the achievement of the Sustainable Development Goals.

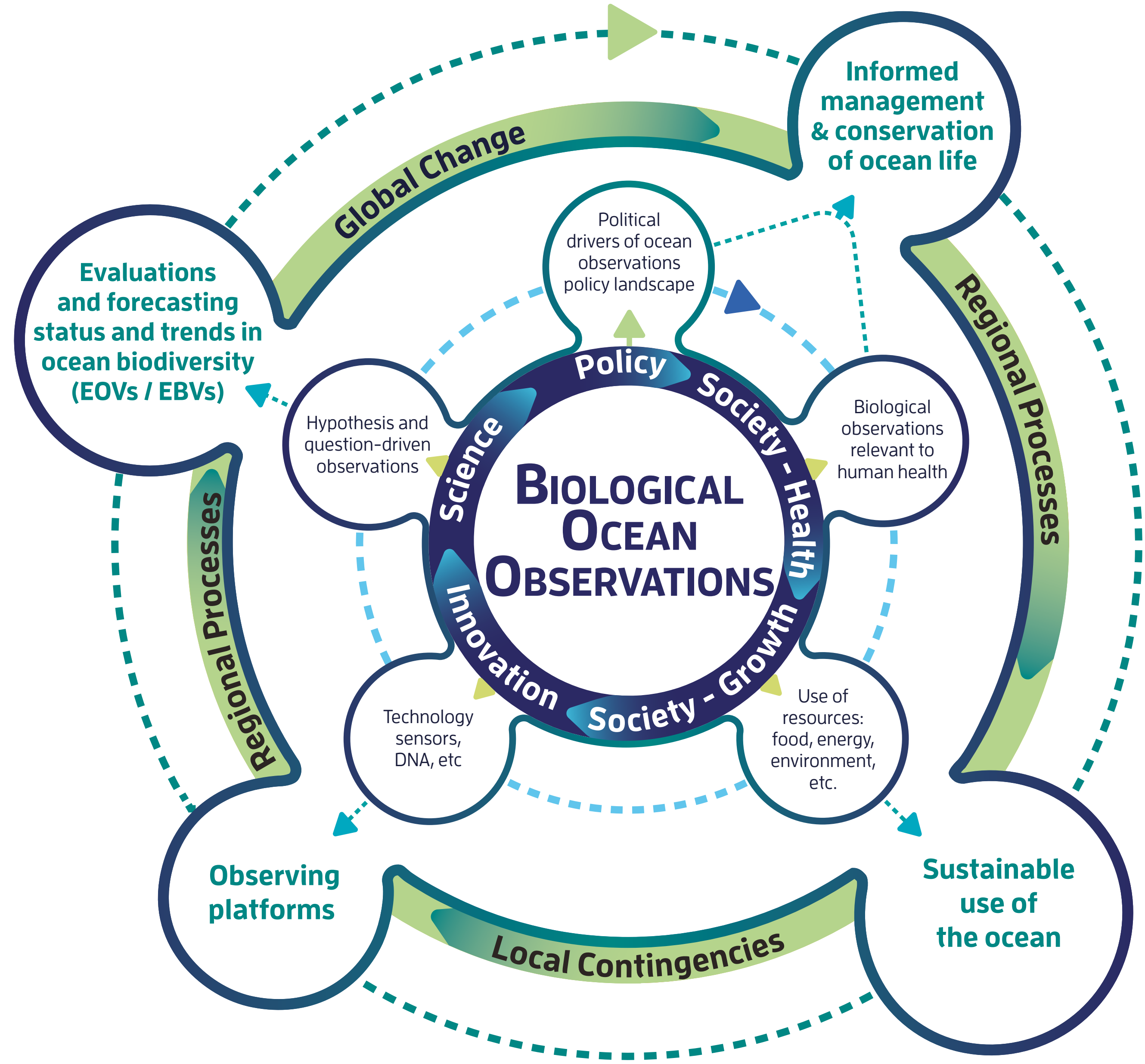
The global ocean provides key functions and services that sustain life, including climate control, oxygen production and provision of food and materials that contribute to human wellness. The ocean is composed of a series of complex systems that could change rapidly and unpredictably. Increasing human domination of the biosphere is affecting marine life in unprecedented ways. Understanding the cumulative effects of human activities at global, regional and local scales has become imperative, and many national and international bodies have implemented a range of policy initiatives to promote the conservation and sustainable use of marine ecosystems. Informed decisions require knowledge of what, where and how, to protect marine systems, but there are still enormous gaps in our understanding of patterns and trends in ocean biodiversity.

The United Nations has proclaimed 2021-2030 as the Decade of Ocean Science for Sustainable Development, with the main objectives of establishing new research networks and enhancing ocean observation systems. Existing observing networks have made substantial progress in harmonizing the collection, storage and dissemination of physical and biogeochemical measurements in the ocean. However, biological observations are lagging behind. The technology needed to automate the collection of high resolution biological data is still inadequate and limited to a few habitats and taxa. However, the pace of innovation in imaging technology, optical methods and metabarcoding (eDNA) is significant and there may be a possibility to automate biological ocean observations even in the short term. The digitalization of the ocean through the deployment of sensor networks will boost a 'Big Data' revolution in ocean science similar to that observed in atmospheric science. As our aptitude to scrutinize the ocean escalates, so will our ability to anticipate significant events, including super-storms, heat blobs, tsunamis, harmful algal blooms and their impacts on species and ecosystems. The role of science in informing policy to protect people, the economy and the ecology will continue to be emphasized.

Following the FOO framework, developing an integrated and sustained observing system requires a focus on socially relevant questions, standardization of observations (including technology and networks for data acquisition), and synthesis of observation products to respond to scientific and societal demands. In this Future Science Brief, we argue that observations should not be taken in a vacuum; they should rather be hypothesis-driven to reflect socially relevant questions, powerful enough to separate signal from noise and robust in design so they will continue to inform scientists, managers and society at large, under shifting environmental scenarios. Understanding how life in the ocean responds to cumulative global, regional and local threats requires comparisons of spatial patterns and temporal trends in contrasting environments. Observations should be obtained according to sampling designs that allow the detection of anomalies and change with respect to spatial and temporal reference points that reflect well-defined hypotheses about potential drivers.

By focusing on well-defined questions, a mature observing system will provide new insights into the role of marine biodiversity in maintaining ecosystem processes and services and elucidate how human activities interact with natural processes.

Essential ocean and biodiversity variables have been defined to facilitate the integration and standardization of biological ocean observations. These are not new variables *per se*, but refer to quantities that have been measured and estimated by marine biologists, ecologists and ocean scientists for decades. The novelty is the emphasis on social relevance and simplicity. Simplicity entails approaching the ideal requirements of quantitative observations with fine spatiotemporal resolution, long-term time series and global coverage, which would be impossible to achieve otherwise (Kissling *et al.*, 2018). Simplicity also allows the implementation of standardized ocean observations in developing countries, where some of the most pristine ocean ecosystems still thrive. Although the implementation of a global ocean observing system based on EOVs and EBVs is in its infancy, these efforts provide a unifying framework to harmonize and standardize ocean biological observations globally. This is a critical step to assess progress against national and international conservation targets and the Sustainable Development Goals (SDGs).



Credit: Stefi Klein Miloslavich

Figure 5.1 The relevance, nature and context of biological ocean observations.

In conclusion, biological ocean observations are necessary to guarantee the sustainable use of the ocean's living resources (Fig. 5.1). A strategic vision is needed to provide the necessary long-term support to coordinated ocean observing systems that integrate biotic and abiotic observations across local, national and global scales. Policy makers, innovators and scientists need to collaborate to identify the key steps for implementing such a vision. Taking ocean observing systems to the next level of maturity offers unique opportunities for technological innovation, and industry will be a key player in this digital revolution. Enhancing the biological ocean observing capacity will strengthen both the vision and implementation of the marine biodiversity conservation and good environmental status assessment, support wider Directives and regulations and promote the development of an integrated system that is adequate to meet user needs and requirements. In Europe, the European Ocean Observing System (EOOS) is a key coordinating framework to further develop the strategy and implementation of Europe's biological ocean observing system, in the context of the full integrated system, and as a contribution to global initiatives.

Recommendations to strengthen Europe's capability in Biological Ocean Observations

This box summarizes the recommendations based on this Future Science Brief to support the integration of biological ocean observations in the wider long-term observation context:

Build relevant biological ocean observations

- Identify key steps for designing and implementing a strategic vision on biological ocean observations, bringing together key stakeholders, to provide the necessary long-term support to a balanced and integrated ocean observing system that is a direct contribution to the European Ocean Observing System (EOOS) and harmonized with the Global Ocean Observing System (GOOS);
- Move towards an integrated approach where expert knowledge is used to implement socially-relevant biological observations;
- Focus on multidisciplinary hypotheses and question-driven biological ocean observation collection and analysis at local and regional scales, and promote systematic network-based observations to evaluate the status and trends of marine biodiversity at the global scale;
- Design and maintain observation programmes at the appropriate spatial and temporal scales that address scientific objectives and meet the needs of environmental policy and practice, industry and wider society;
- Prioritize key questions where improved biological observations will have the largest impact: productivity and the extent of the most productive marine habitats, changes in biological diversity, environmental impacts, including population collapse, regime shifts, resilience and recovery.

Integrate biological ocean observations

- Focus on Essential Ocean Variables (EOVs) and Essential Biodiversity Variables (EBVs), while supporting the collaboration between both GEO BON and GOOS frameworks, and considering additional variables where necessary;
- Coordinate and integrate observation programmes across scales (e.g. from coast to open sea), sources of data (e.g. fisheries programmes, Marine Protected Areas -MPAs, marine stations, satellites), habitats and taxa, and improve the connection between stakeholder communities and the use of shared infrastructure, protocols and data platforms;
- Improve coordination and integration of existing biological observation programmes with physical and chemical observing systems, technologies and modelling initiatives;
- Promote global integration through methodological standardization and best practices, allowing flexibility for biological observation programmes to match local and regional requirements.

Support current capacity on biological ocean observations

- Develop scientific capabilities to allow a greater knowledge of the biological ocean that can enhance the interpretation of data collected in observing systems, maximize their transformation into useful information and feed technological innovation;
- Support technological innovation to implement *in situ* biological observing systems and develop smart technologies for cost-effective automated monitoring of biological variables;
- Support capacity development, especially in taxonomic expertise and in the use of new emerging technologies, data science, analysis and management, as key components of biological observation;
- Promote Citizen Science, to improve observation capacity as well as increase the awareness of the importance of biological observations and their methods, to increase public confidence in science and potentially their emotional connectedness with the marine environment;
- Engage communities with observation programmes through collaboration, communication and education, to show the high value and benefits of monitoring marine ecosystems;
- Enhance biological ocean observing capacity to underpin sustainable management of human activities in the marine environment, to contribute to the achievement of key Sustainable Development Goals (SDGs) and to bring a wide range of benefits to society.

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List of Abbreviations and Acronyms

ActionMed	Action Plans for Integrated Regional Monitoring Programmes, Coordinated Programmes of Measures and Addressing Data and Knowledge Gaps in Mediterranean Sea
AI	Artificial Intelligence
ASSEMBLE	EU FP7 project on Association of European Marine Biological Laboratories
ASSEMBLE plus	Association of European Marine Biological Laboratories Expanded
BACI	Before-After, Control-Impact
BBNJ	Marine biological diversity of areas beyond national jurisdiction
CBD	Convention on Biological Diversity
CC	Community Composition
CCAMLR	Convention for the Conservation of Antarctic Marine Living Resources
CFP	Common Fisheries Policy
CIOOS	Canadian Integrated Ocean Observing System
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMS	Convention on the Conservation of Migratory Species
CO_2	Carbon Dioxide
CPR	Continuous Plankton Recorder
DG MARE	Directorate-General for Maritime Affairs and Fisheries
DNA	Deoxyribonucleic acid
DOM	Dissolved Organic Material
EBM	Ecosystem Based Management
EBSA	Ecologically or Biologically Significant Marine Areas
EBV	Essential Biodiversity Variable
ECV	Essential Climate Variable
eDNA	Environmental Deoxyribonucleic acid
EEA	European Environment Agency
EEZ	Exclusive Economic Zone
EF	Ecosystem Function
EGI Engage	EU project on Engaging the European Grid Infrastructure (EGI) Community towards an Open Science Commons

EMB	European Marine Board
EMODnet	European Marine Observation and Data Network
EMBRIC-ERIC	European Marine Biological Research Centre
EMSO-ERIC	European Multidisciplinary Seafloor and water column Observatory
EOOS	European Ocean Observing System
EOV	Essential Ocean Variable
ES	Ecosystem Structure
ESP	Environmental Sample Processor
ETN	European Tracking Network
EU	European Union
EurOBIS	European Ocean Biodiversity Information System
EuroGOOS	European component of the Global Ocean Observing System
FAO	Food and Agriculture Organization of the United Nations
FOO	Framework for Ocean Observing
FP7	7th Framework Programme
G7	Group of Seven
GC	Genetic Composition
GEO BON	Group on Earth Observations Biodiversity Observation Network
GES	Good Environmental Status
GOOS	Global Ocean Observing System
GRCM	General Fisheries Commission for the Mediterranean
HAB	Harmful Algae Bloom
HELCOM	Baltic Marine Environment Protection Commission
I3	Integrated Infrastructure Initiative
ICES	International Council for the Exploration of the Sea
IEA	Integrate Ecosystem Assessment
IFCB	Imaging Flow Cytobot
ILTER	International Long Term Ecological Research

IMOS	Australian Integrated Marine Observing System
IOC-UNESCO	Intergovernmental Oceanographic Commission of UNESCO
IOOS	U.S. Integrated Ocean Observing System
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
IUU	Illegal, Unreported and Unregulated fishing
JERICO	EU FP7 project on Joint European Research Infrastructure network for Coastal Observatory
JERICO-NEXT	EU Horizon 2020 project on Joint European Research Infrastructure network for Coastal Observatory – Novel European eXpertise for coastal observaTories
JGOFS	Joint Global Ocean Flux Study
LADAR	Laser Detection and Ranging
LIDAR	Light Detection and Ranging
LifeWatch-ERIC	e-Science and Technology European Infrastructure for Biodiversity and Ecosystem Research
MBON	Marine Biodiversity Observation Network
MEDPOL	Programme for the Assessment and Control of Marine Pollution in the Mediterranean
MEOP	Marine Mammals Exploring the Ocean Pole to Pole
MPA	Marine Protected Area
mRNA	Messenger Ribonucleic acid
MSFD	Marine Strategy Framework Directive
MSP	Maritime Spatial Planning
NEPTUNE	Northeast Pacific Time-Series Undersea Networked Experiments
NOAA	U.S. National Oceanic and Atmospheric Administration
NOVANA	Danish National Monitoring and Assessment Programme for the Aquatic and Terrestrial Environments
OBIS	Ocean Biogeographic Information System
OBIS-ENV-DATA	IODE intiated on “Expanding OBIS with environmental data”
OceanObs’09	International Ocean Information for Society conference (2009)
OceanObs’19	International Ocean Information for Society conference (2019)

OECD	Organisation for Economic Co-operation and Development
OPI	Oceans Past Initiative
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
OTN	Ocean Tracking Networks
OTU	Operational Taxonomic Units
PCR	Polymerase Chain Reaction
POGO	Partnership for Observation of the Global Oceans
QS	Quality Status
RFMO	Regional Fisheries Management Organization
RLS	Reef Life Survey
ROOS	Regional Ocean Observing System
RPA	Recombinase Polymerase Amplification
RSC	Regional Sea Convention
SAC	Special Area of Conservation
SAHFOS	Sir Alister Hardy Foundation for Ocean Science
SCI	Sites of Community Importance
SDG	Sustainable Development Goal
SeaDataNet	Pan-European infrastructure for ocean & marine data management
SFPA	Sea Fisheries Protection Authority
SP	Species Populations
SPA	Special Protection Area
SST	Sea Surface Temperature
ST	Species Traits
TBM	Sea Turtles, Seabirds and Marine Mammals
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UNEP/MAP	Barcelona Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean
UNFSA	United Nations Fish Stocks Agreement

U.S.	United States
WFD	Water Framework Directive
WG BIO OBS	EMB Working Group on biological ocean observation
WS	Wild Species
WOA	World Ocean Assessments
WOCE	World Ocean Circulation Experiment
WoRMS	World Register of Marine Species

Annexes

Annex 1: Members of the European Marine Board Working Group on Biological Ocean Observations (WG BIO OBS)

NAME	INSTITUTION
Adriana Zingone	Stazione Zoologica Anton Dohrn, Italy
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Lisandro Benedetti-Cecchi (Chair)	University of Pisa, Italy
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Annex 2: Table of Biological Essential Ocean Variables (EOVs)

Identified by the Biology and Ecosystems panel of the IOC-UNESCO Global Ocean Observing System. In addition to the 8 identified EOVs, there are two emerging EOVs (Microbial diversity and biomass, and Benthic invertebrate distribution and abundance) which will be developed in the near future. MSFD descriptors and indicators related to the EO variables and sub-variables are also included.

EOV	SUB-VARIABLES	DERIVED PRODUCTS	SUPPORTING VARIABLES	RELATED MSFD DESCRIPTORS AND INDICATORS
Phytoplankton biomass and diversity	• Presence/Absence/Relative Abundance • Diversity/Taxonomy, • Genomic information • *In vitro/in vivo* pigment fluorescence • Pigment concentration by spectrophotometry (chlorophyll a, b, HPLC pigments) • Spectral reflectance (ocean color/remote sensing methods) • Primary productivity (different methods)	• Phytoplankton functional types • Diversity indices: species richness; species evenness • Harmful or beneficial algal bloom indices, including harmful algal events • Global biogeography / spatial distribution • Primary production, carbon and nutrient cycling, storage, and export	• Nutrients • Temperature, salinity, oxygen, dissolved inorganic carbon (pCO_2, pH, alkalinity) [for biomass/ productivity] • Particulate organic matter concentration [for biomass/ productivity] • Total suspended organic matter concentration [for biomass/productivity] • Bio-optical variables (remote sensing reflectance, absorption coefficients)	• Biological diversity (D1): dynamics and distribution of life-forms (functional groups); abundance and biomass (total or by size-classes); diversity. • Non-indigenous species (D2): presence, frequency of occurrence and trends of non-indigenous species; relationship between autochthonous and invasive species (for certain key groups); rate of introduction of new species. • Food-webs (D4): primary production; size-spectra. • Eutrophication (D5): chlorophyll a; frequency of occurrence of HABs species; diatoms to dinoflagellates ratio.
Zooplankton biomass and diversity	• Biomass overall; biomass or abundance (or presence/ absence) by taxon, functional group or size class	• Geographical distributions by taxon or functional group • Life history timing • Community size structure	• Sampling location • Sampled volume [EN6]	• Biological diversity (D1): dynamics and distribution of life-forms (functional groups); abundance and biomass (total or by size-classes); diversity • (D2): presence, frequency of occurrence and trends of non-indigenous species; relationship between autochthonous and invasive species (for certain key groups); rate of introduction of new species. • Food-webs (D4): size-spectra; biomass, species composition and spatial distribution of zooplankton. • Sea-floor integrity (D6): meroplankton to holoplankton and ratio.

EOV	SUB-VARIABLES	DERIVED PRODUCTS	SUPPORTING VARIABLES	RELATED MSFD DESCRIPTORS AND INDICATORS
Fish abundance and distribution	• Number, biomass or abundance index of fish of different taxa per unit volume or area of water in a specific region, stock or population, and measured by a standard or known protocol • Numbers or biomass of fish by size/age/stage	• Fish abundance indices • Fish diversity indices • Size-based indicators of fish assemblages, including mean fish size, size spectra, and large fish indicators • Food web indicators, including proportion of predatory fish • Fish production • Fish habitat	• Fisheries management area, Large Marine Ecosystem, FAO area • Fishing effort (where available with catch, to compute Catch per unit Effort, CPUE)	• Commercially exploited fish and shellfish (D3): biomass indices; relationship between catches and biomass indices; fishing mortality; proportion of fishes with size larger that the size at first maturity; spawning stock biomass (SSB); size at first maturity; maximum length per species; abundance and biomass of characteristic demersal species / groups; bathymetric and geographical range of characteristics species. • Food-webs (D4): proportion of large fishes; abundance and biomass of upper trophic levels.
Marine turtles, birds, mammals abundance and distribution	• Species presence/absence • Age • Sex • Count data • Repeated individual presence (tracking/ resights)	• Density • Hotspots • Home range • Utilization distribution (relative occupation of home range) • Movement patterns • Migration pathways • Habitat maps • Population status (increasing, decreasing stable)	None specified	• Biological diversity (D1): • Birds: abundance of key trophic groups; demographic characteristics of populations; distributional range and pattern of populations; biodiversity; abundance of reproducers. • Turtles and mammals: pattern and distributional range of populations; size of the populations • Food-webs (D4): abundance and biomass of top predators.

EOV	SUB-VARIABLES	DERIVED PRODUCTS	SUPPORTING VARIABLES	RELATED MSFD DESCRIPTORS AND INDICATORS
Hard coral cover and composition	• Live coral cover and areal extent • Coral diversity (species, genera and functional type; and alpha, beta or gamma) • Coral condition (diseases, bleaching, mortality (partial and full), predated, silted, other conditions/ syndromes) • Total habitable substrate (less sand/silt substrates, structural complexity) • Coral size classes (recruits/ small corals, size class distribution)	• Maps of coral cover and areal extent • Inventories of coral diversity • Coral condition • Coral recruitment and size class distributions • Coral reef habitat classifications, mapped layers • Coral reef system health (with key fish, urchins, macroalgae EOVs) • Convention indicators (Aichi Target 10, SDG 14.2/5, IPBES)	• Water clarity / turbidity • Temperature • pH • Total Alkalinity (TA) • Salinity • Nutrients (N and P) • Sedimentation • Herbivory	• Biological diversity (D1): abundance, biomass and diversity; bathymetric and geographical range.
Seagrass cover and composition	• Shoot density/cover • Canopy height • Seagrass diversity (species) • Areal extent of seagrass meadows • Photosynthetic efficiency (measured with PAM)	• Primary and secondary production • Global and regional seagrass distribution • Contributions to blue” carbon storage • Essential fish habitat extent • Seagrass habitat fragmentation	• Water clarity / turbidity • Temperature • Salinity • Epiphytic algae and fouling load	• Biological diversity (D1): environmental conditions of seagrass meadows; net population growth of Posidonia oceanica; abundance of opportunistic species in seagrass meadows; bathymetric and geographical range.
Macroalgal canopy cover and composition	• Canopy species diversity • Canopy height • Stem density (kelps) • Plant condition (qualitative: signs of necrosis and potential drivers, fouling and grazing) • Plant size classes (including recruits) • Photosynthetic efficiency • Photosynthetic biomass • Areal extent	• Habitat extent • Canopy health indices • Global geographical distribution • Primary production • Essential fish habitat extent	• PAR • Temperature • Nutrients • Salinity • Sediment • Substratum type • Water clarity • Minimum fluorescence • Effective quantum yield	• Biological diversity (D1): cartography and diversity of macroalgal species (multi-metric indices such as CARLIT – CARtography LIToral and RICQ –Rocky Intertidal Community Quality); abundance, biomass and size of structuring habitat species; bathymetric and geographical range.

EOV	SUB-VARIABLES	DERIVED PRODUCTS	SUPPORTING VARIABLES	RELATED MSFD DESCRIPTORS AND INDICATORS
Mangrove cover and composition	• Mangrove fringe width and area • Mangrove tree species composition and zonation • Tree, algae, and phytoplankton primary production • Canopy height and trunk girth • Trunk and seedling density by species • Soil profile, carbon/nutrient content, and 14C age • Sediment and water column respiration • Intertidal fish and invertebrate densities	• Above and below ground biomass • Ecosystem gross and net primary production • Carbon sequestration rate • Fish and invertebrate productivity	• Water temperature • Air temperature • Salinity • Annual rainfall	• Not applicable in EU waters (except for French offshore territories such as Guyana and Martinique).

Annex 3: Table of Essential Biodiversity Variables (EBVs)

Defined by the Biodiversity Observation Network from the Group on Earth Observations (GEO BON). There are 6 EBV classes and 22 EBV candidates. This set of candidate EBVs aims to account for the full complexity of ecosystem biological components, but with less consideration for the operational needs.

EBV CLASS	EBV CANDIDATE	MEASUREMENT AND SCALABILITY	TEMPORAL SENSITIVITY	FEASIBILITY	RELEVANCE AND RELATED CBD 2020 TARGETS
Genetic composition	Co-ancestry	Pairwise relatedness among individuals or inbreeding coefficient of selected species, within and among populations of each species	Generation time	Available for many species but few populations, and little systematic sampling over time	This variable provides a good measure of the genetic independence of allele frequencies among individuals and about their susceptibility to lowered fitness. Target: 12
	Allelic diversity	Allelic richness from genotypes of selected species (e.g. endangered species and domesticated species) at multiple locations (statistically representative of the species distribution)	Generation time	Data available for several species and for several locations, but little global systematic sampling	It is one the most used variables to measure genetic diversity, and can support the estimation of indicators such as “Trends in genetic diversity of selected species” and the “Red List Index”. Targets: 12, 13
	Population genetic differentiation	Gene frequency differentiation (Fst and other measures) among populations or of a subpopulation compared to the metapopulation of selected species	Generation time	Data available for many species but often for a limited number of populations. Easy to augment datasets	It is one the most used variables to measure genetic diversity, and can support the estimation of indicators such as “Trends in genetic diversity of selected species” and the “Red List Index”. Targets: 12, 13
	Breed and variety diversity	Number of animals of each livestock breed and proportion of farmed area under each local crop variety, at multiple locations	5 to 10 years	Large datasets have been compiled by national organizations and FAO for livestock breeds, but there is insufficient systematic sampling for coverage of local crop varieties	It is an essential variable to estimate the indicator “Trends in genetic diversity of domesticated animals and cultivated plants”. Target: 13
Species populations	Species distribution	Presence surveys for groups of species easy to monitor, over an extensive network of sites with geographic representativeness. Potential role for incidental data from any spatial location	1 to >10 years	Presence surveys are available for a larger number of species than population counts and can make use of existing distribution atlas. Some efforts for data compilation and integration exist (GBIF, IUCN, Map of Life). There is an increasing trend for data contributed by citizen scientists (Observado, iNaturalist)	Abundance & distribution of populations/taxon per se is an intuitive biodiversity metric with public resonance. Abundance & distribution contributes to extinction risk indicators & indicators of supply of ES associated with particular spp. Range shifts expected under climate change. Targets: 4,5,6,7,8,9,10,11,12,14,15

EBV CLASS	EBV CANDIDATE	MEASUREMENT AND SCALABILITY	TEMPORAL SENSITIVITY	FEASIBILITY	RELEVANCE AND RELATED CBD 2020 TARGETS
Species populations	Population abundance	Population counts for groups of species easy to monitor and/or important for ecosystem services, over an extensive network of sites with geographic representativeness	1 year	Population counts underway for a significant number of species in each of the following groups: birds, butterflies, mammals, plankton, important fisheries, coral reef fishes. Most of these extensive networks are geographically restricted. Much of the data are currently being collected by citizen science networks	Abundance & distribution of populations/taxon per se is an intuitive biodiversity metric with public resonance. Abundance & distribution contributes to extinction risk indicators & indicators of supply of ES associated with particular spp. Range shifts expected under climate change. Targets: 4,5,6,7,8,9,10,11,12,14,15
	Population structure by age/size class	Quantity of individuals or biomass of a given demographic class of a given taxon or functional group at a given location	1 year	Available for some managed species (hunting and fisheries), usually geographically restricted	Abundance & distribution of populations/taxon per se is an intuitive biodiversity metric with public resonance. Abundance & distribution contributes to extinction risk indicators & indicators of supply of ES associated with particular spp. Range shifts expected under climate change. Targets: 4,5,6,7,8,9,10,11,12,14,15
Species traits	Phenology	Record timing of periodic biological events for selected taxa/phenomena at defined locations. Examples include: timing of breeding, leaf coloration, flowering, migration, oceans flow pattern shifts, intermittent flows in rivers, extant of wetlands	1 year	Several ongoing initiatives (Phenological Eyes Network, PhenoCam, ClimateWatch, etc.), some resorting to citizen science contributions	Phenology is expected to change with climate change. Targets: 10, 15
	Body mass	Body mass (mean and variance) of selected species (e.g. under harvest pressure), at selected sites (e.g. exploitation sites)	1 - 5 year	Data available for many important marine fisheries, but little data available for bushmeat and other exploited species groups	There is evidence that mean body mass of some species may be changing in response to pressures such as harvesting. Targets: 6,7
	Natal dispersion distance	Record median/frequency distribution of dispersal distances of a sample of selected taxa. In marine species larval lifetime may be a useful surrogate	>10 years	Banding/marking and observation data available for some birds, mammals, turtles, fish, temperate trees	Required in order to assess the impact of habitat fragmentation on species, project the spread of invasive species, project the impact of climate change on species and to combine with abundance data to assess extinction risk. Targets 5,6,9,10,11,12,15

EBV CLASS	EBV CANDIDATE	MEASUREMENT AND SCALABILITY	TEMPORAL SENSITIVITY	FEASIBILITY	RELEVANCE AND RELATED CBD 2020 TARGETS
Species traits	Migratory behaviour	Record presence /absence / destinations / pathways of migrant selected taxa	1 to >10 years	Banding/marking/tagging and observation data available for some birds, mammals, turtles fish, butterflies	Migratory behaviour expected to change under climate change & habitat fragmentation. Riverine migrations expected to be susceptible to dams etc. Targets 5,6,10,11,12
	Demographic traits	Effective reproductive rate (e.g. by age/size class) & survival rate (e.g. by age/size class) for selected taxa at selected locations	1 to >10 years	Data available for some fisheries, plus some birds, mammals, reptile, plants, and others, but little trend data	Necessary to combine with other factors for assessing extinction risk, vulnerability to threats, Targets 4,6,8,9,12,15
	Physiological traits	For instance, measurement of thermal tolerance or metabolic rate. Assess for selected taxa at selected locations expected to be affected by a specific driver	1 to >10 years	Some data available for corals, lizards, amphibians, insects	May determine susceptibility to climate change impacts & may change under climate change. Targets 4,6,8,9,12,15
Community composition	Taxonomic diversity	Multi-taxa surveys (including by morphospecies) and metagenomics at selected in situ locations at consistent sampling scales over time. Hyper-spectral remote sensing over large ecosystems	5-10 years	Many intensive long-term research sites have excellent but uncoordinated data, and there are abundant baseline data for many locations in the terrestrial, marine and freshwater realms. Metagenomics and the possibilities of remote sensing are emerging fields	This is a basic measure of interaction of species: what species live together. It is the basis of community classification and ecosystem health assessments. Functional type composition of the ecosystem is often derived from species composition of observed communities. Targets: 8, 10, 12, 14
	Species interactions	Studies of important interactions or interaction networks in selected communities, such as plant-bird seed dispersal systems	5-25 years	Some studies have monitored the structure of species interaction networks such as mutualistic networks (pollination and seed dispersal), soil food webs, host-parasite and herbivore-plant interactions. There is a lack of global or regional representativeness of these studies	Global change is affecting species interactions, which are determinant in ecosystem functioning and services. Targets: 7, 9, 14, 15

EBV CLASS	EBV CANDIDATE	MEASUREMENT AND SCALABILITY	TEMPORAL SENSITIVITY	FEASIBILITY	RELEVANCE AND RELATED CBD 2020 TARGETS
Ecosystem function	Net primary productivity	Global mapping with modelling from remote sensing observations (FAPAR, ocean greenness) and selected in-situ locations (eddy covariance)	<=1 year	A network of regional networks of in-situ measurements exists (FLUXNET), and some global maps based on models and remote sensing are available. GCOS is also addressing this EBV	Indicator of the energy flow through ecosystem and a measure of health/ degradation; Support biodiversity at multiple dimensions/trophic levels, regulates climate, impacts on human wellbeing, possible of indicator shifts into alternate ecosystem states; underpins all production-based ecosystem services. Targets: 5, 8, 14
	Secondary productivity	Measurement of secondary productivity for selected functional groups, combining in-situ, remote sensing, and models. Example functional groups include: fisheries; livestock; krill; herbivorous birds	1 year	FAO and national statistics on fish and livestock production	Important to assess ecosystem functioning and ecosystem services. Targets: 6, 7, 14
	Nutrient retention	Ratio of nutrient output from the system to nutrient input, measured at selected in situ locations. Can be combined with models and remote sensing to extrapolate regionally	1 year	Some intensive monitoring sites have nitrogen saturation monitoring is some acid-deposition areas; phosphorus retention monitoring in some impacted rivers and estuaries	Nutrient loss or accumulation affects biodiversity and ecosystems services. Targets: 5, 8, 14
	Disturbance regime	Type, seasonal timing, intensity and frequency of event-based external disruptions to ecosystem processes and structure. Examples: sea surface temperature and salinity (RS); scatterometry for winds (RS); trawling pressure (in situ); flood regimes (in situ); fire frequency (in situ, RS); cultivation/ harvest (RS); windthrow; pests (in situ)	1 year	Abundant data is available for several perturbations, sometimes at the global scale, although harmonization and integration is needed	Key determinant of ecosystem function, structure and composition; changes in the disturbance regime lead to changes in biodiversity. Targets: 5, 7, 9, 10, 11, 14, 15

EBV CLASS	EBV CANDIDATE	MEASUREMENT AND SCALABILITY	TEMPORAL SENSITIVITY	FEASIBILITY	RELEVANCE AND RELATED CBD 2020 TARGETS
Ecosystem structure	Habitat structure	Remote sensing measurements of cover (or biomass) by height (or depth) classes globally or regionally, to provide a 3-dimensional description of habitats	<=1 year	Global terrestrial maps available with RS (e.g., LIDAR). Marine and freshwater habitats mapped by combining RS and in situ data	Proxy for biomass in ecosystems; key determinant of habitat suitability for biodiversity; basis for land cover classification. Relevant for targets: 5, 11, 14, 15
	Ecosystem extent and fragmentation	Local (aerial photo and in-situ monitoring) to global mapping (satellite observations) of natural/ semi-natural forests, wetlands, free running rivers, coral reef live cover, benthos cover, etc	1-5 years	Global maps of forests, assessment of fragmentation for major river basins, and local to regional maps of coral reefs already exist, but comparable observations over time are limited and distinction between natural and modified ecosystems (e.g. natural forests versus plantations) is often not made	This is a key measure of human impacts on ecosystems. It can be used to derive indicators such as extent of forests and forest types, mangrove extent, seagrass extent, coral reef condition. Targets: 5, 7, 10, 14, 15
	Ecosystem composition by functional type	Functional types can be directly inferred from morphology (in situ) or from remote sensing	5 years	Implicitly part of current ecosystem maps. Some models (e.g. DGVMs, marine ecosystem models) are based on functional groups	This is a basis for ecosystem classification and lends itself to remote sensing. It can be used to predict ecosystem function and ecosystem services. Targets: 5, 14, 15

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