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A review and prospectus of the mandate for marine environmental monitoring systems: technology challenges and opportunities

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NAUTILOS - New Approach to Underwater Technologies for Innovative, Low-cost Ocean observation is an H2020 project funded under the Future of Seas and Oceans Flagship Initiative, coordinated by the National Research Council of Italy (CNR, Consiglio Nazionale delle Ricerche). It brings together a group of 21 entities from 11 European countries with multidisciplinary expertise ranging from ocean instrumentation development and integration, ocean sensing and sampling instrumentation, data processing, modelling and control, operational oceanography and biology and ecosystems and biogeochemistry such, water and climate change science, technological marine applications and research infrastructures.

NAUTILOS will fill-in marine observation and modelling gaps for chemical, biological and deep ocean physics variables through the development of a new generation of cost-effective sensors and samplers, the integration of the aforementioned technologies within observing platforms and their deployment in large-scale demonstrations in European seas. The fundamental aim of the project will be to complement and expand current European observation tools and services, to obtain a collection of data at a much higher spatial resolution, temporal regularity and length than currently available at the European scale, and to further enable and democratise the monitoring of the marine environment to both traditional and non-traditional data users.

NAUTILOS is one of two projects included in the EU´s efforts to support of the European Strategy for Plastics in a Circular Economy by supporting the demonstration of new and innovative technologies to measure the Essential Ocean Variables (EOV).

More information on the project can be found at: http://www.nautilos-H2020.eu.

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EXECUTIVE SUMMARY

This report documents the outcomes of the work performed in Task 2.1 (Political and societal drivers and requirements), informing on the potential of evolving trends in technological progress in advancing contemporary marine environmental monitoring practices and examining the role any resulting changes in established operating paradigms could play in shaping the socio-political framework defining ocean observing needs at the global and European levels.

It is organized in six main sections:

- **Chapter I: Introduction** provides the background context that motivates marine observations and specifies what NAUTILOS' objectives are.
- **Chapter II: Political and Societal Drivers** contains the review of the main drivers carried out at the global, regional, European and national levels. A subsection is developed for each of them, which also contains an analysis of the gaps in the observations deduced from the documents reviewed.
- **Chapter III: Existing European Marine Observing Infrastructure** describes the infrastructures operating in a long-term scheme in Europe and also other projects involving scientific networks, experimental facilities, services and products dealing with marine research.
- **Chapter IV: European Data Initiatives** describes the role of marine data in knowledge building and provides a review of ongoing global and European initiatives and projects that have this data in their scope.
- **Chapter V: Outlook** analyses the potential for evolving trends in technological development in advancing contemporary marine environmental monitoring practices and how these will help fill existing gaps in relation to monitoring needs.
- **Chapter VI: Conclusion** closes the report highlighting the contribution of NAUTILOS to the measurement of the essential variables to meet the needs of environmental monitoring and study of the processes that underlie the evolution of the ocean and its ecosystems.

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LIST OF ACRONYMS AND ABBREVIATIONS

Abbreviation	Definition
ADRIPLAN	ADRiatic Ionian maritime spatial PLANning
AQUACOSM	EU network of mesocosms facilities for research on marine and freshwater ecosystems
ARICE	Arctic Research Icebreaker Consortium
ASV	Autonomous Surface Vehicles
AUV	Autonomous Underwater Vehicles
BGC	Bio-Geo-Chemical
Blue-Cloud	Piloting innovative services for Marine Research & the Blue Economy
BSC	Black Sea Commission (Commission for the Protection of the Black Sea Against Pollution)
CMF	French Maritime Cluster
CFP	Common Fisheries Policy
CMBR	Centre for the study and sustainable exploitation of Marine Biological Resources
CMEMS	Copernicus Marine Environment Monitoring Service
DAC	Data Assembly Center
DANUBIUS	International Center for Advanced Studies on River –Delta – Sea Systems
DOOS	Deep-Ocean Observing Strategy
DTO	Digital Twin of the Ocean
EC	European Commission
EEZ	Exclusive Economic Zone
EMBRC	European Marine Biological Resource Centre
EMODNET	European Marine Observation and Data Network
EMSO	European Multidisciplinary Seafloor and water-column Observatory
EOOS	European Ocean Observing System
EOV	Essential Ocean Variable
ERIC	European Research Infrastructure Consortium
ESFRI	European Strategy Forum on Research Infrastructures
ESPCE	European Strategy for Plastics in a Circular Economy
EUMR	EUMarineRobots: Marine robotics research infrastructure network
Euro-Argo	European contribution to the international Argo Program
EUROFLEETS+	An alliance of European marine research infrastructure to meet the evolving needs of the research and industrial communities
EuroGOOS	European Global Ocean Observing System
EuroSea	Improving and integrating the European Ocean Observing and Forecasting System
FAIR	Findability, Accessibility, Interoperability, and Reusability
FAO	Food and Agriculture Organization
FINMARI	Finnish Marine Research Infrastructure program
G7	Group of Seven
GEcS	Good Ecological and Chemical Status
GES	Good Environmental Status
GFCM	General Fisheries Commission for the Mediterranean
GLOSS	Global Sea Level Observing System
GOA-ON	Global Ocean Acidification Observing Network
GOOS	Global Ocean Observing System
GNSS-MR	Global Navigation Satellite System Multi-Reflectometry
HELCOM	Helsinki Commission (Baltic Marine Environment Protection Commission)
HIMIOFoTs	Hellenic Integrated Maritime Inland water Observing, Forecasting, and offshore Technology System
ICES	International Council for the Exploration of the Sea
ICOS	Integrated Carbon Observation System
IMP	Integrated Maritime Policy
INSPIRE	INfrastructure for SPatial InfoRmation in Europe
INTAROS	Integrated Arctic observation system

IOC	Intergovernmental Oceanographic Commission
IODE	International Oceanographic Data and Information Exchange
ISC	International Science Council
ISO	International Organization for Standardization
JERICO-S3	Joint European Research Infrastructure of Coastal Observatories: Science, Service, Sustainability
LifeWatch	e-Infrastructure for Biodiversity and Ecosystem Research
MAP	Mediterranean Action Plan
MBON	Marine Biodiversity Observation Network
MedOBIS	Mediterranean Ocean Biodiversity Information System
MINKE	Metrology for Integrated marine maNagement and Knowledge-transfer nEtwork
MonGOOS	Mediterranean Operational Network for the Global Ocean Observing System
MSFD	Marine Strategy Framework Directive
MSP	Maritime Spatial Planning
NEAFC	North East Atlantic Fisheries Commission
NODC	National Oceanographic Data Centre
NorArgo	Norwegian Argo infrastructure
NorSOOP	Norwegian Ships of Opportunity program
OBIS	Ocean Biodiversity Information System
OCEANOPS	Joint Centre for Oceanography and Marine Meteorology in situ Observations Programmes Support
OGS	Open Geospatial Consortium
OSPAR	Oslo/Paris convention (for the Protection of the Marine Environment of the North-East Atlantic)
PSMSL	Permanent Service for Mean Sea Level
RAC	Regional Activity Center
RFB	Regional Fishery Bodies
RFMO	Regional Fisheries Management Organization
RI	Research Infrastructure
RSC	Regional Seas Conventions
RSP	Regional Seas Programme
R/V	Research Vessel
SDG	Sustainable Development Goal
SDN	SeaDataNet
SIMWESTMED	Supporting Implementation of Maritime Spatial Planning in the Western Mediterranean region
SONEL	Système d'Observation du Niveau des Eaux Littorales
UN	United Nations
UNCC	United Nations Climate Change
UNCLOS	United Nations Convention on the Law of the Sea
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle
WFD	Water Framework Directive
WMO	World Meteorological Organization

METHODOLOGY

Global, regional, European and national regulation, strategies and action plans were searched for identifying major drivers of current and future ocean observing needs focussing on the scope for technological development and refinement to advance the current state-of-the-art in global to local-marine environmental monitoring programmes. The focus is on the 17 NAUTILOS instrumentation/tools. For each of the measures, the potential target disciplinary groups are indicated in Table 1. Summary sheets of the documents seen are contained in the annexes of this report.

Table 1. The variables addressed by the instrumentation and tools developed or integrated in NAUTILOS and their potential target disciplinary groups (source: NAUTILOS G.A.).

NAUTILOS Marine Technologies	Variables targeted	Target disciplinary groups
1. Dissolved Oxygen Sensors (ref. Sub-Task 3.1.1 & Sub-Task 3.1.2)	Dissolved oxygen	Marine biogeochemistry Regulatory environmental monitoring
2. Fluorescence Sensor (ref. Sub-Task 3.1.2)	Chlorophyll-a fluorescence	Marine biology/ecology Regulatory environmental monitoring
3. Ocean surface multi/hyperspectral and laser induced chlorophyll-a fluorescence sensors and cameras (ref. Task 3.2)	Sea surface temperature, Laser induced chlorophyll-a fluorescence, Ocean color	Marine biology/ecology Regulatory environmental monitoring Ocean colour community
4. Passive broadband acoustic recording sensor (ref. Sub-Task 3.3.1)	Marine noise (anthropogenic and natural sources, including marine mammals, sea ice cracking, seismic activity, meteorological sources)	Marine biology/ecology Regulatory environmental monitoring
5. Passive acoustic event recorder (ref. Sub-Task 3.3.2)	Marine mammal sound detection (porpoise & dolphin clicks for abundance estimation)	Marine biology/ecology Regulatory environmental monitoring
6. Active Acoustic Profiling Sensor (ref. Task 3.4)	Suspended particle concentration / distribution (zooplankton, microplastics, organic and inorganic sediment)	Marine biology/ecology Marine pollution
7. Sampler for phytoplankton and other suspended matter (ref. Task 3.5)	Concentrated suspended matter samplers for analyses of phyto-pigments, particulate organic matter, microbe biomass and diversity	Marine biology Marine ecological monitoring Climate research Marine pollution
8. Carbonate system/ocean acidification sensors (ref. Task 4.1)	pH, pCO_2,Total Alkalinity	Marine biogeochemistry Climate research
9. Silicate Electrochemical Sensor (ref. Task 4.2)	Silicate concentration (Si)	Marine biogeochemistry
10. Submersible Nano- and Microplastics Sampler (ref. Task 4.3)	Concentrated suspended matter samples	Marine ecology Marine pollution
11. Low-cost Microplastic sensors (ref. Task 4.4)	Concentration and characterisation of microplastics	Marine ecology Marine pollution
12. Deep Ocean CTD (ref. Task 4.5)	Conductivity, Temperature, Pressure (Salinity and Density derived)	Physical oceanography
13. Deep ocean low-level radioactivity sensor (ref. Task 4.6)	Radon gas, potassium ^{40}K, radium ^{226}Ra and ^{228}Ra, and other natural isotopes	Environmental monitoring
14. Integration of existing technologies in animal tagging systems (ref. Task 5.5)	Temperature, Salinity, Chlorophyll-a fluorescence, Dissolved oxygen	Physical oceanography Marine biology/ecology
15. Demonstration of novel equipment for key seabed habitat mapping (ref. Task 6.2)	Live corals, hard corals, seafloor sponges	Marine biology
16. Smartphone NIR Scanner (citizen science application, ref. Task 8.4)	Plastics	Marine pollution
17. Visual marine image annotation (citizen science application, ref. Task 10.4)	Macroplastics, Sponge and cold-water coral cover, major seafloor organism types.	Marine pollution Marine biology/ecology

I. INTRODUCTION

1. Background

Sustainable, multidisciplinary, efficient and fit-for-purpose marine observation is the first brick to building the knowledge needed to meet ocean- and blue growth-related research, political and societal goals. The international community has identified a range of these goals and drivers that require systematic ocean observations in both the open and deep ocean, and coastal and shelf seas (e.g., Farcy et al., 2019; Levin et al. 2019; Miloslavich et al., 2018; Tanhua et al., 2019). At the European level, one of the most relevant drivers is the Marine Strategy Framework Directive (MSFD, European Commission, 2008 and 2017a) whose main goal is to achieve Good Environmental Status (GES) of EU marine waters (European Commission, 2017b).

The ocean environment is vast, remote, and harsh, and collecting any observations over, on or beneath the sea surface is difficult and costly. After decades of advancement in ocean observing and development of related technologies, there is still a significant gap in having the necessary data for each targeted application, and one of the key remaining challenges is how to cost-effectively make measurements at the increased resolution (both in time and space) necessary for assessing complex system processes and rapidly evolving changes especially concerning ocean biogeochemistry, biology, and ecosystems (Wang et al, 2019). Another key challenge is to distinguish what ocean variables are essential (and feasible) from those that are only desirable and to adopt common standards for data collection and dissemination to maximize their utility and re-use following the FAIR (findability, accessibility, interoperability, and reusability) principles (Collins et al., 2018).

A Framework for Ocean Observing emerged from the OceanObs'09 conference (Lindstrom et al., 2012) and was adopted by the Global Ocean Observing System (GOOS, 2020). It is meant to guide the ocean observing community as a whole to establish a coordinated and integrated global observing system based on routine and sustained observations of physical, biogeochemical, and biological Essential Ocean Variables, or EOVs. It addresses the variables to be measured, the approach to measuring them, and how data and products will be managed and made widely available to modelling efforts and a wide range of users. The Framework ensures assessments that cut across platforms and recommend the best, most cost-effective plan to provide an optimal global view for each essential ocean variable.

Platforms, networks, and systems already exist that operate at various maturity levels (Figure 1). The next step in the evolution of the marine monitoring system will be the widespread adoption of autonomous in situ sensing. There is a need to explore and test new technological solutions that will lower the costs of acquiring, deploying and maintaining, monitoring and observing platforms to fill the in situ observational gaps. Increasing the spatial resolution of in situ data and filling gaps in time span, using increasing amounts of information coming from cost-effective and more widely disseminated sensors, would produce many new operational products, forecasting capabilities, and process understanding of the ocean.

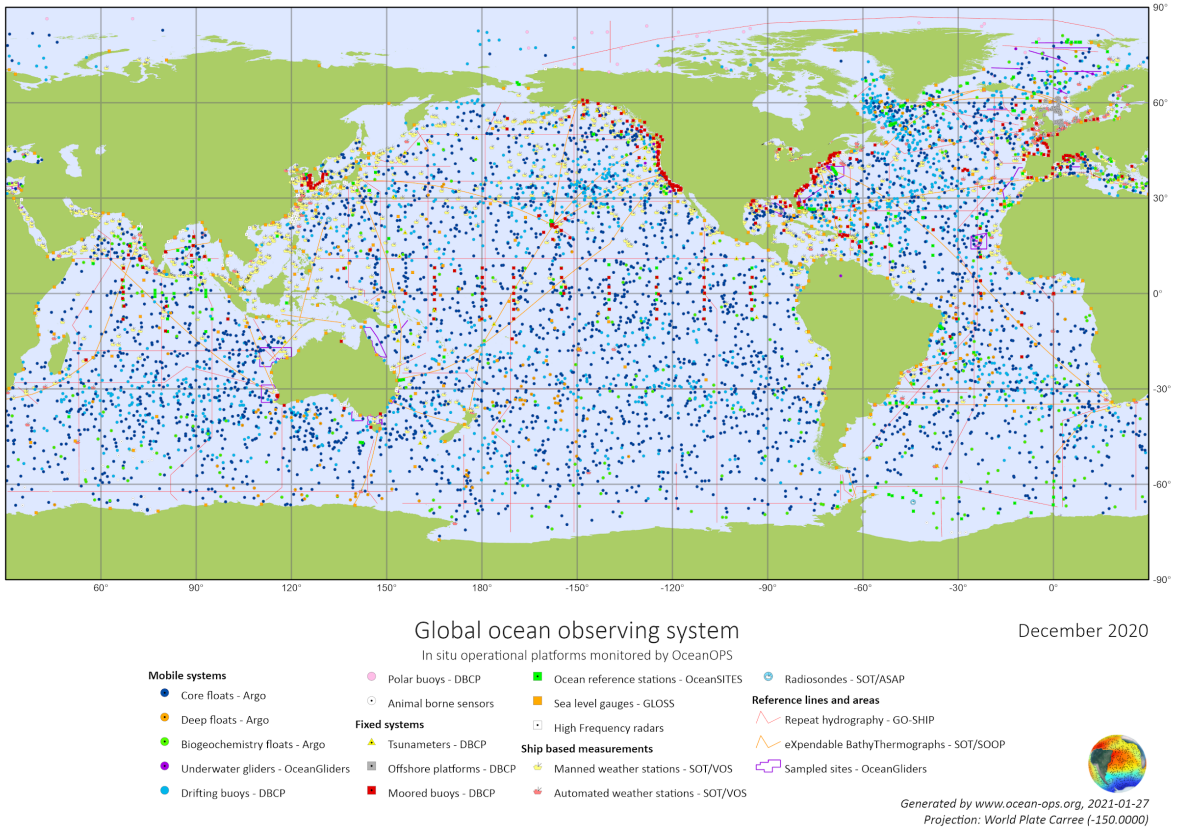


Figure 1. A snapshot of global ocean observations generated by OCEANOPS (download from https://www.ocean-ops.org/board/wa/Archives?t=JCOMMOPS)

2. Objectives of NAUTILOS

NAUTILOS has the strategic objective of filling in marine observation and modelling gaps for chemical, biological and deep ocean physics variables through the development of a new generation of cost-effective sensors and samplers, the integration of the aforementioned technologies within observing platforms and their deployment in large-scale demonstrations in European seas.

The fundamental aim of the project will be to complement and expand current European observation tools and services, to obtain a collection of data at a much higher spatial resolution, temporal regularity and length than currently available at the European scale, and to further enable and democratise the monitoring of the marine environment to both traditional (oceanographers, researchers, and technology suppliers) and other data users (citizen scientists, resource management bodies, policy makers, environmental monitoring groups and other ocean observation stakeholders).

The wide adoption of the technologies developed and demonstrated in the context of the project will increase participation in environmental observation, will help reduce the costs of the technologies proposed and used, thus multiplying the social, economic and environmental benefits.

II. POLITICAL AND SOCIETAL DRIVERS

1. Global level

There are numerous international agreements aimed at preserving the ocean, either in the form of treaties or frameworks, which have various degrees of being legally binding (see for example Ryabinin et al., 2019 for an extensive review). Below are the most relevant ones for NAUTILOS (see Table A1 in Annex 1 for further references).

The 1982 **United Nations Convention on the Law of the Sea (UNCLOS)** is a treaty providing a general regulatory framework for the conservation and sustainable use of the ocean and its resources and underlies all following agreements. Obligations relating to marine monitoring or to marine observation in terms of general obligations to meet all the various needs for ocean data cannot be found in UNCLOS. However, the monitoring and observation commitments, as well as obligations to cooperate in research programmes and in the exchange of ocean data with the aim of protecting the marine environment, are to some extent set out in Article 204 and 200 of part XII of UNCLOS even if they are specifically designed for the pollution of the marine environment (Yoon 2011). Moreover, paragraph 5 of Article 194 obliges the parties to protect and preserve rare or fragile ecosystems as well as the habitat of depleted, threatened or endangered species and other forms of marine life. This is relevant for the European Blue growth strategy, particularly with regards to seabed mining (European Commission, 2012).

At present, two important processes, both adopted in 2015 by the United Nations, are taking place in parallel, committing the ocean community to specific goals to safeguard the marine environment: the **2030 Agenda for Sustainable Development** and its 17 Goals (**SDGs**, Figure 2a) and the **Paris Agreement on climate change**. Both solicit a climate action to combat climate change and its impacts (SDG 13 in the 2030 Agenda) and both have explicitly recognized the role of the ocean in any climate or sustainable development path. In addition, the ocean has specific objectives in the 2030 Agenda under SDG 14 (Life Below Water), the achievement of which will also contribute to the achievement of other objectives, including climate action (Figure 2b). It follows that the implementation of the two agendas must be carried out in a coordinated way. Limited interaction between the processes of the two agendas at both global and national levels, threatens to impede their effective implementation (Dzebo et al., 2019).

The **UN Decade of Ocean Science for Sustainable Development**, registered as a voluntary commitment to the 2017 UN Ocean Conference by the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (IOC-UNESCO) and declared by the United Nations on 5 December 2017, is an unprecedented opportunity for the international ocean science community to organize itself and create the needed synergies, partnerships, connections, and interfaces to support the two agendas with science and knowledge (Claudet et al., 2020).

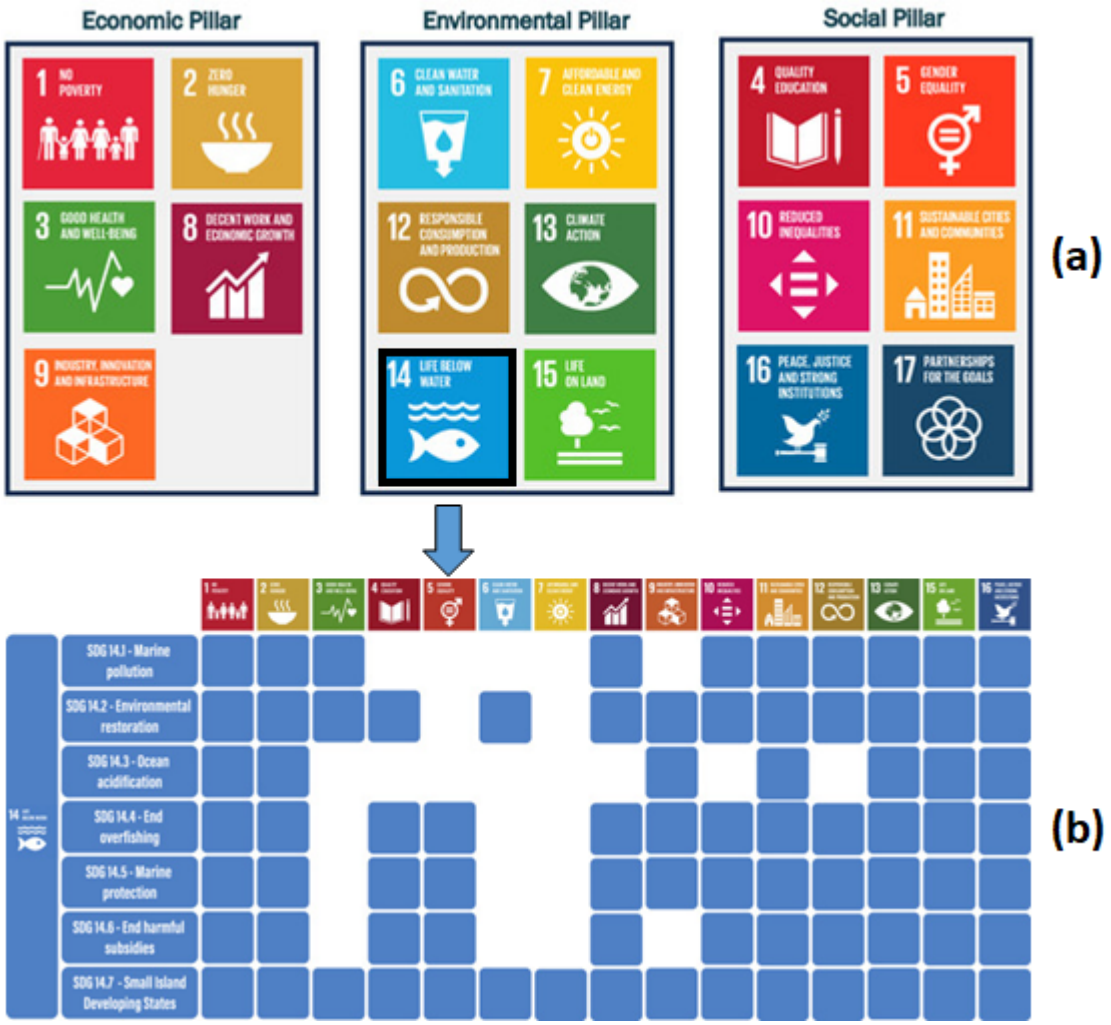


Figure 2. (a) Sustainable development goals clustered into three pillars: economic, environmental, and social (source: Kostoska and Kocarev, 2019); (b) Contribution of Ocean Targets to the Other Sustainable Development Goals. Blue-colored blocks indicate identified potential co-benefits between achieving the ocean targets and other Sustainable Development Goals (source: Claudet et al., 2020)

The Group of Seven (G7), an intergovernmental organization consisting of Canada, France, Germany, Italy, Japan, the United Kingdom and the United States, have also shown interest in the importance of ocean science by launching a number of influential communiqués and blueprints that are highly relevant for the ocean. In 2015 they launched their **Action Plan to Combat Marine Litter**, followed in 2016 by the broader **Future of the Seas and Oceans Initiative,** also known as the Tsukuba Communiqué, and most recently, in 2018, the **Charlevoix Blueprint for Healthy Oceans, Seas and Resilient Communities**. These documents manifest the overall political commitment to actions to address the impacts of plastic pollution and marine litter, the overexploitation of fish stocks, and to ensure the health and sustainability of the oceans, seas, coastal communities and entire ecosystems.

All of the above requires adequate data that can only derive from a globally coordinated, sustained, better integrated, and fit-for-purpose ocean-observing system. Observations are vital and their continuing acquisition should be supported. Such a system is needed to systematically assess ocean status and trends, to support science, assessment, prediction and to help plan adaptation strategies, to

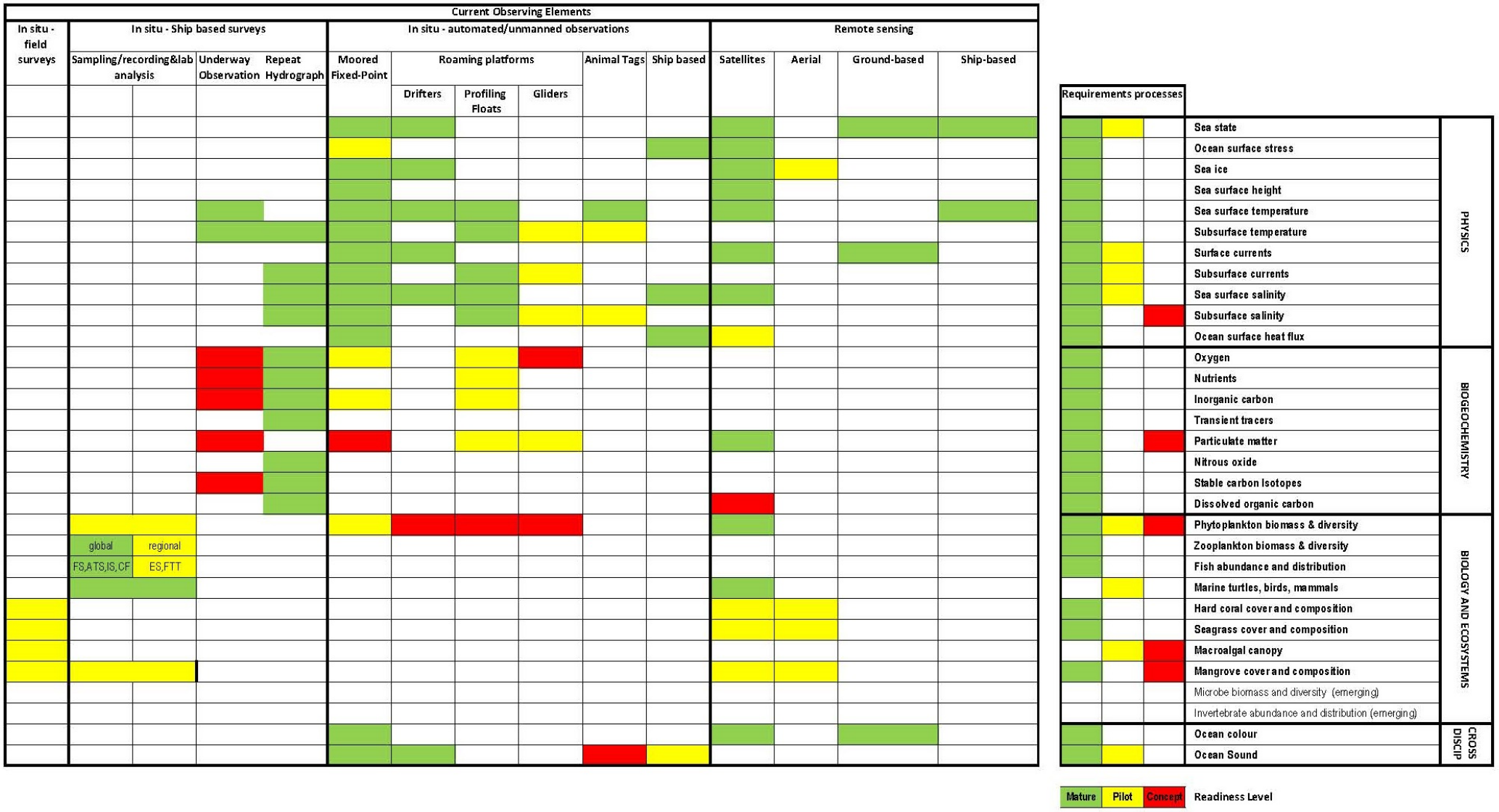
observe the effectiveness of such strategies, and to provide information to policymakers and decision makers that could be used to improve them.

Coordinated ocean observations have been in practice since the creation of the **Global Ocean Observing System (GOOS)** in 1991, which is continuously developing and advancing an integrated system using the Framework for Ocean Observing (Lindstrom et al., 2012). To address climate, real-time services, and ocean health issues, GOOS uses **Essential Ocean Variables (EOVs)** as the common focus and defines the system based on requirements, observations, and data and information as the key components. They are identified by the GOOS Expert Panels and assessed for feasibility, capacity, and impact for each of the three system components. The assessment is based on readiness levels, i.e., concept, pilot, and mature (Moltmann et al., 2019). In Table 2, we present an overview of the EOVs and their readiness level, as well as the readiness level of integration in different observing elements/approaches. The information was processed from the specification sheets of each EOV, as distributed by GOOS (2020) as of the current date.

The dynamic approach to developing EOVs, based on readiness, is effective and new variables will be added in the future, depending on the ability to be able to measure and integrate them into the existing observing system. This is the case of the two variables related to microbes and invertebrates identified as emerging in Table 2 (Miloslavich et al., 2018). Another example concerns observations to address deep-ocean challenges within the physical, biogeochemical, and biological/ecosystem sciences (Levin et al. 2019), for which the Deep-Ocean Observing Strategy (DOOS) is working to include specific EOVs such as *Ocean bottom pressure, Ocean turbulence, and Seafloor fluxes* (Physics), *Seafloor labile organic matter, Seafloor respiration, Seafloor fluid and gas effluxes, Litter including microplastics* (Biogeochemistry), *Body size, Seafloor sponge habitat cover, Connectivity of species* (Biology and Ecosystems).

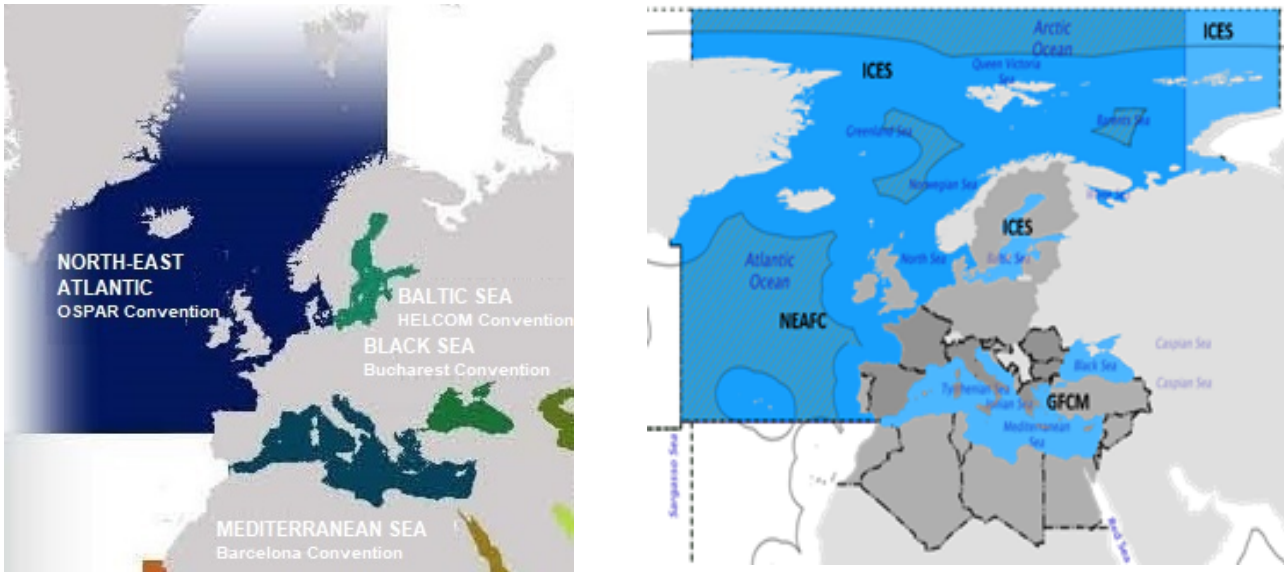
For physical and part of the biogeochemical variables there are sensors or automatic measurement systems that allow their acquisition in a sustained way. Those related to biology and ecosystems are the most lacking from this point of development. Nonetheless progress is underway to develop new technologies, or use existing ones, to make this sector better covered as well (see for example Wang et al., 2019). It must be said that even in the case of variables whose readiness level is mature, activities are underway for the development or adaptation of measurement technologies to different observation platforms that allow the collection of data with high spatial resolution, from coastal areas to those offshore (i.e. gliders and other roaming platforms, ferry-boxes and other Voluntary Observing Ships-based approaches).

Table 2. Overview of Essential Ocean Variables (EOVs), their readiness level and the readiness level of their integration in different Observing elements/approaches as resulting from the specification sheets (GOOS, 2020).



2. Regional Level

At the regional level, the **UN Environment Regional Seas Programme** (UN-RSP) plays an important role in coordinating actions for the protection of the marine and coastal environment. Established in 1974, it covers 18 marine and coastal regions worldwide, including four European Regional Seas Conventions (RSC): the **Helsinki Convention (HELCOM)** in the Baltic Sea; the **OSPAR Convention** in the North East Atlantic Ocean; the **Barcelona Convention/UNEP-MAP** in the Mediterranean Sea; the **Bucharest Convention** in the Black Sea (Figure 3a). In the past four decades these regional alliances have adopted legally binding agreements and action plans, and also produced assessment reports and monitoring guidelines to address the common goal of protecting the marine environment. They have contributed to the implementation of relevant European marine legislation (MSFD, WFD, etc.) and the global targets identified in relevant UN Environment Governing Council Decisions and resolutions of the United Nations Environment Assembly. In 2016, this Assembly recognized the unique role of the RSCs and their action plans in the implementation and reporting of the SDG 14 and other SDG targets relevant for the marine and coastal environment (as SDG-13), in cooperation, with other relevant organizations and forums, such as regional fisheries management organizations. See Table A2 in Annex 2 for further references.



(a) **(b)**

Figure 3. (a) Regional seas conventions around Europe (redrawn from Fig. 2.1 in UN Environment, 2018); (b) Regional Fishery Bodies around Europe, ICES overlaps with NEAFC, but also includes the Baltic Sea (redrawn from: FAO, RFB map viewer, http://www.fao.org/figis/geoserver/factsheets/rfbs.html).

Relevant to this purpose are the existing cooperation agreements between the Barcelona Convention/UNEP-MAP and the Bucharest Convention with the **General Fisheries Commission for the Mediterranean (GFCM)**; between OSPAR and the **North East Atlantic Fisheries Commission (NEAFC)**; and those of OSPAR and HELCOM with the **International Council for the Exploration of the Sea (ICES)**, which overlaps with NEAFC, but also includes the Baltic Sea (Figure 3b). These bodies have different types of links, in terms of institutional relationships, with the **Food and Agriculture Organization (FAO)**. In addition to fisheries issues, these alliances collaborate with the RSC in their region on broader themes

of common interest and concern such as ecosystem science, biological diversity, environment and conservation, and contribute to the periodic assessment reports, especially for issues related to biodiversity and fishery. ICES also acts as data centre for data collected under the OSPAR and HELCOM environmental monitoring programmes (https://ices.dk/data/dataset-collections/pages/default.aspx).

The European RSCs' Action plans are periodically updated to be streamlined with regional and global demands, and these updates do not have common deadlines, but are managed independently within each alliance. The most recent have developed an approach that is comparable and in line with the requirements of the Marine Strategy Framework Directive (MSFD), further described in the next section. This includes the definition of ecological objectives, targets and indicators for monitoring. Updates are currently underway to align their regional objectives and targets with the SDGs, integrate common indicators for reporting, and strengthen partnerships and cooperation towards SDG reporting.

To assess the gaps in observation, we have examined the most recent reports of the European RSCs (Table A2). The results are summarized in Table 3, which focus on three thematic areas: Eutrophication, Marine litter, and Hazardous substances. As the reports are rather heterogeneous compared to each other, we only show the comparison where it was easiest to extract the useful information. We report the parameters used for the evaluation in the four regions and a summary of the knowledge gaps due to the available data, where reported. It should be noted that the marine litter monitoring program is at a preliminary stage in all regions, so the results of the evaluation are not exhaustive in most cases.

A gap across all themes and indicators is that of insufficient data, both in terms of geographical coverage (offshore waters are a problem) and length of time series, which hinder regional and subregional assessments to some extent. The first is necessary to be able to make an assessment at the basin scale, the second to evaluate trends and to define reference values to adequately assess any deviations and, finally, the real health of the marine environment. Improvements can derive from the use of satellite observations (for the variables for which it is possible) and from model simulations, which certainly offer a wide geographical coverage. But the observations in situ, and in the water column, remain an essential element that cannot be given up. In situ conventional monitoring programs should benefit from the development and implementation of new technologies in order to optimise assessment, then environmental management.

Table 3. The variables used by the European RSCs for assessment of A) Eutrophication, B) Marine litter, C) Hazardous substances, and major gaps reported.

A - Eutrophication	Data used	Data Gaps
Black Sea	Concentration of nutrients and oxygen (Secchi disk visibility and phytoplankton biomass limited to some area)	● Limited data availability (both nutrients and chl-a) precludes the assessment in various sub-regions. ● Time series are lacking to estimate trends. ● More data are needed for the creation of criteria for reference condition and thresholds/boundary values. ➔ To foster representative data distribution in time and space, monitoring of nutrient concentrations should be increased, especially in or near eutrophication problem areas. ● The contribution of the atmospheric nitrogen and phosphorus deposition cannot be quantified at the basin scale. ● The duration of blooms of phytoplankton was difficult to determine owing to restricted sampling. ● Assessment of eutrophication status for offshore waters (> 1nm) is still a problem due to the lack of data in these areas.
Mediterranean Sea	Concentration of nutrients and chlorophyll-a	
North East Atlantic Ocean	Concentration of nutrients and chlorophyll-a, inputs of nitrogen via water and air, concentrations of dissolved oxygen near the seafloor, trends in blooms of specific phytoplankton Species.	
Baltic Sea	Concentration of nutrients and chlorophyll-a, cyanobacterial bloom index, Secchi depth during summer, oxygen debt, state of the soft-bottom macrofauna community, coastal waters: indicators developed under the WFD	

B - Marine litter	Data used	Data Gaps
Black Sea Mediterranean Sea	Beach litter, Litter on the seafloor, Floating Litter Major gap: Lack of systematic monitoring and coordination program: the assessments are mainly based on information from research and publications, and in limited cases from national monitoring programmes	Several data issues are reported and these could be improved in the following years. ● Data are often inconsistent and scarce, making the comparability in sub-regions highly restricted. ● More valuable and comparable data could be obtained by standardized approaches (including sampling techniques). ● Reference levels and baselines have not been defined. ● The lack of long-term data makes the assessment of trends extremely difficult. ➔ Longer time series and more monitoring stations are required to detect trends in individual items or types of litter.
North East Atlantic Ocean	Beach litter, Litter on the seafloor; Plastic particles in fulmar stomachs (birds)	
Baltic Sea	Beach litter, Litter on the seafloor, Microlitter Indicators are under development and are only included descriptively in the report.	

Table 3. The variables used by the European RSCs for assessment of A) Eutrophication, B) Marine litter, C) Hazardous substances, and major gaps reported (continued).

C - Hazardous substances	Data used	Data Gaps
Black Sea	Heavy metals (Fe, Zn, Hg, As, Cu, Cd, Pb, Cr, Ni, Mn, Co), POPs, PAHs,TPHs	The monitoring of Hazardous substances is generally done in the three matrices seawater, sediment and biota. Various gaps are reported, some more prevalent in one matrix rather than another. In general: ● The observations mainly concern the coastal areas, because the monitoring sites are located there. ● There is a lack of data for some subregions including but not limited to the most remote areas (for example the Arctic). ● Existing data are not sufficient to define trends, also to be able to evaluate the effect of measures taken by countries. ● Limited spatial coverage, temporal coherence and quality assurance for monitoring activities hinder regional and subregional assessments to some extent.
Mediterranean Sea	Heavy metals (Cd, Hg, Pb), petroleum hydrocarbons, POPs, emerging chemical compounds (environmental phenols, pharmaceutical compounds, personal care products, polycyclic fragrances and many others)	
North East Atlantic Ocean	Heavy metals (Cd, Hg, Pb), PAHs, PBDEs, PCBs, TBT, Organotin, Radioactive Substances, oil spills from ships, offshore oil and gas installations	
Baltic Sea	Heavy metals (Cd, Hg, Pb), PAHs and their metabolite, PBDEs, PCBs, dioxins and furans, TBT and imposex, HBCDD, PFOS, Diclofenac, Radioactive substances, Operational oil spills from ships	

Acronyms
HBCDD - Hexabromocyclododecane
PAHs - Polycyclic aromatic hydrocarbons
PBDEs - Polybrominated Diphenyl Ethers
PCBs - Polychlorinated Biphenyls
PFOS - Perfluorooctane sulphonate
POPs - Persistent Organic Pollutants
TBT - Tributyltin
TPHs - Total petroleum hydrocarbons

3. European Level

The main policy drivers for monitoring in European seas are the **EU Marine Strategy Framework Directive (MSFD)**, and the **Water Framework Directive (WFD)**. References for the legislation and strategies cited in this section are contained in Table A3 of Annex 3.

The WFD sets out rules to halt deterioration in the status of European Union water bodies (surface, ground, inland and transitional) and achieve their Good Ecological and Chemical Status (GEcS). Achieving good status for all waters will allow aquatic ecosystems to recover and to deliver the ecosystem services that are necessary to support life and economic activity that depend on water. The ecological and chemical status of surface waters are assessed in accordance with biological, hydromorphological, physical-chemical and chemical quality elements. The directive defines the standards specifying maximum concentrations for specific water pollutants. If even one such concentration is exceeded, the water body will fail GEcS. It is worth mentioning that this is the first directive from the European Commission which adopts a holistic approach to water environmental protection and regulation providing an integrated policy tool. However, although it covers the catchments and transitional waters, the WFD only covers the narrow band of coastal waters extending either one or 3 nautical miles (depending on country) from high water (Boyes and Elliott, 2014).

The concept of good status is furtherly expanded with the MSFD, which represents the most comprehensive marine environmental legislation, binding Member States to specific actions and measures to achieve **Good Environmental Status** (**GES**) by 2020 in the four European Regional Seas (Baltic, North Eastern Atlantic, Mediterranean and Black Sea), and covering all 'marine waters' which are defined as the water, seabed and subsoil from the baseline out to the EEZ limit of 200 nm, but excluding 'marine waters' which are the responsibility of WFD. It is an innovative instrument that considers the marine environment in a systemic perspective, the Ecosystem-Based Approach. The implementation process is cyclical, with the first cycle starting in 2012 and the second in 2018. Over the first six years of implementation (2012-2017), European Member States had to assess the status of their marine waters; determine GES on the basis of 11 descriptors (Figure 4); set targets, develop and implement monitoring programmes; and finally develop and implement measures to achieve the GES objective.

The effectiveness with which MSFD can achieve GES partially relates to the success of other European legislation (Boyes et al., 2014), including the WFD. Furthermore, the reformed **Common Fisheries Policy** (**CFP**) requires all stock to be above levels capable of producing maximum sustainable yield and to take into account the environmental impacts of fishing. It requires expressly integrating the objectives of the MSFD. Thus, the MSFD complements the CFP, providing the link between fishery policies and other essential aspects of environmental protection. The data collected to support the CFP (https://datacollection.jrc.ec.europa.eu/) are essential for the assessment of the MSFD descriptor 3. The implementation of an Ecosystem-Based Approach through the MSFD forms the environmental pillar of the **Integrated Maritime Policy** (**IMP**), which is a holistic approach to all sea-related European policies. It seeks to provide a more coherent approach to maritime issues, with increased coordination between different policy areas, by coordinating and not replacing them. These include the **Blue growth** and the **Maritime Spatial Planning** (**MSP**) policy areas. Blue growth is a long-term strategy to unlock the potential of maritime economies (the so-called blue economy) and support the development of sustainable marine and maritime economic activities. It focuses on aquaculture, coastal tourism, marine biotechnology, ocean energy and seabed mining. The MSP aims to create a common framework for

integrated ocean management in Europe bringing together multiple users of the ocean with the goal of reducing competition for maritime space (offshore renewable energy equipment, fishing activities, aquaculture and other uses) and making informed and coordinated decisions for efficient, safe and sustainable use of marine resources. It seeks to promote the sustainable growth of the blue economy and the use of marine resources through better conflict management and greater synergy between the different maritime activities.

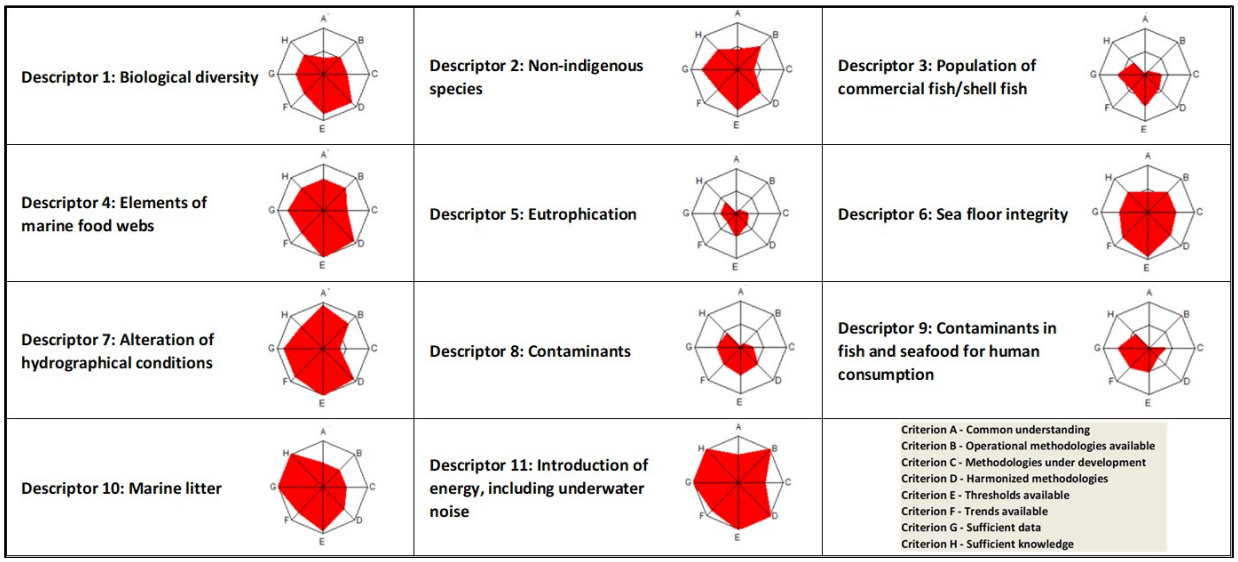


Figure 4. Gap score composition for each MSFD descriptor. These diagrams use polygons to present the aggregated scores per descriptor, while each axis represents each criterion score, having 0 in the center of the polygon, which means no gaps, and 1 on each corner point, which means major gaps (source: Laroche et al., 2013).

Several research projects funded in the past decade have delivered outputs useful for MSFD monitoring. One of these is PERSEUS (Policy-oriented marine Environmental Research in the Southern European Seas, http://www.perseus-net.eu) which produced an analysis of gaps in MSFD assessment elements in the Mediterranean and the Black Sea. The results are summarized in Figure 4 which highlights important gaps in the data and knowledge criteria (Laroche et al., 2013). The lack of data (criterion G) appears to be an important issue for descriptors 1, 2, 3, 4, 6, 7, 8, 9, 10 and 11, also in relation to the lack of time series (criterion F). However, it should be noted that even where this gap is smaller, as for descriptor 5 (Eutrophication), reference is made mainly to the data collected within the WFD, therefore in coastal marine waters, while offshore gaps exist. Several descriptors also need to develop better methodologies and knowledge (criteria C and H). Implementing monitoring programs will provide further data acquisition and experience, which will be useful in improving these aspects as well. Similar conclusions were obtained by the project STAGES (Science and Technology Advancing Governance of Good Environmental Status, http://www.stagesproject.eu), which also identified possible improvements on monitoring that could be implemented at short, medium or long term (Zampoukas et al., 2014). This includes, for the majority of MSFD descriptors: development of cost effective monitoring methods, investment on development and miniaturization of sensors and on automatic data collection systems, investment on common data platforms and on integration of observations from different surveys and sources.

Marine litter is an emerging issue with few data available and lack of harmonisation of sampling methods, which makes the collation and comparison of data problematic (GESAMP, 2019). However,

coordination is existing at the European level that may facilitate the implementation process. In 2018, the **European Strategy for Plastics in a Circular Economy** (**ESPCE**) was adopted, followed by the **Directive on the reduction of the impact of certain plastic products on the environment** one year later. The ESPCE is part of Europe's transition towards a circular economy, and will also contribute to reaching the Sustainable Development Goals, the global climate commitments and the industrial policy objectives of Europe. It will help protect our environment, reduce marine litter, greenhouse gas emissions and our dependence on imported fossil fuels. It will support more sustainable and safer consumption and production patterns for plastics. The Directive delivers on the commitment made in the ESPCE to tackle wasteful and damaging plastic litter through legislative action. New technologies are required in order to monitor the levels of marine litter to assess the implementation of the Directive (paragraphs 30 and 32 of the preamble).

In June 2020, the Commission adopted the last report on the first implementation cycle of the MFSD (European Commission, 2020a). This report shows that while the European framework for marine environmental protection is one of the most comprehensive and ambitious worldwide, persistent challenges remain, such as excess nutrients, underwater noise, plastic litter, and other types of pollution as well as unsustainable fishing, preventing the achievement of good, healthy and productive European seas by 2020. The MSFD must be reviewed by mid-2023 and where necessary, amendments will be proposed. Meanwhile, the **European Green Deal** and the **European Biodiversity Strategy for 2030** were also launched. These are ambitious strategies to protect and restore biodiversity and make Europe the world's first climate-neutral continent.

Climate change, biodiversity, health and food security go together. That is why conserving Europe's natural environment, including our oceans and seas, is a crucial part of the Green Deal. Thus, the success of the MSFD is instrumental for Europe to reach its overarching objectives, such as halting the loss of marine biodiversity and moving towards a zero-pollution society.

4. National Level

This section of the report gives some examples of national implementation of marine policies with regard to observations and related technological development.

4.1 Finland

The Finnish Baltic Sea monitoring programme involves monitoring the state of the sea and other related issues, such as the nutrient load. Annual monitoring reveals the direction in which the sea and marine nature are developing. This is important information for marine management driven both by national regulation and EU regulations such as the MSFD.

A specific maritime management monitoring programme has been established for monitoring purposes. It ensures that monitoring is both systematic and effective. This programme brings together monitoring results carried out by various research institutes and other authorities and is coordinated by the Marine Centre of the Finnish Environment Institute. The ultimate purpose of monitoring is to obtain information on the development of the state of the sea so that it can be managed properly and effectively. Maritime management is a targeted-oriented activity; a common goal for all European Union marine areas is that the sea reaches a good state. A "good" status is defined through a variety of indicators or variables, and it is precisely these variables that are monitored in the Baltic Sea monitoring programme.

The Finnish monitoring programme compiles information from several different research institutions including the Finnish Environment Institute (SYKE), the Finnish Meteorological Institute (FMI), the Natural Resources Institute Finland (Luke), The Finnish National Supervisory Authority for Welfare and Health, the Finnish Food Authority, the Geological Survey of Finland (GTK), Radiation and Nuclear Safety Authority (STUK), and other parties, such as regional environmental authorities, the Finnish Border Guard, the Finnish Museum of Natural History, Metsähallitus and non-profit organisations.

The monitoring programme measures and records physical and chemical conditions, eutrophication, the state of the sea floor, the prevalence of birds, mammals and fish, the concentrations of hazardous substances, littering and noise. Separate monitoring is also carried out to track the nutrient load, use of natural resources (such as fishing) and, for example, the load of hazardous substances. One important aspect of the monitoring programme is biodiversity. This section includes the monitoring of both species and habitats. Species that are being monitored include seals, nesting birds in the archipelago, and wintering waterfowl. Monitored fish species include herring, salmon, whitefish, sea trout, and inshore fish. The monitoring of harmful and hazardous substances is a very specific area. In recent history, the Baltic Sea has been particularly affected by PCBs (Polychlorinated biphenyls), dioxins, and other organic chlorine compounds, as well as heavy metals and oil. The levels of these and other harmful chemicals are monitored from the water, the seabed, and also from fish. Other themes in the monitoring programme include commercial fish stocks, alien species, and eutrophication. Fisheries monitoring is part of the European Union's fisheries data collection programme. In this programme, all Member States collect data on fisheries and fish stocks using the same principles. In Finland, the littering of the sea and beaches is also currently monitored. The monitoring of marine litter is based partly on citizen observations and partly on the collection of micro litter from the water column. Another new target for monitoring is underwater noise.

The Finnish Marine Research Infrastructure program (FINMARI; https://www.finmari-infrastructure.fi/) combines all major components of the Finnish marine research community, representing them on the National Research Infrastructure roadmap funded by the Academy of Finland, which is the main national funding instrument for basic science in Finland. FINMARI address the multiscale variability of the marine environment through synergetic integration of the research foci of the partnership, to create a solid knowledge base for the protection of the Baltic Sea. As part of this all the major monitoring efforts are integrated into the FINMARI program and there is active development of new technologies to further improve the national monitoring program.

Sources: https://www.marinefinland.fi/en-US/Research_and_methods/Monitoring_the_state_of_the_Baltic_Sea
https://www.ymparisto.fi/en-us/Sea/Monitoring_the_state_of_the_Baltic_Sea
https://www.finmari-infrastructure.fi

4.2 France

In France, the movement towards a national maritime ambition was launched at the “Grenelle of the Sea” in 2009, which was outlined at the Sea and Coastal Meetings in 2013, reinforced in the works of the National Council of the Sea and Coastlines in 2014, and was more recently promoted through the mobilisation in France on the topic of Ocean at the COP21.

The National Strategy for the Sea and Coastline (2017) is responsible for providing a framework for public policy on the sea and coast in metropolitan France and in the overseas territories. This includes

the National Strategy for the Ecological Transition to Sustainable Development, the National Research Strategy and the National Biodiversity Strategy, to raise 4 long term objectives:

- the ecological transition for the sea and coastline
- the development of the sustainable blue economy
- the good environmental status of the marine environment and the preservation of an attractive coastline
- France's influence.

Among numerous priority actions, "Getting to know the sea better, developing a marine and maritime knowledge society" and "Support maritime innovations, increase research capacity" are the first ones. "Relying on knowledge and innovation to getting to know the sea better" and "developing a marine and maritime knowledge society and Innovate to recover resources and develop the maritime economy" are the first strategic axes.

This strategy is implemented by 4 Strategic Documents on the Shoreline (east Channel, North Sea-North Atlantic, west Channel-South Atlantic and Mediterranean Sea) which also apply the Maritime Spatial Planning and integrate the MSFD action plans to reach a good environmental status. These tools to set up the integrated maritime policy and the Integrated Coastal Zone Management are discussed during the 4 regional Maritime Councils with stakeholders involved in maritime and coastal activities.

There are also regional initiatives, such as the Regional Conference of the Sea, Coastline in Brittany or the Parliament of the Seas in Occitania, or Regional schemes for the development of marine aquaculture.

The French Maritime Cluster (CMF) is an organization formed in 2006 to represent the French maritime industries to stimulate and promote the French maritime economic sector. It brings together more than 400 members in all sectors: shipping companies, shipbuilding and repair, offshore Oil and Gas service, supply industries, maritime safety and security industries, ports, professional federations and associations, research centres, laboratories, and the French Navy. The CMF acts on three fronts: communication, continuous dialogue with government authorities and the pursuit of synergies between its members, to promote French innovation, research, education and initiatives for environment protection and sustainable exploitation of resources.

Sources: http://www.geolittoral.developpement-durable.gouv.fr/IMG/pdf/17094_strategie-nationale-pour-la-mer-et-le-littoral_en_fev2017.pdf
https://ocean-climate.org/en/french-maritime-cluster/

4.3 Greece

Greece is implementing all the environmental laws and conventions that have been directed by the European Union (e.g. Ramsar Convention, CITES Convention, Berne Convention, Geneva Convention, Kyoto Protocol, Stockholm Convention). Greece has ratified the Convention for the Protection of the Mediterranean Sea Against Pollution (Barcelona Convention) and the relevant Protocols for a) Prevention of the pollution of the Mediterranean Sea by dumping from ships and aircraft and b) Cooperation in Combating Pollution of the Mediterranean Sea by Oil and other Harmful Substances in Cases of Emergency. Greece also supports the MARPOL Convention regarding the prevention of marine pollution by maritime activities and shipping, as well as the OPPRC Convention for petroleum sea

pollution. Greece is implementing the EU Marine Strategy Framework Directive (MSFD) and the Water Framework Directive (WFD).

Greek Research Infrastructures

The GREEK National Roadmap will be the basis for a long-term plan that aims to establish Research Infrastructures in Greece as a foundation for excellent research and to internationally position Greek research in a coordinated manner. In parallel, this Roadmap responds to the ex-ante conditionality for the allocation of EU Structural and Investment Funds for the period 2014-2020. The National Roadmap emphasizes the need to build on the existing strengths and potential of the Greek research ecosystem around national strategic priorities that enhance its synergies with the global research and innovation ecosystem and contribute – through a variable geometry funding model – to the implementation of the ESFRI roadmap. The National Roadmap will not only provide strategic advice, signalling priorities for research infrastructures which are essential to support and enhance the robustness and innovativeness of the Greek R&D system, but will also designate long term engagements in global and European RI initiatives.

HIMIOFoTs (https://www.himiofots.gr/en) is a large-scale national infrastructure aimed to apply an interdisciplinary management approach through the implementation of state-of-the-art technologies and techniques together with innovative solutions in order to support the sustainable development and the provision of relevant services to the society. The main objective of HIMIOFoTS is to provide open access to data from marine and inland waters monitoring networks as well as to related forecasting products that may lead to the development of added value products and services. Furthermore, the accessibility to the HIMIOFoTS infrastructure's nodes is expected to provide the opportunity to the research and academic institutions for the design and implementation of related research activities.

CMBR (http://cmbr.hcmr.gr) is an integrative large-scale facility for Blue Growth supporting access to, and the study & sustainable exploitation of, marine biological resources in the Eastern Mediterranean. With terrestrial resources approaching their physical limits, the sea is increasingly being considered as a last resort for a number of vital resources ranging from food, health, biomass, energy and minerals, to planet equilibrium. The sea has always been a vast resource for food, materials and services, but its tremendous potential for new biotechnological products and for the sustainable use of open-sea products and industrial applications has been largely untapped.

Hellenic Research Fleet. The Hellenic Research Fleet is essential for the implementation of research activities and services in the Greek Seas regarding oceanographic operations and fisheries research in a holistic manner. The modernization and upgrade of the Hellenic Research Fleet is expected to substantially enhance the research capacities and to boost scientific excellence of the national Marine Research Community placing Greece among the scientifically and technologically most advanced countries of Europe and worldwide while substantially extending the marine operational capabilities in regional seas and oceans.

LifeWatchGreece. The national node of LifeWatch in Greece (https://www.lifewatchgreece.eu/) has been established since 2012 and is aiming to address the precise cataloguing of the different Greek ecosystems and the biological species occurring therein, along with the continuous monitoring of species distribution changes through time which are of paramount importance for studying the rich Greek terrestrial and marine biodiversity. Supported studies are powered not only by a scientific incentive but also by a strong societal, industrial and market impact. LifeWatchGreece is participating in

LifeWatch ERIC ESFRI as a national Distributed Centre since 2017. LifeWatchGreece hosts the following virtual laboratories (https://portal.lifewatchgreece.eu/): micro-CT vLab, the MedOBIS vLab, the RvLab and the Ecological Modeling vLab. The Mediterranean Ocean Biodiversity Information System (MedOBIS) is a distributed system established in 2003 which constitutes the Mediterranean node of OBIS and includes multiple taxon-based biogeography datasets for marine organisms (both recent and historical) with a link to satellite environmental data.

POSEIDON system (https://poseidon.hcmr.gr) is a marine observatory research infrastructure of the Eastern Mediterranean basin, for the monitoring and forecasting of the marine environment, supporting the efforts of the international and local community and replying to the needs and gaps of science, technology and society. The POSEIDON general aims are: (a) to establish a sustainable marine observing network in the Eastern Mediterranean, (b) to provide quality and validated forecasts of the marine environment, (c) to provide scientific knowledge and support on the study of the ocean mechanisms and their variability, as well as to address the sensitivity of marine ecosystem and biodiversity to combined natural forcing factors and anthropogenic pressures, and (d) to provide a technology test bed and services to marine policy-makers and society. The system is being developed in accordance to the policy frameworks suggested by IOC/GOOS, EuroGOOS, MonGOOS and GEO while it maintains a balance between the operational and research character of the infrastructure through the integration of methodologies and tools developed in relevant EU initiatives and projects.

4.4 Italy

The Italian Strategy for the Sea (http://www.strategiamarina.isprambiente.it/) implements the MSFD and was established in Italy in 2010 by the Ministry of the Environment which exercises the function of competent authority and coordinates the activities concerning the Italian seas with the support of ISPRA, the Italian Institute for Environmental Protection and Research (https://www.isprambiente.gov.it/en/istitute/index?set_language=en). All the data collected from monitoring within the Marine Strategy flow, according to defined standards, into the Centralized Information System (http://www.db-strategiamarina.isprambiente.it/app/#/), a database accessible to all potential users that allows the collection, management and sharing of the elements acquired at a community level. In addition to ISPRA, the monitoring activities involve the Bodies of the National Network System for Environmental Protection, and other research bodies, experts and volunteers. Most of the data collected and analyzed for the latest state of the sea report released in 2019 comes from ship-based sampling. Since 2010, ISPRA also hosts the Regional Activity Centre- Information and Communication (INFO/RAC) under the Barcelona Convention and coordinates the collection and sharing of information through an IT infrastructure called infoMAP (http://www.info-rac.org/en/infomap-system). Within infoMAP there are various types of information, including those required by the Integrated Monitoring and Assessment Program (IMAP, Table A2), used for the periodic assessment of the state of the marine and coastal environment. The approach followed is of an ecosystem type, that is, also consistent with the MSFD.

The EU MSP Directive was transposed in Italian legislation in 2016, the Ministry of Infrastructure and Transport is the competent authority, and competences are shared among different institutions (https://www.msp-platform.eu/countries/italy). There is currently no legally binding MSP plan for Italy, only guidelines containing criteria for preparing maritime spatial plans were published. Nevertheless, Italy was involved in various projects aiming at carrying MSP initiatives and implementing maritime spatial planning such as ADRIPLAN (ADRiatic Ionian maritime spatial PLANning, http://adriplan.eu/) and

SIMWESTMED projects (Supporting Implementation of Maritime Spatial Planning in the Western Mediterranean region, https://medpan.org/main_activities/projects/simwestmed-project/), both addressing practical aspects of MSP implementation, identification and sharing of best practices, development of tools to enhance understanding of and address concrete issues and challenges linked to MSP implementation.

Regarding systematic marine observations, apart from the periodic cruises conducted by R/Vs, numerous fixed measuring platforms are located mainly along the Italian coast, and to a lesser extent offshore and in deep sea regions. There is no coordination at national level, but many of these platforms are instead coordinated at European level through infrastructure development projects (e.g. EMSO and JERICO). The Italian Government supports this coordination through the National Program for Research Infrastructures (PNIR, http://www.ponrec.it/media/388972/pnir.pdf). The program is being renewed this year, in the previous one the ESFRI RIs were identified as priorities, recognizing their value on scientific progress, on innovation technology and potential suppliers of high-level skills, and their contribution to the National Program of Research, in particular the Blue growth area for marine ESFRI, and the National Strategy of Smart Specialization, which identifies investment priorities, starting from research and development, up to the generation of innovative products and services and the development of the key enabling technologies. Italy is contributing to all the marine ESFRI, and hosting the EMSO ERIC, the Ecosystem Thematic Centre of ICOS and the Service Centre of LifeWatch. Specific Joint Research Units have been activated in Italy to encourage participation in ESFRI RI.

The National Research Program (https://www.miur.gov.it/programma-nazionale-della-ricerca) is organized into 12 thematic areas, identified by crossing two types of indicators: the relevance of Italian research in the various sectors in terms of scientific publications and the innovative capacity linked to patent capacity. The result is a coherent picture of the strategic choices made at European level - especially with the Horizon 2020 framework program - with the intervention policies defined at national and regional level.

The Blue Growth is a high-potential technological area, in which Italy has distinctive assets and skills, which must be supported with the aim of increasing its industrial impact. The Blue Med action (http://www.bluemed-initiative.eu/), led by Italy, is aimed at developing R&D programs designed on blue growth in the marine and maritime sectors. It sees the participation of nine EU member countries committed to jointly defining a Strategic Research and Innovation Agenda. The PNR provides support for the necessary networking and coordination activities of Blue Med within the "Blue Growth" National Technology Cluster (CTN BIG, http://clusterbig.it/). This Cluster was established in 2017 and involves a large group of Universities and Public Research Bodies, private companies and territorial aggregations, which in various capacities deal with the sea. The CTN BIG aims to enhance the existing excellence, to obtain a public-private research system that is more cohesive and synergistic with the productive realities of the Mediterranean.

4.5 Norway

The Water Framework Directive is implemented in Norwegian law through “Vannforskriften” (Norwegian Regulation on a Framework for Water Management) from 2006. The aim is to achieve good environmental status for all water bodies through ecosystem-based management. The Norwegian water management is implemented through regional River Basin Management Plans and Program of Measures, with the current planning period ending in 2021.

Coastal waters outside the baseline are managed through Integrated management plans for the individual basins implemented through governmental white papers, such as the Barents Sea–Lofoten area, the Norwegian Sea, and the North Sea and Skagerrak management plans. The Marine Strategy Framework Directive (MSFD) is not implemented in Norwegian law.

National monitoring programs for coastal waters is financed through the Norwegian Environment Agency and relevant programs include the Ecosystem monitoring of coastal water (ØKOKYST), Norwegian riverine monitoring and the Ocean acidification monitoring program. The programs has a focus on technological developments, and includes monitoring through sensors in fixed locations (e.g. buoys) and autonomous underway platforms, such as FerryBox lines.

Relevant national research infrastructure programs are financed by the Research Council of Norway and includes the Norwegian Ships of Opportunity program (NorSOOP), the Norwegian component of ICOS (ICOS-Norway) and the Norwegian Argo infrastructure (NorArgo).

Sources: https://www.vannportalen.no/
https://www.environment.no/
https://www.regjeringen.no/en/topics/climate-and-environment/biodiversity/innsiktsartikler-naturmangfold/forvaltningsplaner-for-havomrada/id2076485/
https://www.norsoop.com/

Role of ocean observing and related technological development

- Sustained ocean observations provide the basic knowledge for
  - ❑ assessing the state and trends of ocean and marine ecosystems,
  - ❑ planning environmental management, mitigation actions and adaptation strategies,
  - ❑ monitoring effectiveness of management and strategies.
- To fill the observational gaps, a gradual development process of the observation systems is necessary, based on the level of readiness of the measurement (sensors and platforms):
  - ❑ the main gaps in terms of variables relate to biology, ecosystems and emerging pressures (such as marine litter and noise),
  - ❑ in general, gaps exist in relation to geographic coverage (especially in offshore waters) and the lack of time series,
- The development of new monitoring methods promises to be useful for expanding the range of variables measured at the necessary spatial and temporal resolution:
  - ❑ new sensors,
  - ❑ miniaturization,
  - ❑ autonomous systems/new observing platforms.

The contribution of NAUTILOS

- The 17 instruments/tools developed by NAUTILOS, integrated and demonstrated in different observing platforms will increase participation in environmental observation, help reducing the costs of the technologies proposed and used, and thus will multiply the social, economic and environmental benefits and positive impact of the project.
- Observation developed in NAUTILOS will cover 14 Biology and Ecosystem and Biogeochemical EOVs (inorganic carbon, stable carbon isotopes, dissolved oxygen, inorganic macro nutrients, suspended particulates, ocean colour, ocean sound, phytoplankton biomass and diversity, zooplankton biomass and diversity, marine turtles, birds, mammals, abundance and distribution, live coral, sea grass cover, microbe biomass and diversity (emerging) and invertebrate abundance and distribution (emerging), 2 DOOS specific EOVs (litter including micro-plastics, seafloor sponge habitat cover) and 9 MSFD Descriptors (D1, D3, D4, D5, D6, D7, D9, D10, D11).

III. EXISTING EUROPEAN MARINE OBSERVING INFRASTRUCTURE

Marine observation infrastructures are RIs facilities of different types and scales used by the scientific community to conduct research in all scientific domains related to the marine environment. In Europe Marine RIs consist of up to 800 facilities servicing different domains such as coastal and open sea monitoring, marine biology, aquaculture, marine technology and ocean engineering research (eurocean.org, Figure 5)

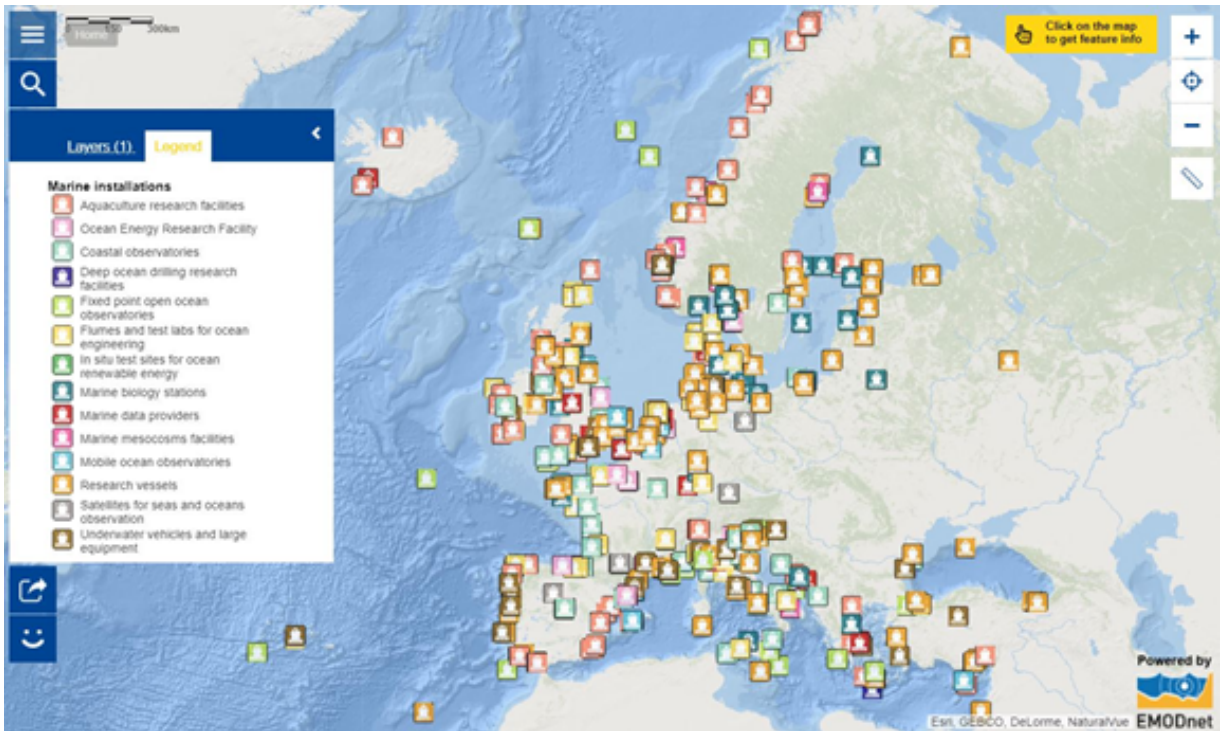


Figure 5. The locations of the different marine research infrastructures listed in the database the European Centre for Information of Marine Science and Technology - EurOcean (https://www.eurocean.org/np4/home).

The infrastructures, operating in a long-term scheme, and offering resources, platforms, instrumentation, services and data management components are forming the European Ocean Observing System (EOOS). There are a variety of infrastructure types such as R/Vs, voluntary ships and autonomous vehicles, fixed and drifting in situ observation networks, remote sensing systems, on shore testing facilities and laboratories, experimental facilities and data centres. The majority of the marine scientific infrastructures are operated by academic and research organizations offering access to a combination of services and products to the community.

The European Strategy Forum on Research Infrastructures (ESFRI) is a strategic instrument created in 2002 by the European Commission and the Member States to support a coherent and strategy-led approach to policy-making on research infrastructures in Europe and to facilitate multilateral initiatives leading to a better use and development of research infrastructures. A first roadmap was produced in 2006 with a list of European scale research infrastructures of vital importance, which was last updated in 2018 (Figure 6). The present status of Marine RI's covering wide scientific fields at different depth scales from surface to deep seafloor included in the last map are summarized in Table A4 (Annex 4).

- *The **European Multidisciplinary Seafloor and water-column Observatory EMSO ERIC**, a long-term multidisciplinary observation of the seafloor and the water-column by means of fixed-point multi-sensor platforms*
- *The **European contribution to the international Argo Program Euro-Argo ERIC**, managing and operating the 25% of the Argo international programme of drifting floats, providing quality controlled data for climate and ocean research.*
- *The **Integrated Carbon Observation System ICOS-ERIC** integrates terrestrial, oceanic and atmospheric observations of atmospheric greenhouse gas concentrations and fluxes at various sites into a single, coherent, highly precise dataset*
- *The **e-Infrastructure for Biodiversity and Ecosystem Research LifeWatch ERIC**, which provides e-Science research facilities for scientists seeking to increase their knowledge on biodiversity and ecosystem functioning/services*
- *The **European Marine Biological Resource Centre EMBRC-ERIC**, that provides access to marine organisms and the facilities to study them, including experimental facilities and technological platforms.*
- *The **International Center for Advanced Studies on River –Delta – Sea Systems DANUBIUS-RI** (ESFRI), a pan-European distributed research infrastructure supporting interdisciplinary research on large river-sea systems.*

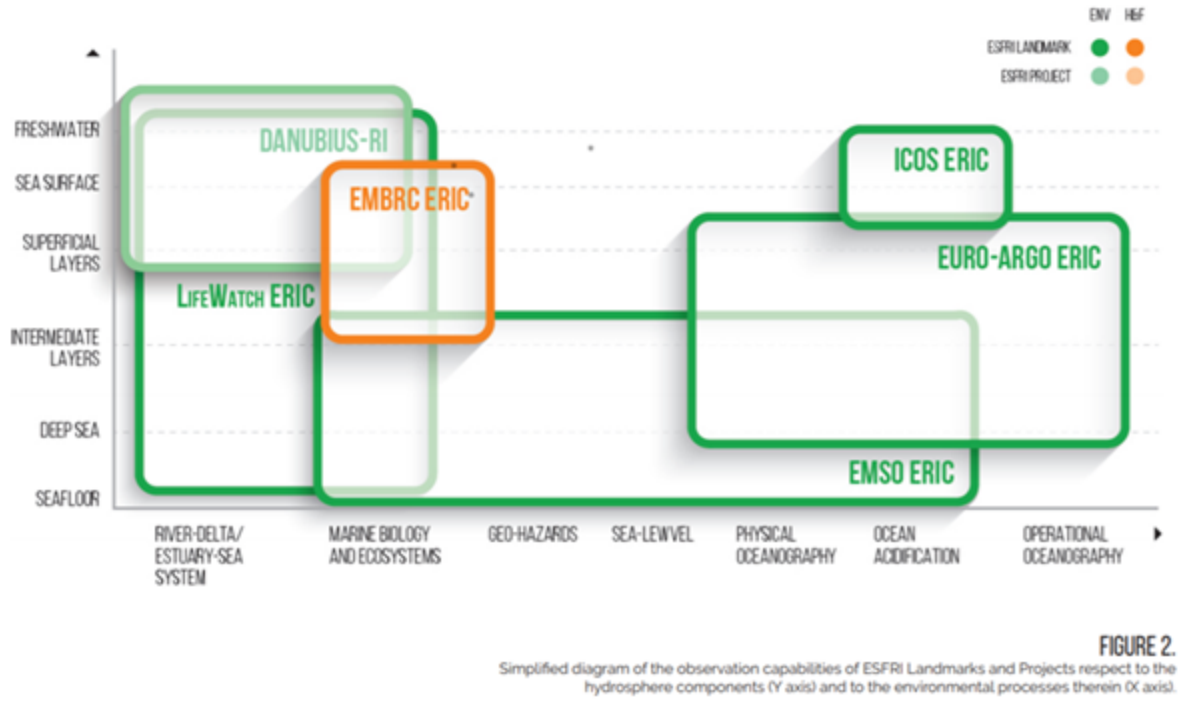


FIGURE 2.
Simplified diagram of the observation capabilities of ESFRI Landmarks and Projects respect to the hydrosphere components (Y axis) and to the environmental processes therein (X axis).

Figure 6. Diagram of the observation capabilities of ESFRI Landmarks and projects (source: https://www.esfri.eu/roadmap-2018).

Apart from the ESFRI map components there are other projects (Table A4) involving scientific networks (coastal observations, R/Vs, autonomous vehicles), experimental facilities (mesocosms facilities, calibration laboratories), services and products dealing with marine research.

- ***AQUACOSM-plus*** *advances European mesocosm-based aquatic RI by integrating the leading mesocosm infrastructures into a coherent, interdisciplinary, and interoperable network covering all ecoregions of Europe.*
- ***EUMarineRobots (EUMR)*** *proposes an access-infrastructure for the deployment of a full-range of aerial, surface and subsurface marine robotic assets, the combined value of which is far greater than the sum of their parts. EUMR will open transnational access to significant national marine robotics R&D assets across Europe.*
- ***ARICE*** *aims to provide Europe with better capacities for marine-based research in the ice-covered Arctic Ocean* and develop strategies to ensure the optimal use of the existing polar research vessels at a European and international level.
- *The* ***EUROFLEETS+*** *project is an H2020 project funded under the Infrastructures initiative whose aim is to facilitate open free of charge access to an integrated and advanced research vessel fleet, designed to meet the evolving and challenging needs of the user community.*
- ***JERICO-S3*** *(coastal observatories)* JERICO-RI is an integrated pan-European multidisciplinary and multiplatform research infrastructure dedicated to a holistic appraisal of coastal marine system changes. It is seamlessly bridging existing continental, atmospheric and open ocean RIs, thus filling a key gap in the ESFRI landscape. JERICO-RI establishes the framework upon which coastal marine systems are observed, analysed, understood and forecasted.
- ***INTAROS*** *will develop an efficient integrated Arctic Observation System by extending, improving and unifying existing and evolving systems in the different regions of the Arctic.*
- **Blue-Cloud** is a European H2020 project with the overarching aim of federating and piloting innovative services for Marine Research & the Blue Economy.
- ***EuroSea*** *works to improve the European ocean observing and forecasting system in a global context, delivering ocean observations and forecasts to advance scientific knowledge about ocean climate, marine ecosystems and their vulnerability to human impacts and to demonstrate the importance of the ocean to an economically viable and healthy society.*
- ***MINKE*** *will integrate key European marine metrology research infrastructures, to coordinate their use and development and propose an innovative framework of "quality of oceanographic data" for the different European actors in charge of monitoring and managing the marine ecosystems.*

Role of ocean observing and related technological development

The Marine RIs are contributing actively to technological developments for more advanced marine monitoring strategies and implementation of environmental policies (Dañobeitia et al., 2020). New technologies are required to address an increasing number of scientific parameters in marine research and the Marine RIs are making a significant contribution by offering access to facilities and means that support both the research community and the industry. The RIs testing and experimental facilities combined with field validations operated at sites with existing instrumentation and data quality techniques, will contribute to the advancement of technological readiness levels and result in products and services tested and validated in a realistic operational environment.

The contribution of NAUTILOS

NAUTILOS will develop sensors and new measurement approaches by motivating different scientific platforms as hosts of the new technological products. In addition to the demonstrations and integration in existing RIs already foreseen in the project, NAUTILOS sensors could be further demonstrated using the transnational access programs opened by several research infrastructures in Europe disseminating the project outcomes.

IV. EUROPEAN DATA INITIATIVES

The use of marine data has seen its importance grow over the years, gaining increasing consideration as a resource for innovation, economic growth, and societal progress. Data and information on the state and variability of the different components and aspects of the marine environment is crucial for understanding changes and finding high-level, coordinated solutions for present issues and upcoming concerns. In this context, European initiatives on marine data collection, elaboration and sharing have spread over the decades, and are currently acting both as *leaders* of technological change and as *demanders* for technological solutions. Ocean and marine data collection in Europe is carried out by hundreds of organizations in many different countries, working across a range of disciplines, collecting valuable information on different parameters and geographical areas.

In 2010, the effort for a new, more comprehensive approach to data inspired the adoption of the European Commission's Marine Knowledge 2020 strategy. At operational level, the strategy resulted in the launch of **EMODnet, i.e. The European Marine Observation and Data Network** (https://www.emodnet.eu), an initiative based on a long-term perspective and on a key principle: *collect data once and use many times*. EMODnet is a long-term, marine data initiative funded by the European Maritime and Fisheries Fund, which, together with the Copernicus space programme and the Data Collection Framework for fisheries, implements the EU's Marine Knowledge 2020 strategy. EMODnet connects a network of over 120 organisations supported by the EU's Integrated Maritime Policy who work together to observe the sea, process the data according to international standards and make that information freely available as interoperable data layers and data products. This 'collect once and use many times' philosophy benefits all marine data users, including policy makers, scientists, private industry and the public. It has been estimated that this kind of integrated marine data policy will save offshore operators at least one billion Euro per year, as well as opening up new opportunities for innovation and growth. The aim of EMODnet is to increase productivity in all tasks involving marine data, to promote innovation and to reduce uncertainty about the behaviour of the sea. This will lessen the risks associated with private and public investments in the blue economy, and facilitate more effective protection of the marine environment. EMODnet provides easy and free access to marine data, metadata and data products and services spanning seven broad disciplinary themes: bathymetry, geology, physics, chemistry, biology, seabed habitats and human activities. Each theme is dealt with by a partnership of organisations that possess the expertise necessary to standardise the presentation of data and create data products. To demonstrate the power of opening up Europe's wealth of marine observations and data, EMODnet turns marine data into maps, digital terrain models, time series & statistics, dynamic plots, map viewers and other applications ready to support researchers, industries and policy makers to tackle grand societal challenges.

Another crucial pan-European infrastructure is **SeaDataNet (SDN -** https://www.seadatanet.org/**)**, aimed at managing, indexing and providing access to marine data sets and data products, acquired by European organizations from research cruises and other observational activities in European coastal marine waters, regional seas and the global ocean. Founding partners are National Oceanographic Data Centres (NODCs), major marine research institutes, UNESCO-IOC, and ICES. The SeaDataNet network has developed its network of data centres and infrastructure with standards, tools, and services during many EU projects (SeaDataNet, SeaDataNet2, Ocean Data Interoperability Platform, and SeaDataCloud). SeaDataNet develops, governs and promotes common standards, vocabularies, software tools, and services for marine data management, which are freely available from its portal and widely adopted and

used, e.g. most of the EMODnet thematics projects largely adopted and support the SDN standards. SDN common standards for the marine domain have been developed and are maintained, collaborating with European and international experts, adopting and adapting ISO and OGC standards, and achieving INSPIRE compliance, where possible. SeaDataNet has focused, with success, on applying these standards for interconnecting data centres enabling the provision of integrated online access to comprehensive sets of multi-disciplinary, in situ and remote sensing marine data, metadata and products.

Since 2015, the range of European initiatives related to sea observation includes the **Copernicus Marine Environment Monitoring Service** (CMEMS, https://marine.copernicus.eu/), and its new web-based visualization platform (https://cmems.lobelia.earth/). The Service produces information and forecasts supporting the application of such products in different fields, including marine safety, marine resources, coastal and marine environment, weather, seasonal forecasting and climate. These products are related to the physical and biogeochemical characteristics of ocean/marine ecosystems, and encompass a description of the current situation (Analysis), the variability at different spatial and temporal scales, the prediction of the situation a few days ahead (Forecast), and the provision of consistent retrospective data records for recent years (Re-analysis).

Closely related and complementary to CMEMS mission, **WEkEO** (https://www.wekeo.eu/) is a cloud computing platform for Earth Observation data, giving access to original Copernicus Programme data as well as to the Sentinel satellite portfolios. WEkEO gives harmonized and seamless access to Copernicus data and information on climate, atmosphere, marine and land characteristics, and offers a distributed infrastructure connected by an ultra high-speed backbone, and from the cloud-based hosted processing with tools.

Continuous and extended data availability, coupled with high usability, is supported also by **PANGAEA - Data Publisher for Earth and Environmental Science** (https://www.pangaea.de/), an initiative hosted by the Alfred Wegener Institute, Helmholtz Center for Polar and Marine Research (AWI) and the Center for Marine Environmental Sciences of the University of Bremen (MARUM). PANGAEA is an Open Access library aimed at archiving, publishing and distributing georeferenced data from earth system research. Long-term availability of its content is guaranteed by the continuous commitment of the hosting institutions. In order to facilitate the navigation and use of the uploaded content, data can be searched on the web platform of PANGAEA based on category (chemistry, oceans, lithosphere, …) or on the geographical area of reference. PANGAEA provides data not only based on their direct and exclusive relation to natural parameters, but also with reference to human activities (e.g. agriculture).

Relevant initiatives in the field of sea observation and monitoring include global systems with a regional dimension. Among them, **OBIS - Ocean Biodiversity Information System** (https://obis.org/) operates as a global open-access data and information clearing-house on marine biodiversity for science, conservation and sustainable development. Its aim is to develop a taxon-based biogeography database and online data server with a link to survey and provide satellite environmental data. It is hosted by HCMR, and includes more than 20 nodes around the world, connecting 500 institutions from 56 countries. Collectively, these nodes have provided over 45 million observations of nearly 120 000 marine species, from Bacteria to Whales, from the surface to 10 900 meters depth, and from the Tropics to the Poles. The datasets are integrated in order to allow searching and mapping them all seamlessly by species name, higher taxonomic level, geographic area, depth, time and environmental parameters.

A strong technological development is envisioned and needed by OBIS, especially with reference to the initiatives related to the UN Decade of Ocean Science for Sustainable Development. As stated in the

IODE Steering Group for OBIS (SGOBIS), gathered in November 2020, the OBIS Strategic Advisory Task Team will develop a roadmap and architectural plan for the next generation international OBIS infrastructure (OBIS3.0), taking into account the continuing increases in demand for new features and services (expected to increase also under the Ocean Decade), and ensure keeping up with the accelerating pace of technological developments.

With a closer relation to NAUTILOS geographical scope of action, OBIS' Mediterranean distributed system **MedOBIS** (the related Integrated Publishing Toolkit is available at http://ipt.medobis.eu/) allows users to search multiple datasets simultaneously for biogeographic information on marine organisms. MedOBIS, as a node of OBIS, follows the vision and needs of technological development expressed above, especially with reference to new services, and the extensive application of 'FAIR' principles to sea observations.

EuroGOOS (https://eurogoos.eu/), the European component of the Global Ocean Observing System of the Intergovernmental Oceanographic Commission of UNESCO (IOC GOOS - https://www.goosocean.org/), is part of a global initiative gathering in situ networks, satellite systems, governments, UN agencies and individual scientists in a single collaborative system. Based in Brussels, EuroGOOS serves 44 members and supports five regional systems for the development of common strategies, priorities and standards, thanks to the activity of working groups, networks of observing platforms (task teams), and regional systems. The task teams, promoting scientific synergy and technological collaboration focus on specific ocean observing infrastructures and on the exchange of open source tools, especially with reference to FerryBox, tide gauges, gliders, HF radars, Argo floats (Euro-Argo), fixed platforms and animal-borne instruments. Each of these instruments, platforms and methodologies requires and drives technological development in the field of ocean observation, thus making EuroGOOS a technology- and innovation-driven initiative.

MonGOOS - Mediterranean Operational Network for the Global Ocean Observing System (http://www.mongoos.eu/) is one of the regional systems supported by EuroGOOS. The network conducts activities related to the production and use of operational oceanography services, acting as an operational network for GOOS in the Mediterranean. In its 2018 Strategic Plan, MonGOOS has identified crucial challenges, painting an accurate picture of technological needs in the field of marine observation. The main ambitions that emerge from the Strategic Plan concern aspects related to monitoring techniques, but also modelling perspectives and information availability. The major challenges presented include: *RT monitoring* of hydrodynamics, biochemical fluxes (nutrients and plankton), contaminants levels, and fishery from the basin to the shelf/coastal scale; *capability to model* the hydrodynamics and the biochemical fluxes and food webs from the basin scales to the coastal areas; data assimilation tools; *uncertainty quantification* related to simulating and forecasting the dynamics and biogeochemical processes in the Mediterranean Sea; development of an *information management system* for the Mediterranean Sea for RT dissemination of both observed and model estimates of the state of the system, with new interfaces to make this information available to policy makers.

With specific reference to sea level monitoring, the **PSMSL - Permanent Service for Mean Sea Level** (https://www.psmsl.org/) is responsible for the collection, publication, analysis and interpretation of sea level data from the global network of tide gauges. Established in 1933, the Service maintains the global data bank for mean sea level, and acts as the GLOSS Data Archive with the British Oceanographic Data Centre. The PSMSL works in close collaboration with Member Nations (providing monthly time

series) and with the international sea level community, providing not only data, but derived-products that can support decision making.

Acquisition of new technologies in the field of sea level observation, especially related to tide gauges, is currently a major field of scientific debate and cooperation within the international community, and the need for experimental technologies (e.g. Global Navigation Satellite System Multi-Reflectometry technique - GNSS-MR), emerged clearly from the 1st EuroSea Tide Gauge Network Workshop (12-14 January 2021) included a session on the status, challenges, and advantages of existing and experimental technologies.

Other major initiatives in the field of sea monitoring include:

- **Système d'Observation du Niveau des Eaux Littorales - SONEL** (https://www.sonel.org), aiming at providing high-quality continuous measurements of sea- and land levels at the coast from tide gauges (relative sea levels) and from modern geodetic techniques (vertical land motion and absolute sea levels) for studies on long-term sea level trends, but also the calibration of satellite altimeters, for instance. SONEL serves as the GNSS data assembly centre for the Global Sea Level Observing System (GLOSS), which is developed under the auspices of the IOC/UNESCO. It works closely with the PSMSL and the University of Hawaii Sea Level Center (UHSLC) by developing an integrated global observing system, which is linking both the tide gauge and the GNSS databases for a comprehensive service to the scientific community. It also acts as the interface with the scientific community for the French tide gauge data.
- **Joint Research Center - Tsunami Array Device** - Inexpensive Device for Sea Level Measurements - is a network of mareograph devices designed at the Joint Research Centre (JRC) of the European Commission (EC) in order improve the sea level network in use for the Tsunami Hazard monitoring in the Mediterranean Sea and in the North Atlantic area (NEAMTWS area of UNESCO).

Coriolis Operational Oceanography (http://www.coriolis.eu.org/), contributing to the French operational oceanography program for the in-situ observations, thanks to the joint efforts of the institutes involved in operational oceanography in France (CNES, CNRS, Ifremer, IPEV, IRD, Météo-France, Shom). Coriolis aims at organizing and maintaining data acquisition in real-time and delayed mode of in-situ measurements, with high attention paid to the necessary technology. Coriolis is also hosting the European Global Data Assembly Center (GDAC) for the international ocean observing programs. The CORIOLIS data portal provides a single access point for in situ data and products, thanks to the innovative equipment used for data acquisition. Among the technological equipment used by the Coriolis DAC, we can consider the 453 BGC-Argo floats, *i.e*. floats equipped with bio-geo-chemical (BGC) sensors.

OCEANOPS (https://www.ocean-ops.org/), working to ensure increased technical coordination across different communities of observers around the world, including over 100 countries in the provision of sea-related data and metadata. The responsiveness of the system, one of the key value statements affirmed in OceanOPS strategic plan for 2021-2025, needs to be supported by advanced technological development, also needed to ensure the evolution and continuous support to the effectiveness in delivery of data and metadata.

Finally, related to emerging observing approaches, **MEOP** (http://meop.net/) is a consortium bringing together several national programmes to produce a comprehensive quality-controlled database of oceanographic data obtained in Polar Regions from instrumented marine mammals. These data are

available to the public, and scientific and operational oceanographic communities. At the moment, the dataset consists of temperature and salinity measurements only, but it could be integrated with EcoBio EOV in the future (Harcourt et al., 2019).

The general picture emerging from the review of this range of initiatives with different focuses, disciplinary scope and type of tools involved highlights common paths towards user-oriented solutions, increased and continuous data availability and enhanced cooperation with public as well as private actors. Such a development of the European data system requires a strong technological support in the phases of data collection, elaboration and management. In some of the cases presented above, this is explicitly considered as a priority for the immediate future. In others, this trend emerges from the activities carried out and the recent release of new products and web platforms, in spite of the lack of explicit formalization.

Summary of chapter IV

Role of ocean observing and related technological development

- As the variety of European initiatives has incremented in terms of intensity, connection and scope of action, a stronger technological support is needed to ensure data availability, accuracy, interoperability
- The intense activity of European data initiatives is enhancing the possibilities for a more democratic access to data
- European data initiatives are increasingly focused on user-oriented solutions

The contribution of NAUTILOS

- State-of-the-art, cost-effective sensors and samplers, to be considered as tools for an expanded, more open marine data system, will give access to data for a wider range of users, responding to the various needs of a *diverse* and *growing* user base.

V. OUTLOOK

Scientists, maritime industries, as well as environmental and climate change policymakers need reliable data and services to access these data. Oceanographic and marine data, as traditionally collected, include a wide range of measurements and variables, covering a broad, multidisciplinary spectrum of projects and programmes. Oceanographic and marine data are collected by over a thousand research institutes, governmental organisations, and private companies in the countries bordering the European seas. This monitoring is done via heterogeneous observing sensors that are installed on research vessels, aircraft, moorings, drifting buoys, gliders and other underwater vehicles, floats, fixed platforms, and satellites. The sensors measure physical, chemical, biological, geological and geophysical parameters, with further data resulting from the analysis of water and sediment samples for a wide variety of parameters. These data are of high quality, but at the same time these data are collected at a very high cost, and research takes place mostly out of sight of the citizen. Despite the current large effort and funding to collect these data, there are critical data gaps that prevent knowledge-based and sustainable usage of our marine environment.

GOOS-EOVs for biogeochemistry (such as inorganic carbon, nutrients, and particulate matter), and biology/ecosystems (e.g., plankton biomass and diversity, marine species distribution and abundance) need to be measured by platforms and sensors with the requisite level of technological readiness. Expanding spatial coverage of physical observing into coastal and offshore waters requires additional technologies (Moltmann et al., 2019). Emerging networks, such as the Global Ocean Acidification Observing Network (GOA-ON) and the Marine Biodiversity Observation Network (MBON) will provide future directions for developing these observations (Tilbrook et al. 2019; Muller-Karger et al., 2021).

Among the emerging pressures, particular attention is paid to marine litter (MSFD D10, DOOS specific EOVs, UN SDG indicator 14.1.1), which is mainly made up of plastics of various sizes (80% according to UNEP, 2016). It is a growing problem for environment and human health, and policies have included monitoring as an important tool to evaluate both trends and the efficiency of reduction measures (Barnes et al., 2009; Derraik, 2002; Dixon and Dixon, 2003). To tackle the problem, from the local to the global scale, robust and homogeneous datasets are needed, but these are lacking, as is the harmonization of sampling methods (no internationally established methodology or standards are yet available). This makes the collation and comparison of data problematic. For example, EMODnet Chemistry developed a data management plan for marine litter that may be used as a basis for marine litter assessment at pan-European scale (Molina Jack et al., 2019), but there is a need for new and more data flowing into such database. Limitations in sampling effort (i.e. small number of samples or spatial and temporal replication) may not produce sufficiently accurate estimates to detect changes in abundance. This needs to be addressed as part of the overall sampling strategy, which in the future can benefit from the increasing automation of sampling and sample analysis to have more materials to analyse, thus reducing part of the uncertainty in the measurements (GESAMP, 2019). Furthermore, citizen engagement can be a useful strategy both to assist in data collection and to raise awareness and take action. Finally, the UN Decade of Ocean Science for Sustainable Development presents an opportunity to collaborate with the broader ocean science community to develop a more effective, reliable and cost-effective global monitoring framework to address this pressing issue.

Cost-effective instruments have been developed and used in coastal ocean monitoring over the last decade, e.g., FerryBox systems and shallow water Argo profiles (with oxygen and Chl-a measurements). For the purpose of environmental assessment, a significant amount of chemical and biological

observations is made in coastal waters and should be expanded offshore. Efforts are underway to integrate the Argo floats, originally focused on temperature and salinity, with other parameters, such as biogeochemical variables and to extend their capacity to the deep sea.

Animal tracking technologies enable sustained observing of species distribution and abundance, besides information on physical parameters in the water column, in a wide range of environments ranging from coastal to open oceans and from tropical to polar regions (Harcourt et al., 2019). But they need to be further integrated into existing observation systems.

A number of commercially available Unmanned Underwater Vehicles (UUVs) and Unmanned Surface Vehicles (USVs) offer a real revolution in the marine technology field and these are increasingly being used by the research community and industry (Whitt et al., 2020). Some platforms incorporate internal automatic control to increase mission times and reduce communication bandwidth or operational costs. These programmable, robotic vehicles have become known as Autonomous Surface Vehicles (ASVs) and Autonomous Underwater Vehicles (AUVs). They have advanced in their payload capacity, computational capabilities, communication capabilities, and autonomy but navigation and localization remain two of the most important challenges (González-García et al., 2020). There are still many types of sensors that cannot be fitted to platforms whose objective is to have endurance of months or years. The primary challenges for sensors lie in power consumption, size and stability over time (including issues of biofouling). Biological and biogeochemical sensors have posed the greatest difficulty (Whitt et al., 2020)

There is a growing awareness that closing the data gaps cannot be accomplished solely by modifying or upscaling current data collection approaches.

Over the last decade, citizen science projects, as listed on https://eu-citizen.science/, have provided a cost-effective means to collect extensive data sets covering vast spatio-temporal scales where conventional data collection cannot operate. Such projects can be used in scientific research, to develop conservation policy and to promote environmental awareness. Many citizen science initiatives start with lofty ambitions to make a difference, some bottom up as real citizen initiatives, some more top-down from research institutes. Yet, many of the concepts fail to reach the success of sustainability: lacking full uptake of data next to traditional data, not reaching end-users, nor meeting data quality requirements. A key obstacle facing citizen science are perceptions regarding data quality, despite several studies demonstrating that the data meets accepted quality standards (Kosmala et al., 2016; Schläppy et al., 2017). Regardless of previous difficulties, marine citizen science must be elevated and expanded in order to both meet the growing monitoring requirements in coastal regions, and to foster an educated and engaged society.

Another challenge for the marine community is to publish data in such a way as to encourage Big Data processing, the quickest way being to make these data Open. Whilst some data lend themselves to big data (e.g. some physical oceanographic parameters with automated quality control and vessel density tracking data, etc.), other data are less easily suitable (e.g. marine biological datasets). A key challenge will be that as the community scales up towards wider automation and near real-time delivery of data, including the potential for big data sets we need to do this in a stepwise approach to organise and optimise the data value chain. We should ensure quality and provenance of data (though metadata descriptions) so that we do not move towards big data until we can ensure the quality and structure of the data so it will be used by the user community.

The Digital Twin of the Ocean (DTO) is the next step, filling the need to integrate a wide range of existing and new data sources, to transform data into knowledge and to connect, engage, and empower citizens, governments and industries by providing them with the capacity to inform their decisions (European Commission, 2020b). Building on the integration of existing EU leading-edge capacities in ocean observation (such as EuroArgo, EMSO, Eurofleets+, Jerico, etc.), data infrastructures (such as EMODnet, SeaDataNet, PANGAEA, OBIS, etc.) and forecasting services (Copernicus, Blue Cloud, EuroSeas, etc.) with innovative digital technologies (cloud, super HPC capacities, AI and data analytics), it will bring together infrastructures and communities into a digital component that represents a consistent high-resolution, multi-dimensional and (nearly) real-time description of the ocean. The technology exists to create such a digital copy of the ocean, which would be useful for simulating risk scenarios and the effectiveness of mitigation and adaptation plans, for example, and to support the EU Green Deal and societal transitions.

VI. CONCLUSION

Measurement of EOVs is essential to understanding the oceanic system – the state of the ocean, its dynamics and properties, to quantify the forcing of the atmosphere-ocean boundary and to understand the role the ocean plays in Earth's climate. Similarly, in situ observations are essential for an evidence-based understanding of carbon and contaminant transfers through the marine environment, and the health of its constituent ecosystems. They help us understand the adverse and related climatic effects on ocean ecosystems: eutrophication and anoxia in coastal oceans, alteration in primary production and effects on fish stocks of socio-economic importance, diffusion of known and emerging pollutants and marine contaminants (including plastics), and proliferation of invasive species such as harmful algal blooms and parasites of wild and farmed fish operations. These data are also fundamental for the forecasting, analysis and reanalysis of the oceans and the development, validation and improvement of the models of the ocean and Earth's-system.

In addition to the GOOS EOVs, deep ocean specific EOVs recommended by the Deep-Ocean Observing Strategy (DOOS, Levin et al. 2019) and the Descriptors of GES-Good Environmental Status (according to the EU-MSFD) for in situ assessment have been identified as target variables to be sampled/detected by NAUTILOS' technologies. Such targeted variables have been identified and chosen according to the current maturity of relevant sensors/equipment in the Technology Readiness Levels scale (European Commission, 2014).

NAUTILOS will cover 14 Biology and Ecosystem and Biogeochemical EOVs (inorganic carbon, stable carbon isotopes, dissolved oxygen, inorganic macronutrients, suspended particulates, ocean colour, ocean sound, phytoplankton biomass and diversity, zooplankton biomass and diversity, marine turtles, birds, mammals, abundance and distribution, live coral, sea grass cover, microbe biomass and diversity (emerging) and invertebrate abundance and distribution (emerging), 2 DOOS specific EOVs (litter including microplastics, seafloor sponge habitat cover) and 9 MSFD Descriptors (D1, D3, D4, D5, D6, D7, D9, D10, D11) by the sensors and samplers as identified in Figure 7.

The wide adoption of the technologies developed and demonstrated in the context of the project will increase participation in environmental observation, will help reduce the costs of the technologies proposed and used, thus multiplying the social, economic and environmental benefits.

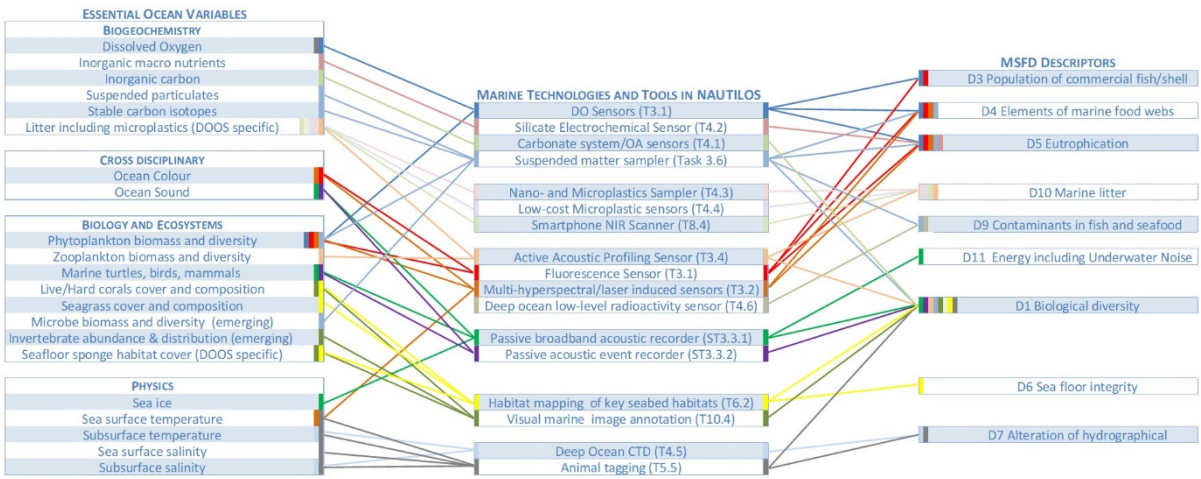


Figure 7. Environmental variables as covered by NAUTILOS instrumentation and tools.

APPENDIX 1: REFERENCES AND RELATED DOCUMENTS

ID	Reference or Related Document	Source or Link/Location
1	NAUTILOS Grant Agreement	NAUTILOS ownCloud

References

Barnes, D. K., Galgani, F., Thompson, R. C., Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. Philosophical transactions of the royal society B: biological sciences, 364(1526), 1985-1998. doi: 10.1098/rstb.2008.0205

Boyes, S.J., Elliott, M. (2014). Marine legislation –The ultimate 'horrendogram': international law, European directives & national implementation. *Marine Pollution Bulletin*, 86:39–47. doi:10.1016/j.marpolbul.2014.06.055

Claudet, J., Bopp, L., Cheung, W.W.L., Devillers, R., Escobar-Briones, E., Haugan, P., et al. (2020). A Roadmap for Using the UN Decade of Ocean Science for Sustainable Development in Support of Science, Policy, and Action. *One Earth*, 2(1):34-42. doi: 10.1016/j.oneear.2019.10.012

Collins, S., Genova, F., Harrower, N., Hodson, S., Jones, S., Laaksonen, L., Mietchen, D., Petrauskaité, R., Wittenburg, P. (2018). Turning FAIR into reality. Final Report and Action Plan from the European Commission Expert Group on FAIR Data. EU publications, Research policy and organisation. doi: 10.2777/1524

Dañobeitia, J.J., Pouliquen, S., Johannessen, T., Basset, A., Cannat, M., Pfeil, B.G., et al.. (2020). Toward a Comprehensive and Integrated Strategy of the European Marine Research Infrastructures for Ocean Observations. *Frontiers in Marine Science* 7: 186. doi:10.3389/fmars.2020.00180

Derraik, J.G. (2002). The pollution of the marine environment by plastic debris: a review. Marine Pollution Bulletin, 44: 842-852. doi: 10.1016/S0025-326X(02)00220-5

Dixon T.R, Dixon T.J. (2003). Marine litter surveillance. Marine Pollution Bulletin, 12:289-295. doi: 10.1016/0025-326x(81)90078-3

Dzebo, A., Janetschek, H., Brandi, C., Iacobuta, G. (2019). Connections between the Paris Agreement and the 2030 Agenda. The case for policy coherence. Stockholm Environment Institute, Working Paper. https://cdn.sei.org/wp-content/uploads/2019/08/connections-between-the-paris-agreement-and-the-2030-agenda.pdf

European Commission (2008). Establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). *Official Journal of the European Union*, Directive 2008/56/EC, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0056&from=EN

European Commission (2012). Blue Growth opportunities for marine and maritime sustainable growth. COM(2012) 494 final, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52012DC0494

European Commission (2014). HORIZON 2020 – WORK PROGRAMME 2014-2015 General Annex G - Technology readiness levels (TRL). Commission Decision C(2014)4995. https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

European Commission (2017a). Amending Directive 2008/56/EC of the European Parliament and of the Council as regards the indicative lists of elements to be taken into account for the preparation of marine strategies. Official Journal of the European Union, Commission Directive (EU) 2017/845. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017L0845&from=EN

European Commission (2017b). Laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardised methods for monitoring and assessment, and repealing Decision 2010/477/EU. Official Journal of the European Union, Commission Decision (EU) 2017/848. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017D0848&from=EN

European Commission (2020a). Report on the implementation of the Marine Strategy Framework Directive (Directive 2008/56/EC), COM(2020) 259 final.
https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1593613439738&uri=CELEX:52020DC0259

European Commission (2020b). A transparent & accessible ocean: Towards a Digital Twin of the Ocean. https://ec.europa.eu/info/sites/info/files/research_and_innovation/green_deal/gdc_stakeholder_engagement_topic_09-3_digital_ocean.pdf

Farcy, P., Durand, D., Charria, G., Painting, S.J., Tamminem, T., Collingridge, K., Grémare, A.J., Delauney, L., Puillat, I. (2019). Toward a European Coastal Observing Network to Provide Better Answers to Science and to Societal Challenges; The JERICO Research Infrastructure. *Frontiers in Marine Science*, 6:529. doi: 10.3389/fmars.2019.00529

GESAMP (2019). Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean. Gesamp Reports and Studies, 99. http://www.gesamp.org/publications/guidelines-for-the-monitoring-and-assessment-of-plastic-litter-in-the-ocean

GOOS (2020). Global Ocean Observing System - Essential Ocean Variables.
Available at: https://www.goosocean.org/index.php?option=com_content&view=article&id=14&Itemid=114 (accessed December 14, 2020).

González-García, J., Gómez-Espinosa, A., Cuan-Urquizo, E., García-Valdovinos, L.G., Salgado-Jiménez, T., Escobedo Cabello, J.A. (2020). Autonomous Underwater Vehicles: Localization, Navigation, and Communication for Collaborative Missions. *Applied Sciences*, 10:1256. doi:10.3390/app10041256

Harcourt, R., Sequeira, A.M.M., Zhang, X., Roquet, F., Komatsu, K., et al. (2019) Animal-Borne Telemetry: An Integral Component of the Ocean Observing Toolkit. *Frontiers in Marine Science*, 6:326. doi: 10.3389/fmars.2019.00326

Kosmala, M., Wiggins, A., Swanson, A., Simmons, B. (2016). Assessing data quality in citizen science. *Frontiers in Ecology and the Environment*, 13:551– 560. https://doi.org/10.1002/fee.1436

Kostoska, O., Kocarev, L. (2019). A Novel ICT Framework for Sustainable Development Goals. *Sustainability*, 11(7):1961. doi: 10.3390/su11071961

Laroche, S., Andral, B., Cadiou, J.-F., Pantazi, M. , Gonzalez Fernandez, D., Vasile D., et al. (2013). Identified gaps on MSFD assessment elements. PERSEUS Project. ISBN 978-960-9798-01-3.
http://www.perseus-net.eu/assets/media/PDF/deliverables/2840.pdf

Levin, L.A., Bett, B.J, Gates, A.R , Heimbach, P., Howe. B.M, Janssen, F., et al. (2019). Global Observing Needs in the Deep Ocean. *Frontiers in Marine Science*, 6:241. doi: 10.3389/fmars.2019.00241

Lindstrom, E., Gunn, J., Fischer, A., McCurdy, A., Glover, L. K. (2012). A Framework for Ocean Observing. By the Task Team for an Integrated Framework for Sustained Ocean Observing, UNESCO 2012, IOC/INF-1284 rev., doi: 10.5270/OceanObs09-FOO

Miloslavich, P., Bax, N. J., Simmons, S. E., Klein, E., Appeltans, W., Aburto-Oropeza, O., et al. (2018). Essential ocean variables for global sustained observations of biodiversity and ecosystem changes. *Global Change Biology*, 24:2416–2433. doi: 10.1111/gcb.14108

Molina Jack, M. E., del Mar Chaves Montero, M., Galgani, F., Giorgetti, A., Vinci, M., Le Moigne, M., Brosich, A. (2019). EMODnet marine litter data management at pan-European scale. Ocean & Coastal Management, 181. https://doi.org/10.1016/j.ocecoaman.2019.104930.

Moltmann, T., Turton, J., Zhang, H.-M., Nolan, G., Gouldman, C., Griesbauer, L., et al. (2019). A Global Ocean Observing System (GOOS), Delivered Through Enhanced Collaboration Across Regions, Communities, and New Technologies. *Frontiers in Marine Science*, 6:291. doi: 10.3389/fmars.2019.00291

Muller-Karger, F.E., Montes, E., Pelletier, D., Azofeifa-Solano, J.C., Obura, D. (2021). Marine Biodiversity Observation Network (MBON). *Frontiers in Marine Science*, Research Topic. https://www.frontiersin.org/research-topics/11437/marine-biodiversity-observation-network-mbon

Ryabinin, V., Barbière, J., Haugan, P., Kullenberg, G., Smith, N., McLean, C., Troisi, A., Fischer, A., Aricò, S., Aarup, T., Pissierssens, P., Visbeck, M., Enevoldsen, H.O., Rigaud, J. (2019). The UN Decade of Ocean Science for Sustainable Development. *Frontiers in Marine Science*, 6:470. doi: 10.3389/fmars.2019.00470

Schläppy, M.-L., Loder, J., Salmond, J., Lea, A., Dean, A. J., Roelfsema C.M. (2017). Making Waves: Marine Citizen Science for Impact. *Frontiers in Marine Science*, 4:146. doi: 10.3389/fmars.2017.00146

Tanhua, T., Pouliquen, S., Hausman, J., O'brien, K., Bricher, P., Bruin, T. D., et al. (2019). Ocean FAIR data services. *Frontiers in Marine Science*, 6:440. doi:10.3389/fmars.2019.00440

Tilbrook, B., Jewett, E.B., DeGrandpre, M.D., Hernandez-Ayon, J.M., Feely, R.A., et al. (2019). An Enhanced Ocean Acidification Observing Network: From People to Technology to Data Synthesis and Information Exchange. *Frontiers in Marine Science*, 6:337. doi: 10.3389/fmars.2019.00337

UNEP (2016). Marine plastic debris and microplastics - global lessons and research to inspire action and guide policy change. United Nations Environment Programme (UNEP), Nairobi.
https://wedocs.unep.org/handle/20.500.11822/7720

UN Environment (2018). Regional Seas Follow Up and Review of the Sustainable Development Goals (SDGS). UN Environment Regional Seas Reports and Studies, No. 208. https://wedocs.unep.org/handle/20.500.11822/27295

Wang, Z.A., Moustahfid, H., Mueller, A., Michel, A.P.M., Mowlem, M., et al. (2019). Advancing Observation of Ocean Biogeochemistry, Biology, and Ecosystems With Cost-Effective in situ Sensing Technologies. *Frontiers in Marine Science*, 6:519. doi: 10.3389/fmars.2019.00519

Whitt, C., Pearlman, J., Polagye, B., Caimi, F., Muller-Karger, F., Copping, A., et al. (2020). Future Vision for Autonomous Ocean Observations. *Frontiers in Marine Science*, 7:697. doi: 10.3389/fmars.2020.00697

Yoon, Y.-K. (2011). States' obligations relating to marine monitoring and observation. *WMU Journal of Maritime Affairs*, 10:25–43. doi:I 10.1007/s13437-011-0004-z

Zampoukas, N., Palialexis, A., Duffek, A., Graveland, J., Giorgi, G., Hagebro, C., et al. (2014): Technical guidance on monitoring for the Marine Strategy Framework Directive, JRC Scientific and Policy Reports, Publications Office of the European Union, doi: 10.2788/70344.

ANNEX 1: REVIEW OF POLITICAL AND SOCIETAL DRIVERS - GLOBAL LEVEL

Table A1. Relevant documents that are part of the review of political and societal drivers - Global level

Title	Promoting organization	Type	Timeframe	Goals	Source or Link/Location	Target disciplinary groups	Relationship with ocean observation/technology development
UN Convention on the Law of the Sea (UNCLOS)	UN	Regulation	Signature: 1982 Entry into force: 1994	Conservation and sustainable use of seas and oceans and their resources.	https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf	Marine pollution	It encourages collaboration and coordination for marine observations, which are highly dependent on the use of technologies and their development.
Global Ocean Observing System (GOOS)	UNESCO/ IOC UN/WMO UNEP ISC	Program	Established:1991	The creation of GOSS was a result of the desire of many nations to gather the information required to improve forecasts of climate change, the management of marine resources, mitigation of the effects of natural disasters, and the use and protection of the coastal zone and coastal ocean.	https://www.goosocean.org/index.php?option=com_content&view=article&id=7&Itemid=101	Cross-cutting	Coordinating ocean observations, continuously developing and advancing an integrated system is the mandate of GOOS to address climate change, real-time services and ocean-health issues.
Essential Ocean Variables (EOVs)	GOOS	Strategy	2009 - present	Based on the Framework for Ocean observing the main aim of the EOVs is to ensure assessments of ocean state and drivers that cut across platforms and recommend the best, most cost effective plan to provide an optimal global view for each EOV. EOVs are classified into three Readiness levels (concept, pilot, mature) based on requirement processes (technology, sampling, quality control), coordination (global review, documentation) and data management and information products (standardized data outputs, availability and distribution).	https://www.goosocean.org/eov http://www.oceanobs09.net/foo/FOO_Report.pd	Cross-cutting	The readiness level approach allows for timely implementation of components that are already mature, while encouraging innovation and research to improve readiness and capacity building. Targeting EOV-based GOOS investments, coupled with improved readiness levels for sustained observation, fosters research and innovation that best shape system evolution
2030 Agenda for Sustainable Development - SDGs	UN	Policy	Adopted: 2015	It provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries in a global partnership to promote prosperity while protecting the planet to deliver by 2030. SDGs 13-Climate action and 14-Life Below Water are the goals most relevant for ocean-related issues.	https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E https://sdgs.un.org/goals	Climate research Regulatory environmental monitoring	Quality, accessible, timely and reliable disaggregated data will be needed to measure progresses and help decision making. Data for several of the targets remain unavailable, and the Agenda calls for increased support for strengthening their collection.
Paris Agreement on climate change	UNCC	Regulation	Adopted: 2015 Entry into force: 2016.	Limiting the global temperature increase, and increasing the capabilities of the Parties towards low greenhouse gas emissions and climate-resilient development.	https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement	Climate research	Systematic observation will be needed to help plan adaptation strategies, to observe their effectiveness, and to provide information that could be used to modify them as climate change unfolds.

Table A1. Relevant documents that are part of the review of political and societal drivers - Global level (continued)

Title	Promoting organization	Type	Timeframe	Goals	Source or Link/Location	Target disciplinary groups	Relationship with ocean observation/technology development
Action Plan to Combat Marine Litter	G7	Policy	Launched: 2015	The document manifests the overall commitment of the G7 to improve existing systems to prevent, reduce and remove marine litter and encourages support through international development assistance and investments, the development and implementation of national and/or regional action plans to prevent and reduce waste, the removal of existing waste and the sharing of best practices.	http://www.g7.utoronto.ca/summit/2015elmau/2015-G7-annex-en.pdf	Marine pollution	Unbiased and reliable monitoring / assessment technologies for macro- and micro-plastics pollution are still critically needed. To improve harmonized data collection at the international level, further work is needed to develop innovative detection, removal, and quantification technologies (e.g. remote sensing, innovative sensors, sampling equipment)
Future of the Seas and Oceans Initiative (Tsukuba Communiqué and its second attachment)	G7	Policy	Launched: 2016	The Initiative promotes actions to develop the scientific knowledge necessary to assess ongoing ocean changes and their impact on economies. The aim is to implement science-based management, conservation and sustainable use of the Oceans, Seas and Marine Resources.	https://www8.cao.go.jp/cstp/english/others/20160517communique.pdf https://www8.cao.go.jp/cstp/english/others/20160517communique_2.pdf	cross-cutting	The Initiative supports to enhance global sea and ocean observation. The related G7 experts group recommend the continuation of existing observations that are augmented by new technologies, and the use of new autonomous observing systems.
UN Decade of the Oceans for Sustainable Development	UNESCO/ IOC UN	Policy	Declared: 2017	Supporting the implementation of the ocean-related actions to achieve the 2030 Agenda for Sustainable Development, in particular addressing the ocean science needed to implement SDGs 13 and 14.	https://www.oceandecade.org/	Climate research Regulatory environmental monitoring	The Decade can mobilize the ocean community behind the ideas of sustainable development and serve to focus the research and technological development in the marine domain. The private sector is involved to develop and share new technologies needed to achieve key Decade objectives.
Charlevoix Blueprint for Healthy Oceans, Seas and Resilient Communities	G7	Policy	Endorsed: 2018	The G7 Leaders acknowledged the need for action to address the impacts that plastic pollution and marine litter, overexploitation of fish stocks, and extreme weather events have on the health and sustainability of the oceans, seas, coastal communities and entire ecosystems.	https://www.international.gc.ca/world-monde/assets/pdfs/international_relations-relations_internationales/g7/2018-06-09-healthy_oceans-sante_oceans-en.pdf	Regulatory environmental monitoring Marine pollution	Recognizing the value of ocean science, observation and seabed mapping, the Communiqué commits the Member States to expand global observation and tracking efforts. Enhanced global monitoring of ocean, and coordinating access to ocean science information will significantly improve the availability of data.

ANNEX 2: REVIEW OF POLITICAL AND SOCIETAL DRIVERS - REGIONAL LEVEL

Table A2. Relevant documents that are part of the review of political and societal drivers - Regional level

Title	Promoting organization	Type	Timeframe	Region	Goals	Source or Link/Location	Target disciplinary groups	Relationship with ocean observation/technology development
Regional Seas Programme								
UN Environment Regional Seas Programme (RSP)	UN Environment	Agreement	Established: 1974	Global	A major role of the Programme is to support regions in fulfilling their responsibilities with respect to priorities identified in relevant UN Environment Governing Council Decisions and resolutions of the United Nations Environment Assembly, to contribute to reaching global targets such as the Sustainable Development Goals.	https://www.unenvironment.org/explore-topics/oceans-seas/what-we-do/working-regional-seas/regional-seas-programmes	Regulatory environmental monitoring	The lack or limited availability of data, and gaps in data management are among the main challenges regarding the implementation of the SDG14.
UN Environment Regional Seas Reports and Studies No. 208	UN Environment	Guidelines	Published : 2018	Global	The aim of this report is to provide an overview, with good examples and practical guidance to enhance the role and contribution of regional seas to the SDG follow-up and review process. The focus of these guidelines is on SDG 14.	https://wedocs.unep.org/handle/20.500.11822/27295		
Helsinki Convention	Baltic Marine Environment Protection Commission (HELCOM)	Agreement	Established: 1974 Updated: 1992 and 2000.	Baltic Sea	The main goal is to protect the marine environment of the Baltic Sea from all sources of pollution through intergovernmental cooperation. By bridging policy and science, it serves as a platform for environmental policy making at the regional level.	https://helcom.fi/about-us/convention/	Marine pollution Regulatory environmental monitoring	Article 24 contains obligations to cooperate in the fields of science and requires research and monitoring activities, the exchange of data as well as contribution to programmes aimed at developing methods that assess pollution.
Baltic Sea Action Plan (BSAP)	HELCOM	Agreement	Adopted: 2007 First draft update: 2020	Baltic Sea	It is an ambitious and comprehensive regional programme of measures and action for a healthy marine environment. The overall objective is to reach Good Environmental Status (GES) of the Baltic Sea by 2021.	https://helcom.fi/baltic-sea-action-plan/ http://maps.helcom.fi/website/HELCOMexplorer/		There are several targets/actions taking place that would benefit from new technology development related to biodiversity, eutrophication, hazardous substances and litter, and sea-based activities. Several thematic areas are identified as requiring technological / method development HELCOM is also closely following projects studying how carbonate system variables could be monitored by automated methods in the Baltic.
State of the Baltic Sea - Second HELCOM holistic assessment 2011-2016	HELCOM	Report	Published : 2018	Baltic Sea	The report provides an update on the environmental situation in the Baltic Sea for the period 2011–2016. It aims to support an adaptive and regionally coordinated management to improve the environmental status of the Baltic Sea. It highlights a broad range of aspects, covering the state of the ecosystem, environmental pressures and human well-being.	https://helcom.fi/baltic-sea-trends/holistic-assessments/state-of-the-baltic-sea-2018/reports-and-materials/	Regulatory environmental monitoring	

Table A2. Relevant documents that are part of the review of political and societal drivers - Regional level (continued)

Title	Promoting organization	Type	Timeframe	Region	Goals	Source or Link/Location	Target disciplinary groups	Relationship with ocean observation/technology development
OSPAR Convention	OSPAR Commission	Agreement	Entered into force: 1998	North-East Atlantic	Protecting the marine environment and securing a clean, healthy, and biologically diverse North-East Atlantic that used sustainably.	http://www.ospar.org	Regulatory environmental monitoring	The Convention and its Annexes commits the parties to undertake joint assessments of the quality status of the marine environment, carrying out repeated monitoring programmes of the marine environment (water, sediments and biota). The fact that it makes the term monitoring explicit for its purpose can be interpreted to include the various methods of collecting ocean data and therefore the related benefits brought by the technological development of monitoring tools.
Measures and Actions Programme (MAP)	OSPAR Commission	Implementation plan		North-East Atlantic	It is an overarching and integrative instrument to support planning and development and to track progress in implementing measures and actions. The MAP aims to internally structure OSPAR's approach to measures and externally enhance the visibility and transparency of what OSPAR has achieved and is currently working on. It contains all the recommendations and decisions for implementing OSPAR activities.	https://www.ospar.org/work-areas/cross-cutting-issues/map		The programme includes both monitoring data from direct measurements (e.g. litter or hazardous substances) as well as data derived from monitoring through modelling and/or aggregation of parameters (e.g. for noise or certain biodiversity indicators).
Coordinated Environmental Monitoring Programme (CEMP)	OSPAR Commission	Implementation plan	Published: 2016	North-East Atlantic	Coordinating the operation of monitoring, data collection and assessment to address six thematic objectives, which includes subcategories. The following is relevant for this review: ocean acidification, marine litter, impulsive noise, eutrophication, nutrient concentration in seawater, direct and indirect eutrophication effects, hazardous substances, radioactive substances.	https://oap.ospar.org/en/ospar-monitoring-programmes/cemp/		

Table A2. Relevant documents that are part of the review of political and societal drivers - Regional level (continued)

Title	Promoting organization	Type	Timeframe	Region	Goals	Source or Link/Location	Target disciplinary groups	Relationship with ocean observation/technology development
Intermediate Assessment 2017	OSPAR Commission	Report	Published: 2017	North-East Atlantic	The IA 2017 is an assessment of the marine environment in OSPAR's waters, demonstrating progress towards realising its vision of a clean, healthy and biologically diverse North-East Atlantic, used sustainably. Developed in online format, it provides access to high-level summaries and detailed background documents for common indicator assessments, as well as links to the relevant data. It contains an assessment of knowledge gaps for all indicators.	https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/	Regulatory environmental monitoring	Assessments report knowledge gaps, including lack of monitoring data for some parts of the OSPAR Maritime Area, especially from offshore and remote ones, and lack of data for the assessment of temporal trends. Development and implementation of new technologies (high spatial and resolution products from coastal to offshore areas) are hoped to optimize the assessment, therefore environmental management.
Third OSPAR Integrated Report on the Eutrophication Status of the OSPAR Maritime Area, 2006-2014	OSPAR Commission	Report	Published: 2017	North-East Atlantic	The overall objective of the OSPAR Eutrophication Strategy is to achieve a healthy marine environment where no eutrophication occurs. To determine progress towards the objective, the OSPAR Common Procedure was applied by nine Contracting Parties using data from 2006 to 2014. This report describes the main findings, also providing an analysis of the gaps and indications for further efforts are needed.	https://www.ospar.org/documents?v=37502		
Barcelona Convention	UNEP	Agreement	Adopted: 1976 Amended: 1995	Mediterranean Sea	Principal regional legally binding multilateral environmental agreement in the Mediterranean. It commits the parties to prevent, abate, combat and to the fullest possible extent eliminate pollution of the Mediterranean Sea Area and to protect and enhance the marine environment in that Area so as to contribute towards its sustainable development.	https://www.unenvironment.org/unepmap/who-we-are/barcelona-convention-and-protocols	Marine pollution Regulatory environmental monitoring	To consolidate the assessment of the various ecological indicators, data availability needs improvement both in terms of geographical coverage and of temporal extension. Evaluating trends and defining criteria for base-line conditions and thresholds / boundary values is currently a substantial gap. The application of new technologies is favorably seen to overcome this problem. Ecological indicators particularly concerned: Eutrophication, Chemical pollution, Marine Litter, Biodiversity, Hydrography.
Mediterranean Action Plan (MAP)	UNEP	Agreement	Established:1975	Mediterranean Sea	Overarching objective of ensuring the sustainable management of natural marine and land resources and protecting the marine environment and coastal zones of the Mediterranean Sea from pollution.	https://www.unenvironment.org/unepmap/		
2017 Mediterranean Quality Status Report	UNEP-MAP	Report	Published: 2017	Mediterranean Sea	It is the first assessment of the status of the Mediterranean ecosystem and the achievement of GES based on the MAP Ecological Objectives and IMAP indicators; it builds upon existing data and is complimented with inputs from numerous diverse sources where appropriate. An assessment of knowledge gaps is provided for all indicators.	http://www.medqsr.org/sites/default/files/inline-files/2017MedQSR_Online_0.pdf	Regulatory environmental monitoring	

Table A2. Relevant documents that are part of the review of political and societal drivers - Regional level (continued)

Title	Promoting organization	Type	Timeframe	Region	Goals	Source or Link/Location	Target disciplinary groups	Relationship with ocean observation/technology development
Convention on the Protection of the Black Sea against Pollution (Bucharest Convention)	Commission for the Protection of the Black Sea Against Pollution (BSC)	Agreement	Signed: 1992, Ratified: 1994	Black Sea	It is the basic legal framework for regional cooperation to protect the coastal and marine environment.	http://www.blacksea-commission.org/_convention.asp	Marine pollution Regulatory environmental monitoring	The Black Sea State of Environment Report 2009-2014/5 identifies significant gaps in knowledge in terms of in situ data and looks for the advance of the new emerging technologies to overcome this problem.
Strategic Action Plan for the Environmental Protection and Rehabilitation of the Black Sea	BSC	Agreement	Adopted: 1996, Amended: 2002	Black Sea	This document represents an agreement between the six Black Sea Coastal states to act in concert to assist in the continued recovery of the Black Sea and is a step in the process towards attaining sustainable development in the Black Sea region.	http://www.blacksea-commission.org/_bssap1996.asp	Marine pollution	
Black Sea State of Environment Report 2009-2014/5	BSC	Report	Delivered 2019	Black Sea	Scientific marine environmental assessment report to trace the state of knowledge and to propose measures for improvement of the quality of environment and protection of ecosystems from impact of anthropogenic activities.	http://www.blacksea-commission.org/Inf.%20and%20Resources/Publications/SOE2014/	Marine pollution Regulatory environmental monitoring	
Regional Fishery Bodies								
North East Atlantic Fisheries Commission (NEAFC)	Contracting Parties	Convention	Entered into force: 1982	North-East Atlantic	The objective of NEAFC is to ensure the long-term conservation and optimum utilisation of the fishery resources in its Convention Area, providing sustainable economic, environmental and social benefits.	https://www.neafc.org/	Fishery Regulatory environmental monitoring	
Memorandum of Understanding between NEAFC and OSPAR. OSPAR Agreement 2008-4	OSPAR, NEAFC	Agreement	Adopted: 2008	North-East Atlantic	It promote mutual cooperation towards the conservation and sustainable use of marine biological diversity including protection of marine ecosystems in the North-East Atlantic, through cooperation in the following areas: data sharing, management of human activities impacting on the marine environment and the living marine resources, marine spatial planning and area management, encourage the funding and conduct of marine science,	https://www.ospar.org/documents?v=32953	Fishery, Biodiversity Regulatory environmental monitoring	

Table A2. Relevant documents that are part of the review of political and societal drivers - Regional level (continued)

Title	Promoting organization	Type	Timeframe	Region	Goals	Source or Link/Location	Target disciplinary groups	Relationship with ocean observation/technology development
International Council for the Exploration of the Sea (ICES)	Participating countries	Convention	Founded: 1902	North-East Atlantic & Baltic Sea	ICES is a leading forum for the promotion, coordination, and dissemination of research on the physical, chemical, and biological systems in the North Atlantic and advice on human impact on its environment, in particular fisheries effects in the Northeast Atlantic. It is the oldest intergovernmental marine science organization in the world. .	https://www.ices.dk/	Fishery Regulatory environmental monitoring	The development, evaluation and harnessing of new techniques and technologies in order to advance knowledge of marine systems, inform management and increase the scope and efficiency of monitoring) is one of the scientific priorities mentioned in the 2019 Science plan of ICES
Memorandum of Understanding between OSPAR and the ICES. OSPAR Agreement 2006-08	OSPAR, ICES	Agreement	Adopted: 2006	North-East Atlantic	Scientific information and advice: ICES will provide scientific information and advice to OSPAR), Data handling: ICES Secretariat will serve as data centre for data collected under the Co-ordinated Environmental Monitoring Programme ("CEMP") under the OSPAR Joint Assessment and Monitoring Programme ("JAMP"), such as: contaminants, data resulting from biological monitoring, data on nutrients and eutrophication effects.	https://www.ospar.org/documents?d=32623	Regulatory environmental monitoring	
Baltic Sea (HELCOM) Monitoring Data	HELCOM, ICES	Contract		Baltic Sea	ICES currently holds a contract with HELCOM for managing all "at sea" observations collected as part of the HELCOM's COMBINE programme.	https://ocean.ices.dk/helcom/	Regulatory environmental monitoring	
General Fisheries Commission for the Mediterranean (GFCM)	FAO	Agreement	Established: 1949	Mediterranean & Black Sea	GFCM is a regional fisheries management organization (RFMO) whose main objective is to ensure the conservation and the sustainable use of living marine resources as well as the sustainable development of aquaculture in the Mediterranean and in the Black Sea. It has the authority to adopt binding recommendations for fisheries conservation and management and for aquaculture development.	http://www.fao.org/gfcm/about/en/	Fishery Biodiversity Regulatory environmental monitoring	The advice provided by the GFCM subsidiary bodies (e.g. Scientific Advisory Committee on Fisheries, Scientific Advisory Committee on Aquaculture etc.) relies on the availability of data. GFCM developed its own Data Collection Reference Framework (DCRF; http://www.fao.org/gfcm/data/dcrf/en/). Innovative monitoring technologies might contribute to the improvement of parties' data collection thus contributing to ecosystem approach to fisheries and aquaculture resources management.
Memorandum of Understanding between UNEP/MAP and FAO/GFCM	UNEP/MAP, FAO/GFCM	Agreement	Adopted: 2012	Mediterranean & Black Sea	It provides a framework of cooperation between UNEP/MAP and GFCM to facilitate collaboration in relation to the conservation of the marine environment and ecosystems and the sustainable use of marine living and other resources.	https://wedocs.unep.org/bitstream/handle/20.500.11822/10567/MoU_MAP_GFCM.pdf		

ANNEX 3: REVIEW OF POLITICAL AND SOCIETAL DRIVERS - EUROPEAN LEVEL

Table A3. Relevant documents that are part of the review of political and societal drivers - European Commission

Title	Type	Timeframe	Goals	Source or Link/Location	Target disciplinary groups	Relationship with ocean observation/technology development
Water Framework Directive-WFD Directive 2000/60/EC	Regulation	Adopted: 2000	It sets out rules to halt deterioration in the status of European Union water bodies (surface, ground, inland and transitional) and achieve their 'good status'.	https://ec.europa.eu/environment/water/water-framework/index_en.html	Regulatory environmental monitoring	For some types of data, the uptake of innovative monitoring technologies, including satellite data and automated monitoring technologies, has great potential to improve data collection, reduce the costs of monitoring and enhance confidence in WFD status classification.
Integrated Maritime Policy - IMP COM (2007) 575 final	Policy	Adopted: 2007	It is a holistic approach to all sea-related EU policies. It is based on the idea that the Union can draw higher returns from its maritime space with less impact on the environment by coordinating its wide range of interlinked activities related to oceans, seas and coasts. Hence, the IMP aims at strengthening the so-called blue economy, encompassing all sea-based economic activities.	https://www.europarl.europa.eu/factsheets/en/sheet/121/integrated-maritime-policy-of-the-european-union	Regulatory environmental monitoring	
Marine Strategy Framework Directive - MSFD Directive 2008/56/EC	Regulation	Adopted: 2008 Amended: 2017	The aim is to provide directions for sustainably managing human activities having an impact on the marine environment, basing on Ecosystem Approach and integrating the concepts of environmental protection and sustainable use, to reach Good Environmental Status (GES).	https://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive/index_en.htm	Regulatory environmental monitoring	Gaps and needs for further research differ between descriptors depending on their level of maturity in respect to the methods, indicators and existing datasets. Possible improvement could derive from the development of cost effective monitoring methods, development and miniaturization of sensors and automatic data collection systems, data platforms, and integration of observations from different surveys and sources.
Blue growth strategy COM(2012) 494 final	Policy	Adopted: 2012	Blue growth is a long-term strategy to support the sustainable development of the blue economy. It is one of the 5 cross-cutting policies in the Integrated Maritime Policy and is focused on the growth of five emerging sectors: blue energy; aquaculture; maritime, coastal and cruise tourism; marine mineral resources; blue biotechnologies.	https://ec.europa.eu/maritimeaffairs/policy/blue_growth_en https://ec.europa.eu/maritimeaffairs/sites/maritimeaffairs/files/docs/body/com_2012_494_en.pdf	Regulatory environmental monitoring	Advances in marine observing technologies (autonomous underwater vehicles, remotely operated/piloted vehicles, deep ocean buoys, state-of-the-art environmental sensors, etc.) will increase knowledge of the marine environment, bringing the capacity to collect, process and provide more accurate data and in real time from oceans and coasts, thus supporting blue "knowledge-based" growth and sustainable exploitation of marine resources.

Table A3. Relevant documents that are part of the review of political and societal drivers - European Commission (continued)

Title	Type	Timeframe	Goals	Source or Link/Location	Target disciplinary groups	Relationship with ocean observation/technology development
Common Fisheries Policy- CFP EC Council Regulation No 2371/2002	Regulation	Adopted: 1970s Reformed: 2014	It sets rules for managing European fishing fleets and for conserving fish stocks, and includes aquaculture and stakeholder involvement. The main goal is 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 current policy stipulates that between 2015 and 2020 catch limits should be set that are sustainable and maintain fish stocks in the long term.	https://ec.europa.eu/fisheries/cfp_en https://ec.europa.eu/fisheries/reform	Regulatory environmental monitoring Fishery and aquaculture	Fisheries management is based on data and scientific advice; innovative monitoring technologies may improve data collection (in terms of data type, quality of data, space and time), reduce the costs of monitoring and accelerate scientific feedback (e.g. improving ecosystem approach to fisheries resources management).
Maritime spatial planning- MSP Directive 2014/89/EU	Policy	Adopted: 2014	It aims to create a common framework for integrated ocean management in Europe bringing together multiple users of the ocean with the goal of reducing competition for maritime space (offshore renewable energy equipment, fishing activities, aquaculture and other uses) and making informed and coordinated decisions for efficient, safe and sustainable use of marine resources.	https://ec.europa.eu/maritimeaffairs/policy/maritime_spatial_planning_en	Regulatory environmental monitoring	Advances in marine observing technologies will increase knowledge of the marine environment, bringing the capacity to collect, process and provide more accurate data from oceans and coasts, thus supporting Member States implementing their Maritime Spatial Plans.
Good Environmental Status.- GES Decision 2010/477/EU	Regulation	Adopted: 2017	It defines detailed criteria and methodological standards to help Member States implement the Marine Strategy Framework Directive.	https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1495097018132&uri=CELEX:32017D0848	Regulatory environmental monitoring	Gaps and needs for further research differ between descriptors depending on their level of maturity in respect to the methods, indicators and existing datasets. Possible improvement could derive from the development of cost effective monitoring methods, development and miniaturization of sensors and automatic data collection systems, data platforms, and integration of observations from different surveys and sources.
European Strategy for Plastics in a Circular Economy (ESPCE) COM/2018/028 final	Policy	Adopted: 2018	ESPCE will promote better design of plastic products, higher plastic waste recycling rates, more and better quality of recycled products, which will help boosting the market for recycled plastics. It will deliver greater added value for a more competitive, resilient plastics industry. The strategy is part of Europe's transition towards a circular economy, and will also contribute to reaching the SDGs, the global climate commitments and the EU's industrial policy objectives. This strategy will help protect our environment, reduce marine litter, greenhouse gas emissions and our dependence on imported fossil fuels. It will support more sustainable and safer consumption and production patterns for plastics.	https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1516265440535&uri=COM:2018:28:FIN	Regulatory environmental monitoring Marine pollution	The Strategy aims to enforce the development of recycling technologies. Innovative solutions for advanced sorting, chemical recycling and improved polymer design can have a powerful effect. For instance, scaling up new technological solutions such as digital watermarking could allow much better sorting and traceability of materials, with few retrofitting costs. Also, innovative technologies for the retrieval of some of the plastics floating in the oceans are supported by EU funds.

Table A3. Relevant documents that are part of the review of political and societal drivers - European Commission (continued)

Title	Type	Timeframe	Goals	Source or Link/Location	Target disciplinary groups	Relationship with ocean observation/technology development
Green Deal EU Agenda COM(2019) 640 final	Policy	Adopted: 2019	It is a growth strategy that will transform the European Union into a modern, resource-efficient and competitive economy, where a) there are no net emissions of greenhouse gases by 2050, b) economic growth is decoupled from resource use, and c) no person and no place is left behind. The Green Deal is an integral part of this Commission's strategy to implement the UN 2030 Agenda and the Sustainable Development Goals.	https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en https://ec.europa.eu/info/publications/communication-european-green-deal_en	Regulatory environmental monitoring	
Directive on the reduction of the impact of certain plastic products on the environment Directive 2019/904/EU	Regulation	Adopted: 2019	Single Use Plastic (SUP) products represent about 50% and fishing-related items about 27% of all marine litter items found on European coasts. The Directive aims on eliminating the ten most found SUP and fishing gear. Where alternatives are readily available and affordable, SUP products are to be banned from the market, while for products without straight-forward alternatives, the target is on limiting their use. The Directive delivers on the commitment made in the European Plastics Strategy to tackle wasteful and damaging plastic litter through legislative action.	https://eur-lex.europa.eu/eli/dir/2019/904/oj	Regulatory environmental monitoring Marine pollution	The Directive requires developing technologies to create new biodegradable products and efficient waste management. Also new technologies are required in order to monitor the levels of marine litter to assess its implementation.
EU Biodiversity Strategy for 2030 COM/2020/380 final	Policy	Adopted: 2020	The EU's biodiversity strategy for 2030 is a comprehensive, ambitious and long-term plan to protect nature and reverse the degradation of ecosystems. The strategy aims to put Europe's biodiversity on a path to recovery by 2030, and contains specific actions and commitments. It is the proposal for the EU's contribution to the upcoming international negotiations on the global post-2020 biodiversity framework. A core part of the European Green Deal, it will also support a green recovery following the Covid-19 pandemic.	https://ec.europa.eu/environment/strategy/biodiversity-strategy-2030_en https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1590574123338&uri=CELEX:52020DC0380	Regulatory environmental monitoring Biodiversity	

ANNEX 4: EXISTING EUROPEAN MARINE OBSERVING INFRASTRUCTURE

Table A4. Relevant information that is part of the review of Existing European Marine Observing Infrastructure

Title	Timeframe	Parties involved	Goals	Source or Link/Location	Target disciplinary groups	Relationship with ocean observation/technology development
ERIC						
EMSO European Multidisciplinary Seafloor and water-column Observatory	2016 -	8 EU countries	Long-term multidisciplinary observation of the seafloor and the water-column by means of fixed-point multi-sensor platforms.	emso.eu	Interaction between the geosphere, the biosphere, the hydrosphere, and the lithosphere; including natural hazards, climate change, and marine ecosystems.	The objective is to offer features beyond the state-of-the-art.
EuroARGO European contribution to the international Argo Program	2014 -	12 countries	To deploy and operate an array of floats, providing quality controlled data for climate and ocean research.	euro-argo.eu	Ocean and climate research, operational oceanography and ocean monitoring.	The Argo floats are a unique type of ocean observatories under continuous technological improvements.
EMBRC European Marine Biological Resource Centre	2018 -	9 countries	It provides access to marine organisms and the facilities to study them, including experimental facilities and technological platforms.	http://www.embrc.eu	Biodiversity Marine biology	EMBRC promotes the development of blue biotechnologies and the application of new genomic tools to study marine organisms.
LifeWatch e-Infrastructure for Biodiversity and Ecosystem Research	2017 -	7 countries	LifeWatch ERIC is a European Infrastructure Consortium which provides e-Science research facilities for scientists seeking to increase their knowledge on biodiversity and ecosystem functioning/services in order to support civil society in addressing key planetary challenges.	lifewatch.eu	Biodiversity	The activities of LifeWatch ERIC support a) domain knowledge, b) open and FAIR data, c) semantic resources and tools, d) BIG DATA analysis, e) web services, f) computational power, g) VREs and vLabs, h) training centre, i) stakeholder connection, j) biodiversity management support, k) citizens inclusion and l) LifeWatch on Demand.
ICOS Integrated Carbon Observation System	2015 -	12 countries	ICOS consists of a network of standardized, long-term, high-precision integrated monitoring of atmospheric greenhouse gas concentrations and fluxes. The infrastructure integrates terrestrial, oceanic and atmospheric observations at various sites into a single, coherent, highly precise dataset. This data allows a unique regional top-down assessment of fluxes from atmospheric data, and a bottom-up assessment from ecosystem measurements and fossil fuel inventories. Target is a daily mapping of sources and sinks at scales down to about 10 km, as a basis for understanding the exchange processes between the atmosphere, the terrestrial surface and the ocean.	icos-cp.eu	Climate research	ICOS Ocean Thematic Centre (OTC) aims to have a high quality standardised station network across Europe and therefore all the stations entering into ICOS network must go through a station labelling process. This process includes a testing period and training to become familiar with the ICOS methodology.There are two classes of marine stations according to the set of parameters monitored.

Table A4. Relevant information that is part of the review of Existing European Marine Observing Infrastructure (continued)

Title	Timeframe	Parties involved	Goals	Source or Link/Location	Target disciplinary groups	Relationship with ocean observation/technology development
ESFRI RI						
Danubius International Center for Advanced Studies on River –Delta – Sea Systems	2016 -	9 countries	DANUBIUS is a pan-European distributed research infrastructure supporting interdisciplinary research on large river-sea systems.	https://www.danubius-ri.eu	Interdisciplinary river-sea system research Environmental monitoring	The DANUBIUS-RI Infrastructure Hub will provide a „one-stop access point" for sharing knowledge and good practices, access to standardized harmonized data, a platform for interdisciplinary research, education and professional training
H2020						
EuroFleets+ An alliance of European marine research infrastructure to meet the evolving needs of the research and industrial communities	2019-2023	42 institutes from 24 countries	EuroFleets+ enable access to a unique fleet of 27 state-of-the-art research vessels from European and international partners.	https://www.eurofleets.eu	The project will undertake joint research in challenging and highly relevant areas, including deep ocean research and exploration, data management, and enabling future virtual access.	The project provides access to marine observatories (ships) with an aim to provide up to data research infrastructure.
JERICO-S3 Joint European Research Infrastructure of Coastal Observatories: Science, Service, Sustainability	2020-2024	39 partners in 16 countries	JERICO-S3 will provide a state-of-the-art, fit-for-purpose and visionary observational RI, expertise and high-quality data on European coastal and shelf seas, supporting world-class research, high-impact innovation and a window of European excellence worldwide. It will preliminarily develop an e-infrastructure in support to scientists and users by offering access to dedicated services; progress on the design of the RI and its strategy for sustainability.	www.jerico-ri.eu	Coastal ecosystems	Major user-driven improvements will be realised in terms of observing the complexity of coastal seas and continuous observation of the biology, access to facilities, data and services, best practices and performance indicators, innovative monitoring strategies, cooperation with other European RIs.
BlueCloud Piloting innovative services for Marine Research & the Blue Economy	2019-2022	20 partners	Blue-Cloud is a European H2020 project with the overarching aim of federating and piloting innovative services for Marine Research & the Blue Economy. One of the main outputs of the Blue-Cloud project will be its strategic Roadmap to 2030. The Roadmap will be a policy document providing the basis for the future strategic development of the Blue-Cloud well embedded as a leading system in the wider marine community and as a component of the European Open Science Cloud (EOSC)	https://www.blue-cloud.org/	Cross-cutting the marine domain	Related to cloud storage and data handling

Table A4. Relevant information that is part of the review of Existing European Marine Observing Infrastructure (continued)

Title	Timeframe	Parties involved	Goals	Source or Link/Location	Target disciplinary groups	Relationship with ocean observation/technology development
ARICE Arctic Research Icebreaker Consortium: A strategy for meeting the needs for marine-based research in the Arctic	2018-2022	16 partners	Making the Arctic and Arctic research vessels accessible for excellent science by: 1) Networking 2)Transnational access 3)Joint research activities	www.arice.eu	Cross-cutting the marine domain	The ARICE Research Icebreaker consortium determines the general needs of oceanographic sensors both in terms of what types of sensors are required by the Arctic Ocean research community, but also how sensors are integrated onto platforms that are deployed and/or visited by ARICE Research Vessels. There are also technology requirements that are being developed alongside the maritime industry via the Joint research activities
INTAROS Integrated Arctic observation system	2016-2021	49 partners	INTAROS will develop an efficient integrated Arctic Observation System by extending, improving and unifying existing and evolving systems in the different regions of the Arctic.	www.intaros.eu	Multidisciplinary focus, with tools for integration of data from atmosphere, ocean, cryosphere and terrestrial sciences. Global climate and environment	INTAROS is enhancing the sensors and systems to improve data collection in both ice covered and open ocean areas. This includes deployment of instrumented mooring arrays, seafloor observatories, ice-tethered instrumentation, FerryBoxes, quadcopters, BioArgo floats, and gliders in the Arctic for physical, chemical, and biological observations. Strong focus on developing instrumentation platforms that could be used in Arctic research
MINKE Metrology for Integrated marine maNagement and Knowledge-transfer nEtwork	2021-2025	23 partners	MINKE will integrate key European marine metrology research infrastructures, to coordinate their use and development and propose an innovative framework of “quality of oceanographic data” for the different European actors in charge of monitoring and managing the marine ecosystems. The MINKE consortium uniquely combines leading expertise on metrology, Marine RIs, data analysis, data management, networking, citizen science and citizen observatories.		Ocean & Coastal Observation communities	MINKE proposes a new vision in the design of marine monitoring networks considering two dimensions of data quality, accuracy and completeness, as the driving components of the quality in data acquisition.
EuroSea Improving and integrating the European Ocean Observing and Forecasting System	2019 - 2023	56 partners	EuroSea is a European Union Innovation Action bringing together key European actors of ocean observing and forecasting with users of oceanographic products and services.	eurosea.eu	Interdisciplinary observing and forecasting system; Operational services, ocean health, and climate	The project is aimed at increasing the Technology Readiness Levels (TRL) of critical components of ocean observations systems and tools. It has the ambition of improving European and international coordination, design of the observing system adapted to European needs, in situ observing networks, FAIR data delivery, integration of remote and in-situ data, and forecasting capability

ANNEX 5: EUROPEAN DATA INITIATIVES

Table A5. Relevant information that is part of the review of European Data Initiatives

Title	Type	Timeframe	Goals	Source or Link/Location	Target disciplinary groups	Relationship with ocean observation/technology development
EMODnet European Marine Observation and Data Network	Marine data and product infrastructure	20101 - ongoing	The European Marine Observation and Data Network (EMODnet) is a network of organisations, supported by the EU's integrated maritime policy, working together to observe the sea, process the data according to international standards and make that information freely available as interoperable data layers and data products. The "collect once and use many times" philosophy behind EMODnet benefits all marine data users, including policy makers, scientists, private industry and the public.	https://www.emodnet.eu/	cross-cutting observation of sea	EMODNET is an end-to-end, integrated and inter-operable network of systems of European marine observations and data communications, management and delivery systems. It is supported by a comprehensive user-oriented toolkit to enable implementation of the Integrated Maritime Policy for Europe and to provide service for users. In this framework, EMODnet Physics has developed a prototype data portal with advanced data services providing straightforward access to centrally-curated circumpolar datasets and metadata records. The portal is composed of a map interface displaying the spatial distribution of observing platforms and plotting tools for datasets. The prototype is similar to the portal SOOS-map set up for the Southern Ocean elaborated by EMODnet Physics and the Southern Ocean Observing System (SOOS) initiative to improve access to key Southern Ocean datasets
SeaDataNet Pan-European infrastructure for ocean & marine data management	Marine Data Infrastructure	2006 - ongoing (SeaDataNet, SeaDataNet 2, SeaDataCloud)	SeaDataNet aims to: 1) manage large and diverse sets of data deriving from in situ of the seas and oceans; 2) provide on-line integrated databases of standardized quality; 3) provide access to in-situ data, meta-data and products through a single portal	https://www.seadatanet.org/	cross-cutting	SeaDataNet manages large and diverse sets of data from in situ observation of the seas and oceans. On-line access to in-situ data, meta-data and products is provided through a single portal interconnecting the interoperable node platforms constituted by the SeaDataNet data centres.
CMEMS Copernicus Marine Environment Monitoring Service	Marine data and services provider		CMEMS aims to provide regular and systematic reference information on the physical and biogeochemical state, variability and dynamics of the ocean and marine ecosystems - focus on the global ocean and European regional seas	https://marine.copernicus.eu https://cmems.lobelia.earth/	cross-cutting	CMEMS provides an interactive catalogue with information and forecasts related to ocean and marine ecosystems, physical and biogeochemical characteristics of ocean/marine ecosystems. A web-based visualization platform is available.
WEkEO	Cloud computing platform for Earth observation data	-	WEkEO was launched as a cloud computing platforms with the following aims: 1) to give harmonized and seamless access to Copernicus data and information on climate, atmosphere, marine and land characteristics; 2) to offer a distributed infrastructure connected by an ultra high-speed backbone, and from the cloud-based hosted processing with tools.	https://www.wekeo.eu/	climate, atmosphere, marine and land data	

Table A5. Relevant information that is part of the review of European Data Initiatives (continued)

Title	Type	Timeframe	Goals	Source or Link/Location	Target disciplinary groups	Relationship with ocean observation/technology development
PANGAEA Data Publisher for Earth & Environmental Science	Open Access data library		PANGAEA aims to: 1) archive, publish and distribute geo-referenced data from earth system research; 2) ensure long-term availability of its content.	https://www.pangaea.de/	cross-cutting	PANGAEA is open to any project, institution, or individual scientist to use or to archive and publish data. The huge volume of such data requires further technological development to ensure interoperability, efficiency and availability of the collected data.
OBIS Ocean Biodiversity Information System	Information system	Preparatory activities: 1999-2000. OBIS International Committee: 2001. Adopted as a project under IOC-UNESCO's IODE programme in 2009	OBIS aims at building and maintaining a global alliance that collaborates with scientific communities to facilitate free and open access to, and application of, biodiversity and biogeographic data and information on marine life	https://obis.org	Marine biology Biodiversity	A strong technological development is envisioned and needed by OBIS, especially with reference to the new initiatives related to the UN Decade of Ocean Science for Sustainable Development. As stated in the IODE Steering Group for OBIS (SGOBIS), that gathered in November 2020, the OBIS Strategic Advisory Task Team will develop a roadmap and architectural plan for the next generation international OBIS infrastructure (OBIS3.0), taking into account the continuing increases in demand for new features and services (expected to increase also under the Ocean Decade), and ensure keeping up with the accelerating pace of technological developments.
MEDOBIS Mediterranean Ocean Biodiversity Information System	Node of OBIS information system	2003 - ongoing (with important changes)	The aim of MEDOBIS is to develop a taxon-based biogeography database and online data server with a link to survey and provide satellite environmental data.	https://obis.org/node/1ad35eb9-c615-4733-864a-b585aebcfb70 http://ipt.medobis.eu/ https://www.lifewatchgreece.eu/?q=content/medobis-0	Environmental data from observation	MedOBIS, as a node of OBIS, follows strictly the technological development which is envisioned and needed by OBIS (e.g. new services, FAIR principles). . Currently, the MedOBIS vLab, a virtual lab offering data visualisation services, is part of the LifeWatchGreece portal, and is available only for registered users: https://portal.lifewatchgreece.eu/
EuroGOOS European Global Ocean Observing System	International non-profit association	1994	EuroGOOS goals are to identify strategies, cooperate, co-produce, and promote the operational oceanography value for society. EuroGOOS is achieving this through a broad network of organizations and initiatives operating at various levels. Collectively through EuroGOOS, its members and partners improve the overall European capacity and competitiveness in ocean observing sectors	https://eurogoos.eu/	Cross-cutting	The focus of EuroGOOS 'task teams' on different solutions for observational oceanography includes specific actions on FerryBox, tide gauges, gliders, HF radars, Argo floats (Euro-Argo), fixed platforms and animal-borne instruments. These instruments, technologies and methodologies call for a consistent, systematic technological advance.

Table A5. Relevant information that is part of the review of European Data Initiatives (continued)

Title	Type	Timeframe	Goals	Source or Link/Location	Target disciplinary groups	Relationship with ocean observation/technology development
MONGOOS Mediterranean Operational Network for the Global Ocean Observing System	Monitoring infrastructure	2012 - ongoing	The objective of MONGOOS is to act as an operational network for GOOS in the Mediterranean for the production and use of operational oceanography services.	http://www.mongoos.eu/	cross-cutting	In the strategic plan published in March 2018, the following technological challenges have been identified: 1) Monitor in Real Time the hydrodynamics, biochemical fluxes, contaminants levels, and fishery ; 2) Improve the capability to model the hydrodynamics and the biochemical fluxes and food webs from the basin scales to the coastal areas, including the connection with the surface and underground water input to the coastal areas, the contaminants fate and impact on the environment and the connections between fishery and environment; 3) Improve data assimilation tools in order to consider all the relevant real time measurements for the hydrology and biogeochemical parameters; 4; Develop techniques to quantify the uncertainty related to simulating and forecasting the dynamics and biogeochemical processes in the Mediterranean Sea 5) Develop an information management system for the Mediterranean Sea that will disseminate in real time both observed and model estimates of the state of the system, and develop interfaces to make this information available to policy makers.
PSMSL Permanent Service for Mean Sea Level	Data portal for in situ relative sea level mean validated data	1933 - ongoing	The PSMSL is responsible for the collection, publication, analysis and interpretation of sea level data from the global network of tide gauges.	https://www.psmsl.org/	Sea level monitoring	New sea level technologies associated with tide gauges are currently under discussion within the international community. The 1st EuroSea Tide Gauge Network Workshop (12-14 January 2021) included a session on the status, challenges, and advantages of existing and experimental technologies such as the Global Navigation Satellite System Multi-Reflectometry technique (GNSS-MR)
SONEL Système d'Observation du Niveau des Eaux Littorales	Data portal for geodetic sea level data	-	SONEL was launched with the aims of: 1) developing in a reasonable and rational manner activities carried out in the field of 'in situ' observations of coastal sea level using tide gauges; 2 exchanging know-how and results; 3) storing historic observations; 4) allowing scientific exploitation of observations made by organisations which do not always have this vocation	https://www.sonel.org	Sea level monitoring	New sea level technologies associated to tide gauges are currently under discussion within the international community. The 1st EuroSea Tide Gauge Network Workshop (12-14 January 2021) included a session on the status, challenges, and advantages of existing and experimental technologies such as the Global Navigation Satellite System Multi-Reflectometry technique (GNSS-MR).
JRC TAD Joint Research Center - Tsunami Array Device	Data portal	2016 - ongoing	JRC TAD data portal collects data from a new Inexpensive Device for Sea Level Measurements designed at the Joint Research Centre (JRC) of the European Commission (EC) in order improve the sea level network in use for the Tsunami Hazard monitoring in the Mediterranean Sea and in the North Atlantic.	https://webcritech.jrc.ec.europa.eu/	Sea level monitoring	

Table A5. Relevant information that is part of the review of European Data Initiatives (continued)

Title	Type	Timeframe	Goals	Source or Link/Location	Target disciplinary groups	Relationship with ocean observation/technology development
CORIOLIS GDAC PORTAL	Data portal for in situ data and products	2001 - ongoing	The aim of CORIOLIS GDAC PORTAL is to develop continuous, automatic, and permanent observation networks, and to enable water properties (e.g. temperature, ocean circulation, etc.) to be mapped	http://www.coriolis.eu.org	Water properties observation	As stated in the 2019 activity report, the Coriolis DAC manages 453 BGC-Argo floats from 4 families. These are innovative floats equipped with bio-geo-chemical (BGC) sensors.
OCEANOPS	Joint center for in-situ observation	-	OCEANOPS works to assist in deploying observing programs (such as Argo floats and drifters); assist in developing and tracking timely exchange of data and metadata; monitor the status and growth of the system.	https://www.ocean-ops.org/	In-situ observation	Technological development is needed to ensure the evolution and continuous support to the effectiveness in delivery of data and metadata. The responsiveness of the system is one of the key value statements affirmed in OceanOPS strategic plan for 2021-2025.
MEOP Marine Mammals Exploring the Oceans Pole to Pole	Data portal	2007 - ongoing	MEOP aims to produce a comprehensive quality-controlled database of oceanographic data obtained in Polar Regions from instrumented marine mammals.	http://meop.net/	Temperature and salinity measurements	MEOP encourages the valorisation of marine mammals as data-collection platforms, to be considered as a cost-effective solution for observation