

STRENGTHENING INTERNATIONAL OCEAN RESEARCH, DATA AND KNOWLEDGE

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1. INTRODUCTION

This working group will focus on how the EU can advance the role of ocean science in international ocean governance, and in supporting the upcoming UN Decade of Ocean Science for Sustainable Development¹ (2021–2030, the Ocean Decade) and the UN Decade on Ecosystem Restoration² (2021–2030). The needs of ocean governance are the prerequisite and driving force behind creating an international ocean knowledge base that feeds into decision-making. Therefore, improving ocean knowledge through co-designed science and research, innovation, observations, data, and operational climate, ocean and marine biological modelling (among other types of modelling) is crucial for supporting sustainable decisions and actions in tackling threats to ocean health and their cumulative impacts. The management and sustainable use of marine resources under a changing climate must be based on sound scientific knowledge and data to facilitate the development of a sustainable blue economy. This requires well-functioning science-policy and science-society interfaces. As experienced decades ago in the meteorology sector for improving weather predictions, strong international cooperation is needed to fully benefit from the opportunities provided by an inter- and transdisciplinary ocean knowledge base that is reliable, accessible, transparent and based on the best available science and operational oceanography.

Ocean science, as defined in the IOC's Global Ocean Science Report (UNESCO, 2017), "includes all research disciplines related to the study of the ocean: physical, biological, chemical, geological, hydrographic, health and social sciences, as well as engineering, the humanities and multidisciplinary research on the relationship between humans and the ocean. Ocean science seeks to understand complex, multiscale socioecological systems and services, which requires observations and multidisciplinary and collaborative research." The main objective of ocean science is to understand how the ocean works, its current state and how it changes in relation to natural and anthropogenic pressures. We use ocean research to assess the status of marine resources, habitats and ecosystems and to make decisions on the sustainable use and protection of marine ecosystems. The main governance applications of ocean science are to understand how the ocean influences climate change and how it is impacted and responds to climate change and other stressors, including human uses; to protect ocean ecosystems and ecosystem services; to assess ocean resources and their sustainable exploitation; and understanding the interaction between uses of the ocean under the Blue Economy and resilience of the ocean to these pressures. Here we also specifically include operational oceanography in the broader definition of ocean science, specifically as it pertains to ocean governance. Operational oceanography supports operations at sea, exploitation of marine resources and coastal environmental monitoring thanks to sustained routine observations, forecasts and past trends in ocean characteristics.

Ocean data includes both data obtained from ocean observations (*in situ* or remotely), including the environmental impact that humans have on the ocean, observations on human uses of the ocean, as well as the impact that the ocean might have on humans. Through the scientific process, e.g. data analysis, inference, or modelling of ocean dynamics and the ocean component of the earth system (climate modelling), this data is turned

into knowledge (defined as facts, information, and skills acquired through experience or education) which is then used as evidence to address policy questions. Such capacities to virtualize the ocean ecosystem through data and modelling helps develop what-if scenarios supporting short-term to long-term decision-making for ocean governance, particularly when building strategies for climate change mitigation and resilience, and the sustainable exploitation of ecosystems services.

The Global Ocean Observing System (GOOS) 2030 Strategy (IOC-UNESCO, 2019) highlights that the world needs a step change in ocean observations. Observations today are the backbone for ocean and weather forecasts and predictions and projections for the global climate system, and their optimal spatial and temporal resolution across the global ocean will reduce uncertainties in forecasts, predictions and projections.

The ocean observing system needs to fully integrate all properties of the ocean (physical, chemical, biological, ecological, human) from the global to the local scale, enhancing ocean drivers globally through Essential Ocean Variables, Essential Ecosystem Variables, Essential Biological Variables, Essential Climate Variables (Canonico et al., 2019; Miloslavich et al., 2018), and in the future, possible Essential Coastal Variables. In the EU, each member state must adhere to Maritime Spatial Planning (MSP) and Good Environmental Status (GES) legislation and its associated targets and indicators as part of the Marine Strategy Framework Directive (2017/848/EU), and therefore they may need to collect additional data, notably in coastal waters and on continental shelves. These include the physical, biological and chemical pressures on the marine environment, as well as the associated activities generating these pressures. The resulting data need to be freely and openly available and abide by the FAIR data principles (Findable, Accessible, Interoperable and Reusable) to be able to create knowledge through a range of assessments, forecasts, data products and services.

In addition, ocean modelling capacities need to further progress and integrate scientific outcomes to ensure they are dynamic and holistic representations of ocean social-ecological systems. Multidisciplinary modelling capacities need to be brought together to better understand links between climate, ocean, ecosystems and human systems, to link global and local processes, and to better integrate processes from surface waters down to the deepest parts of the ocean, pelagic system to the benthos, and from inland waters to the open ocean through the coast and estuaries. This will allow better understanding of the ocean system, which will lead to better support for the development of the bio-economy, improved environmental protection, and better preparation for risks. Ocean science involves dimensions of space (in surface and depth), time (past, present and future), sphere (physical, biogeochemical and biological), human uses and the interlinkages between all of these. Solutions will become reliable and usable only when both the observing systems and modelling capacities can scale up and down to address important global issues (e.g. changes in migration patterns of highly migratory species) and local issues (e.g. impact of surges, tides and waves as a chaotic system, on coastal erosion or stability of marine infrastructures).

This working group will highlight challenges and opportunities for making ocean research, data and knowledge more responsive to the needs of decision-makers for successful international ocean governance, and better able to support the management of human pressures on the ocean in

1 <https://www.oceandecade.org/>

2 <https://www.decadeonrestoration.org/>

order to act sustainably. It will consider if the data and information needs developed under the MSFD that link activities to pressures and impacts, i.e. the indicators of GES, is a useful holistic approach to data needs in other parts of the global ocean. It will link to TWG2 “Reducing pressure on the ocean and seas and creating conditions for a sustainable blue economy” by considering how to improve data collection and dissemination based on the needs of ocean users and mechanisms of providing knowledge to the blue economy. It will link with TWG1 “Improving the international ocean governance framework” by providing advice on improving the backbone of international ocean knowledge governance that is responsive to and therefore improves the institutional and policy framework established to manage human activities and ensure the conservation and sustainable use of the ocean resources. The topics covered in this working group have been identified as important for strengthening the international ocean knowledge system to support the implementation of the UN 2030 Agenda and its 17 Sustainable Development Goals³ (SDGs) as well as the European Commission’s (EC) Green Deal⁴.

At the time of writing this paper all relevant ocean governance meetings were postponed amid the COVID-19 pandemic, including the 2020 UN Ocean Conference, the fourth meeting of the Intergovernmental Conference on the negotiation of a new legally-binding instrument for the conservation and sustainable use of marine biological diversity beyond national jurisdiction (BBNJ), and the EU International Ocean Governance Forum. In an effort to maintain momentum, preparatory processes moved online and meetings take place virtually. Although it is far too early for any assessment, it can be expected that the devastating human, societal and economic consequences of this crisis will also affect how humanity is dealing and interacting with the ocean, and possibly affect international or regional collaborations and governance processes, and the role of science in decision making. Despite potential setbacks, the International

2. KEY CHALLENGES

2.1. Improved Ocean Science-Society-Policy Interface

A strategic and comprehensive approach to co-design marine research and to translate and embed marine scientific knowledge and data into policy measures is essential to prevent the transgressions of planetary boundaries. This will be needed to achieve the SDGs, to implement the European Green Deal, and for many other policy measures. The recognition of the ocean-climate nexus in the Paris agreement implementation process, the United Nations Framework Convention on Climate Change⁵ (UNFCCC) negotiations, and in the recommendations of the International Panel on Climate Change⁶ (IPCC) and the Intergovernmental Platform on Biodiversity and Ecosystem Services⁷ (IPBES) reports is of utmost importance. The developments and needs for incorporating ocean observations and science into the UN World Ocean Assessment⁸ process as well as the G7 Future of Seas and Oceans initiative are also priorities. There is a need to federate and streamline different ocean communities, at regional and global level, into an integrated system for increased and improved ocean science-policy cooperation with scientific bodies for capacity building (e.g. International Oceanographic Commission of UNESCO⁹ (IOC-UNESCO), Global Ocean Fo-

rum¹⁰ (GOF), World Ocean Network, European Marine Board¹¹). The role of regional and global institutions, such as the Commission for the Conservation of Antarctic Marine Living Resources¹² (CCAMLR) and the IOC-UNESCO, in the implementation of new global agreements for ocean governance should be explored, e.g., in the implementation of a new legal agreement on biological diversity in areas beyond national jurisdiction. Key governance challenges to be addressed include:

- ▶ How to better listen and respond to decision makers and citizens so we can co-design the research, data, and knowledge they need;
- ▶ How to use knowledge to create an effective operational tool for ocean health monitoring and decision-making at multiple scales: from international to EU, regional and national scale;
- ▶ How to develop effective science-society-policy interfaces and decision making processes that are designed to effectively use data and knowledge, and that are more evidence-based;
- ▶ How to developing joint learning processes and communication channels to pass on scientific knowledge to policy makers and encouraging them to take it up;
- ▶ How to integrate and transfer global to local scale ocean science into operational ocean services; and
- ▶ How to strengthen citizen engagement and ocean literacy among decision-makers and feed it into narratives that resonate with them.

2.2. Supporting Ocean Research

Ocean research and technological developments are essential for successful ocean governance. Amongst other initiatives, the UN Ocean Decade provides a huge opportunity for the marine scientific community to advance scientific knowledge by creating new synergies, partnerships, interfaces, and new ways of conducting and funding science that will strengthen international ocean research and data provision for decision-making. As suggested by Peter Haugan, the then chair of the IOC of UNESCO, in the Prologue to Navigating the Future V (European Marine Board, 2019), “*the goal for the next decade will be to provide nutritious food, clean energy, water, medical services and decent living conditions for all people on Earth [...] without overstepping the carrying capacity of the planet.*” This will require stronger links between research, society and policy, because we cannot properly manage the unknown. There are certain gaps in knowledge about how the ocean functions, how the ocean benefits people, and the impact of human activities on the ocean, and these gaps are bottlenecks that hold back effective international ocean governance. Similarly, we have not systematically tried to understand what data and science decision-makers need to best care for the ocean, manage ocean impacts and users, and chart a course for a sustainable blue economy. A key governance issue is how to address marine research priorities through international collaboration for effective management of human interactions with the ocean to achieve the 17 Sustainable Development Goals of the UN 2030 Agenda. Priorities for marine research during the next decade have been identified in Navigating the Future V (European Marine Board, 2019), which closely align and support the six societal outcomes of the Ocean Decade:

3 <https://www.un.org/sustainabledevelopment/development-agenda/>
4 https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en
5 <https://unfccc.int/>
6 <https://www.ipcc.ch/>
7 <https://ipbes.net/>
8 <https://www.grida.no/publications/112>
9 <http://ioc-unesco.org/>

10 <https://globaloceanforum.com/>
11 <https://www.marineboard.eu/>
12 <https://www.ccamlr.org/en/organisation/home-page>

- ▶ Understanding the interplay between multiple stressors affecting the ocean, including climate change, pollution, changing human and economic conditions, demand for ocean resources including sustainable ecosystem services, and over-exploitation of resources. We need to understand how and when the individual or combined effects of these factors lead to crossing ecological tipping points, how to predict the boundaries of tipping points, and how to manage our oceans to avoid crossing these tipping points. We need a better understanding of the impact of land-based sources of pollution (including nutrients, chemicals, plastics, heavy metals, and other contaminants, etc.) on the ocean so we can improve or develop new measures to prevent and reduce them. In addition, we need to understand how restoration can serve to restore the ecological well-being of ocean ecosystems, especially in the face of climate change;
- ▶ Understanding ocean connectivity and the links between the physical-, chemical-, biological- and geological ocean and humanity in space and time. This will provide the basis for developing improved international ecosystem-based management frameworks that include coherent spatial units of biodiversity distribution and ecosystem function, which will provide a basis for creating a digital twin of the ocean. We can then begin to manage all four dimensions of the ocean i.e. in the three dimensional ocean over time;
- ▶ Understanding extreme events such as storm surges, marine heat waves, dynamic sea-floor processes and tsunamis, as well as chronic but potentially equally catastrophic changes like harmful algal blooms, irreversible loss of species including bio-engineers (e.g. coral and shellfish reefs), so we can safeguard the lives of populations living at our coasts; and
- ▶ Developing knowledge at an appropriate resolution to understand the interaction of ocean dynamics as a continuum from ocean to land and *vice-versa*, and representing the different scales of change from the global ocean to coasts and in estuaries, all interacting at very high-resolution.

Addressing these knowledge gaps requires a strategic, collective, holistic, and flexible approach to ocean research. A key challenge will be to go from single discipline science to transdisciplinary “sustainability science”. Sustainability science encompasses both natural- and social science and the humanities and it goes beyond interdisciplinary approaches by including different stakeholders in co-design and co-implementation of research as knowledge producers. This process of co-design will help scientists to understand what decision makers need. Linking research with operational deployment of ocean forecasting and ocean climate projections and organizing this transfer of knowledge on a sustained basis, as happens in meteorology, will be key to sound decision-making based on the best of available science.

2.3. Strengthening Ocean Observations

The UN 2030 Agenda, the adaptation and mitigation of climate change impacts, the prevention of the transgression of planetary boundaries and the achievement of the SDGs will require a strategic approach to ocean observing. This must be supported by appropriate infrastructure, investments and mandatory international cooperation to create a coordinated effort by the ocean observation communities to provide knowledge and capacity to measure progress. Global ocean observations currently predominantly include physical and biogeochemical observations, while in more coastal

areas a wider range of observations also include some biological and human observations, although these are mostly still uncoordinated. The further development of biological observations and observations of human activities, associated pressures they place on the ocean, and the dependence of humans on healthy ecosystems should be strengthened. Bathymetric surveys should also be expanded, both in the open ocean and coastal seas, as bathymetry provides an important basis for ocean modelling and there are currently many gaps in coverage. At European level, increased efforts are needed to make survey data sets from government, research and industry available, for instance to improve the EMODnet Digital Terrain Model (DTM), which represents the European contribution to the global Seabed 2030¹³ initiative. Bathymetry and habitat mapping have already stepped up within the context of the All Atlantic Ocean Research Alliance with the aim of mapping the whole Atlantic Ocean at high resolution within the next years. The Atlantic Ocean Research Alliance¹⁴ (AORA) Atlantic Seabed Mapping International Working Group has been established and several projects (e.g. ATLAS¹⁵, SponGES¹⁶) have been funded. A globally coordinated ocean observing system is needed that is fit-for-purpose, sustainable, that responds effectively to policy demands, is better integrated into decision making processes, is pivotal for enabling ocean research, assessing trends, making predictions, and creating knowledge to inform decision makers. The lack of financial sustainability is a key challenge as most observations are funded on an *ad-hoc* basis, with only a one, two, three or four-year time horizon of certainty. A recent assessment by EuroGOOS¹⁷ for the European Environment Agency found that currently only 28% of ocean observation systems are sustainable versus 68% of meteorological observations¹⁸. There is also a lack of capacity in ocean observations in the Global South with the highest frequency of ocean observations for weather prediction in the North Atlantic (López-Ballesteros et al., 2018). Difficulty in reaching some areas of the ocean, e.g., the Global South, means that innovative technologies are needed such as animal borne instrumentation. Deep ocean observations are key to understanding the contribution of ocean vertical mixing to global warming. GOOS and other international efforts are continually advancing but challenges remain in standardized measurements, scientific and technical innovations, FAIR data access and management, financial commitments, capacity development, and technology transfer.

2.4. Improving Alliances

At research level, the 2013 Galway statement¹⁹ (AORA), the 2017 Belém statement²⁰ and other cooperation agreements have led to the All Atlantic Ocean Research Alliance, which strengthens marine research cooperation in the Atlantic between the EU and the USA, Canada, Brazil, South Africa, Argentina and Cape Verde. Other partnerships including the EU-China partnership and European research partnerships (BlackSea Connect²¹, BlueMed and Banos²²/Bonus²³) are also relevant and enable international collaboration on research priority setting and advancing research and scientific knowledge. A key challenge at regional level is the cooperation

13 <https://seabed2030.gebco.net/>

14 <https://www.atlanticresource.org/aora>

15 <https://www.eu-atlas.org/>

16 <http://www.deepeatlases.org/>

17 <http://eurogoos.eu/>

18 <https://insitu.copernicus.eu/library/reports/Sustainabilitysurveyupdatedreportfinal.pdf>

19 https://ec.europa.eu/research/iscp/pdf/galway_statement_atlantic_ocean_cooperation.pdf

20 https://ec.europa.eu/research/iscp/pdf/belem_statement_2017_en.pdf

21 <https://ims.metu.edu.tr/slider/black-sea-connect>

22 https://www.banoscsa.org/banos_csa

23 <https://www.bonusportal.org/>



between the regional conventions (e.g. HELCOM²⁴, OSPAR²⁵) with the Regional Operational Oceanographic Systems (ROOS) and ocean observation communities e.g. Atlantic (AtlantOS²⁶) and Arctic (SAON²⁷ and INTAROS²⁸), in terms of aligned observations and campaigns, and data exchange. Mobilizing existing alliances, creating new ones (e.g. that include the Indian, Pacific, and Southern Oceans), and ensuring their focus includes social science and economics are key challenges.

The Copernicus programme²⁹ in charge of operational ocean forecasting services and climate services at global and EU scales, established international cooperative agreements with foreign countries across the world (USA, Australia, Chile, Columbia, Brazil, Serbia, African Union, India, Ukraine) to favour the exchanges of ocean and climate data and develop common best practices in terms of ocean monitoring. Moving towards operational ocean services across the world, sharing science and methodologies may be a way forward to set international ocean capacities. Biological and human use Alliances of note that should be emulated here include the International Council for the Exploration of the Sea³⁰ (ICES) and the UN's Food and Agriculture Organisation³¹ (FAO) that both collect and collate information on fisheries and aquaculture extractions and stock analyses in the North Atlantic and across the world, respectively. ICES also has alliances with the North Pacific Marine Science Organization³² (PICES) and with South Atlantic science organisations. In addition, national/regional programmes such as the Norwegian Nansen programme also support the implementation of the ecosystem approach to fisheries management by helping with stock surveys and assessments in West Africa and beyond. In addition, Regional Fisheries Bodies such as the Convention on the Conservation of Antarctic Marine Living Resources³³ (CCAMLR), North Atlantic Fisheries Organization³⁴ (NAFO), International Commission for Southeast Atlantic Fisheries (ICSEAF), General Fisheries Council for the Mediterranean³⁵ (GFCM) are important and the potential contribution from Non-Governmental Organisations (NGOs) should be addressed here.

2.5. Supporting Data Frameworks and Ocean Services

Given the growth in autonomous observing systems and the need for more complex, transdisciplinary analyses to understand our ocean and predict future scenarios, an important challenge is the regional and global integration of large amounts of data from a variety of sources and stakeholders. Many different stakeholders including scientists, governments and industries such as fishing, aquaculture and oil and gas collect ocean data. These data need to be integrated into public operational ocean services that provide sustained and quality-controlled data products, forecasts, projections, and previous trends for decision makers. European marine data management infrastructures include Copernicus Marine Environmental Monitoring Service³⁶ (ocean analysis and forecasting), EMODnet³⁷ (bathymetry, chemistry, geology, physics, biology, seabed habitats, and human activities), ELIXIR-ENA³⁸ (biogeochemicals), Euro-Argo³⁹ (ocean physics and marine biogeochemistry),

EurOBIS⁴⁰ (marine biodiversity), INTAROS⁴¹ (Arctic), ICOS-Ocean⁴², SeaDataNet⁴³ (marine environment). These infrastructures have developed data standards and have established links with data originators to facilitate data collection, validation, storage and distribution, and several are also increasingly generating data products and models. However, not all data originators and funding agencies are aware of these marine data management infrastructures and do not yet make use of them for sharing their data sets to a much larger community of users. Some data originators also do not conform to FAIR principles and other data sharing best practices. A challenge is to increase the use of these infrastructures and to determine the enabling factors needed to transform data sharing and best practices, and the removal of policies and market failures that prevent these. Better adoption of best practices will lead to higher data quality from research, monitoring programmes and the public sector. There are also increasing requirements from users towards the quality, documentation and provenance information of data and services, which challenges these infrastructures to improve the FAIRness of their data, data products and services, and to anticipate increases in large volumes real-time, heterogeneous data i.e. big data, artificial intelligence, and web-based science developments. This requires further work and additional funding for the existing infrastructures to expand their capabilities for handling all kinds of data sets, to strengthen the interoperability between them, and to develop cyber platforms and services for integrated data access and computational capabilities.

These infrastructures are working together in new EU projects (such as ENVRI-FAIR⁴⁴ and the Blue-Cloud⁴⁵) to support the establishment of the European Open Science Cloud (EOSC), *"a trusted space for researchers to store their data and to access data from researchers from other disciplines ... to create a pool of information leading to a web of research insight."* Ursula von der Leyen, President of the European Commission. The Blue-Cloud project is piloting a thematic marine EOSC serving the Blue Economy, Marine Environment and Marine Knowledge agendas by federating existing European marine data management infrastructures and e-infrastructures and working to better integrate the marine research community into EOSC⁴⁶. The sustainability of cloud-computing infrastructures for data sharing and analysis as part of EOSC is a key challenge. The Blue-Cloud project will build a roadmap to 2030 for its expansion and sustainability mobilizing input from major stakeholders.

An interoperable framework that builds on existing marine data management infrastructures and that fully federates global sources of heterogeneous data is a priority for the Ocean Decade to achieve a 'transparent and accessible ocean'. During the All Atlantic Ocean Research Forum in February 2020, the need for a 'Digital Ocean' or 'DIGI TWIN for the Oceans', as proposed in Navigating the Future V (European Marine Board, 2019), where all historical and current data about the ocean could be uploaded, accessed, updated in real-time and used in decision-making, was confirmed by many stakeholders who recognised the need for regional funding to support such initiative. The Blue-Cloud project will mobilize a larger global Blue-Cloud programme that will encompass global infrastructures such as the General Bathymetric Chart of the Oceans⁴⁷ (GEBCO), Group on Earth Observations⁴⁸

24 <https://helcom.fi/>

25 <https://www.ospar.org/>

26 <https://www.atlantos-h2020.eu/>

27 <https://www.arcticobserving.org/>

28 <http://www.intaros.eu/>

29 <https://www.copernicus.eu/en>

30 <http://www.ices.dk/Pages/default.aspx>

31 <http://www.fao.org/home/en/>

32 <https://meetings.pices.int/>

33 <https://www.ccamlr.org/en/organisation/home-page>

34 <https://www.nafo.int/>

35 <http://www.fao.org/gfcm/en/>

36 <http://marine.copernicus.eu/>

37 <https://www.emodnet.eu>

38 <https://www.ebi.ac.uk/ena>

39 <https://www.euro-argo.eu/>

40 <https://www.eurobis.org/>

41 <http://www.intaros.eu/>

42 <https://otc.icos-cp.eu/>

43 <https://www.seadatanet.org>

44 <https://envri.eu/home-envri-fair/>

45 <https://www.blue-cloud.org/>

46 <https://www.blue-cloud.org/news/blue-cloud-position-paper-eosc>

47 <https://www.gebco.net/>

48 <http://www.earthobservations.org/index.php>

(GEO) and Ocean Biogeographic Information System⁴⁹ (OBIS). Work is ongoing to link European and Asian data infrastructures through a joint project with the Chinese National Marine Data and Information Service.

Another challenge is the need for management actions when the only data that are available are imperfect leads to decision-making under uncertainty, in which case models are useful. Management of fisheries is a good example. However, the uptake of ecosystem models that are based on ecological principles can help make fisheries management more sustainable, but the challenge is to create an ensemble of models that link socio-economic models to food web models, biogeochemical models and physical models (Heymans et al., 2018). Models need data for calibration and validation and these models have not thus far been used in practice because of unavailable amounts of data, and their lack of predictive capability, although that is slowly changing. The ensemble approach that has worked to get a consensus on future predictions in climate change science by the IPCC should also be implemented here. A further challenge to be considered is strengthening the sustainable development indicators developed by the European Union Statistical Office⁵⁰, Eurostat), which monitor progress towards the SDGs⁵¹.

3. OPPORTUNITIES FOR IMPROVING OCEAN SCIENCE

3.1. Improved Ocean Science–Society–Policy Interface

Strengthening citizen engagement and ocean literacy among decision-makers and citizens is an important opportunity. Building an effective ocean knowledge and innovation system will require open access to data and scientific publications, science communication, ocean literacy, co-creation of research, and science policy interfaces. Programmes for ocean education can be developed and more professionals trained in science communication. Incentives can be improved to encourage scientists to engage in communicating their research to policy-makers and the public as an imperative. Provision of more incentives for researchers to make their research and data open-access will help as will supporting services to host research outputs and data i.e. open-access scientific journals and data services. Stronger infrastructures are needed to translate research into actionable knowledge for decision-makers.

? Proposed questions for the working group discussion

- ▶ How can we ensure that ocean research is translated into actionable knowledge for decision makers?
- ▶ How can we ensure that knowledge is swiftly taken up by policy developers and decision makers?
- ▶ Can we make open-science the norm internationally given the pay-wall for open science is often not manageable, particularly in the global South and even some European countries?
- ▶ What programmes/initiatives should be developed to improve ocean literacy among policy-makers?
- ▶ How can the World Ocean Assessment (WOA) be strengthened (perhaps in cooperation with IPBES and IPCC) to deliver a more authoritative and policy relevant State of the Ocean Assessment, that is policy relevant and delivers an assessment of the attainment of SDG1.4 and other ocean related SDGs?

- ▶ How to better integrate and support regional assessments, as developed through regional seas agreements such as the Oslo-Paris Convention (OSPAR Commission) and the Helsinki Convention (HELCOM commission) as well as regional science bodies such as ICES and WIOMSA?
- ▶ How can international collaboration continue in the framework of UN SDG's, Space and ocean research, and marine resource exploitation through specialized UN and national authorities?

3.2. Supporting Ocean Research

A shift in the way that science is carried out so that it accurately responds to the needs of decision makers will be imperative. Scientific research programmes should be focused on producing knowledge that can be used in decision-making and innovation. This should be based on sustainability science and designed by co-creation involving all relevant stakeholders and using a transdisciplinary approach. New governance structures can then be developed that consider resilience strategies and trade-offs that include the most up-to-date science. Addressing knowledge and data gaps will require sustainable, long-term ocean observations (IOC-UNESCO, 2019) and enhanced citizen science (Garcia Soto et al., 2017). Smarter ocean observations are needed to assess the state of the ocean and predictions of how it will change in the future, particularly in the face of climate change. Ocean science will need to adapt when faced with a fast changing climate and changes in technology.

If we want to be able to predict regime shifts in ecosystems, or impacts of multiple stressors into the future under climate, pollution and human use scenarios, we will need to extent our current modelling capacities and develop ensembles of models, coupled with data assimilation schemes and AI algorithms that describe both spatial and temporal dynamics and uncertainties at much higher resolution for the global ocean and coastal seas. Without these improvements in all aspects of ocean science, decision-makers will not be able to address the trade-offs that we need to make between the ecosystem services that are provide by the ocean (Austen, 2014).

In the forthcoming EMB Future Science Brief on Big Data in Marine Science, it is indicated that modelling approaches based on machine learning, such as Bayesian statistics or neural networks, should be more widely used in marine research since they offer the opportunity for more complex analyses to enhance our understanding of the ocean. Scientists are also increasingly deal with a plethora of large, heterogeneous data sets. This will require specialized training for marine scientists and close collaborations with computer scientists.

49 <https://obis.org/>

50 <https://ec.europa.eu/eurostat>

51 [https://www.europarl.europa.eu/thinktank/en/document.html?reference=EPRS_BR\(2019\)644218](https://www.europarl.europa.eu/thinktank/en/document.html?reference=EPRS_BR(2019)644218)

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Proposed questions for the working group discussion

- ▶ How can we design marine research programmes that are transdisciplinary and based on sustainability science (i.e. including stakeholders in the co-design of research that combines natural sciences, social sciences, and humanities), with the aim of producing quality-controlled knowledge that can be used in decision-making?
- ▶ How can we design marine research programmes that allow for adaptability to rapidly changing climate and technological advances in research methods?
- ▶ How can we foster the transition from research to operational ocean services, accessible to local and international communities for decision-making, impact assessment and development of best practices?
- ▶ How can we foster the development of co-creation between actors based on new digital technologies that would foster the development of new policies and best practices?
- ▶ How can we leverage EU research infrastructures to better support international ocean research and governance e.g. the European Research Infrastructure Consortium (ERIC) and the European Strategy Forum on Research Infrastructures (ESFRI); and
- ▶ How can we optimize marine research to provide solutions to human pandemics like COVID -19? Can we accelerate research on oceans and human health and improve governance measures to protect marine biodiversity with human health benefits?

3.3. Strengthening Ocean Observations

Equitable ocean observations, i.e. equal in number and frequency, need to be achieved in all ocean basins through sustained funding. There is a need for a coordinating framework designed to align and integrate Europe's ocean observing capacity for the long term. This should promote a systematic and collaborative approach to collecting information on the state and variability of our seas and ocean, and underpin sustainable development, protection and conservation of the marine environment and its resources i.e. a future European Ocean Observing System (EOOS)⁵² integrating users requirements and operational activities (EuroGOOS). Developing and keeping human capacity as well as building technical and infrastructural capacity in the Global South will be invaluable for improving our knowledge of the ocean and the links between the ocean and climate. In addition, capacity development in deep ocean science, biogeochemical and biological observations, and even the social sciences of ocean uses would be imperative. Improvements of ocean observation technologies and data handling will be needed and the continued support of global ocean observation systems such as GOOS and by European countries, through EuroGOOS.

Proposed questions for the working group discussion

- ▶ How can we enable capacity development for biogeochemistry (including for CO₂ and pollution) and biological observations?
- ▶ How do we observe human activities: sustenance, extractive, exploitive and recreational?
- ▶ How do we ensure sustained funding for ocean observations?
- ▶ How can we enable capacity development for ocean observations in the Global South?
- ▶ How can we enable capacity development for biogeochemistry (including for CO₂ and pollution) and biological observations?

3.4. Improving Research Alliances

Increased international collaborations will support research needed to underlie effective ocean governance. There are opportunities for strengthening research alliances, creating new alliances and ensuring their focus is transdisciplinary including social science and economics.

Proposed questions for the working group discussion

- ▶ How can existing research alliances be mobilized to adopt transdisciplinary sustainability science to increase understanding of the four-dimensional ocean?
- ▶ How can we create better cooperation between the regional conventions (e.g. HELCOM, OSPAR) and the Regional Operational Oceanographic Systems (ROOS)
- ▶ What new research alliances should be created?
- ▶ How do we enable the Global South to fully participate in these Research Alliances when there is such a discrepancy in resources?

3.5. Supporting Data Frameworks and Ocean Services

Two major programmes are available to both produce, store and disseminate ocean data and information products in Europe; the Copernicus programme operating ocean services (forecasts, real-time observation, climate records) and EMODnet acting as the EU marine knowledge database. There are numerous other European ocean data frameworks, and they are implementing FAIR data principles. This means that complex data and data products can be built, combined and processed by both humans and machines, and the integration of artificial intelligence, including machine-learning techniques are being explored. An interoperable framework ("a global Blue-Cloud") that fully federates global ocean data from many heterogeneous sources and that builds on existing data infrastructures is needed for the widespread use of artificial intelligence to inform international ocean governance.

STRENGTHENING INTERNATIONAL OCEAN RESEARCH, DATA AND KNOWLEDGE

? Proposed questions for the working group discussion

- ▶ How can we establish interoperability between standards and services from Europe and other regions for global discovery, access, and usability of all available multi-disciplinary data?
- ▶ How can we address artificial intelligence related issues for data privacy, policy and management?
- ▶ How can we motivate and leverage data originators and their funding agencies to make use of existing marine data management infrastructures for sharing and long-term stewardship of their data sets and making these part of the 'digital ocean' offerings?
- ▶ How can we motivate international marine data management infrastructures and their regional funding agencies to join the 'digital ocean' initiative?
- ▶ How can we interact with user communities and best co-design data products that will meet end-user needs to improve ocean governance?
- ▶ How can we collaborate with e-infrastructures and engage with EOSC to get access to the computing and storage infrastructures necessary to host big data and perform increasingly complex analyses using artificial intelligence?
- ▶ How can we collaborate with the private sector to develop and exploit data infrastructures based on FAIR principles?
- ▶ How can we promote well-designed data management plans, which are needed for big data applications?
- ▶ How can we increase efforts to make marine survey data sets from government, research and industry available to the maximum extent?
- ▶ How can we address the human-dimension of data sharing, determine the enabling factors needed to transform data sharing and the adoption of best practices, and removal policies and market failures that prevent these.

4. FUTURE PERSPECTIVES FOR EU ACTION

[It is the intention that this section will be further developed based on working group discussions and provide ideas for the EU to take action towards the development of an EU outlook on ocean governance.]

The EU should consider:

- ▶ How can the EU and its Member States contribute to ensure that the Ocean Decade will be successful in delivering the research, data and knowledge needed to inform international ocean governance?
- ▶ What does the EU expect from the Ocean Decade?
- ▶ How can the uptake of ocean science by decision and policy makers be strengthened?
- ▶ How can researchers in the EU do a better job of creating the science and data that decision makers need?
- ▶ How can the EU and its Member States contribute to enabling coordinated and sustainable ocean observations that are fit for purpose to progress international ocean governance?
- ▶ How can the EU and its Member States contribute to enabling the collection of data by non-traditional actors and making sure that these data are based on the FAIR principles and are integrated into our knowledge and evidence base?
- ▶ How can the EU and its Member States contribute to connecting and making ocean data accessible and interoperable on a European, national and a global scale moving towards a global "Blue-Cloud" and a 'digital ocean twin'?
- ▶ How can the EU and its Member States further strengthen research alliances to support international collaboration to deliver societally relevant ocean research, data and knowledge?
- ▶ How can the EU incorporate ocean research (including sustained ocean services) in the Green Deal?
- ▶ How can the EU and its Member States support the development of a strong ocean knowledge base to support international ocean governance?

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