



The UN Decade of Ocean Science for Sustainable Development

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Our civilization needs a clean, resilient, productive, safe, well-observed, documented and predicted ocean. “The ocean we need for the future we want” was the motto of the Intergovernmental Oceanographic Commission proposal to the United Nations to consider the merit of an Ocean Science Decade. By proclaiming the Decade, the UN General Assembly offered the oceanographic community a unique, once in a life-time, opportunity to change the way we do things, make oceanography fit for purpose of effectively supporting sustainable development, and energize the ocean sciences for future generations. The Decade is the chance to put in place a more complete and sustainable observing system and feed the resulting data into a science-based informed decision-making system allowing increased reliance of our civilization on the ocean, its ecosystem services and, at the same time, preserving ocean health. Strong and proactive engagement of the oceanographic community in the design of the Decade and its observing component and subsequent energetic implementation of the ideas are sought. Participants in OceanObs’19 are invited to consider the additional possibilities and requirements associated with the Decade in their contributions to and brainstorming at the Conference. It is essential to use collective wisdom of OceanObs’19 to help developing an ambitious and also realistic implementation plan for the Decade, with a strong observational component.

Keywords: ocean observing, science, observations, decade, sustainable development, societal, data management

INTRODUCTION

The Intergovernmental Oceanographic Commission (IOC) of UNESCO, a specialized organization of the United Nations system for ocean observations, data, services and related capacity development, proposed to the United Nations to proclaim in 2021–2030 an international Decade of Ocean Science for Sustainable Development. The idea of an ocean decade was directly linked to the 2030 Agenda adopted by the United Nations in 2015. The Decade can mobilize the ocean community behind the ideas of sustainable development and serve to focus the research and technological development in oceanography on existentially important issues of protection

and sustainable use of the ocean. This will be a decisive contribution by the ocean community to the implementation of the Sustainable Development Goals (SDGs) – not only the 14th (“Ocean”) SDG, but many others as well. Ocean observations are at the heart of this initiative.

The IOC proposal to the United Nations was successful and the UN Decade of Ocean Science for Sustainable Development was proclaimed by the United Nations General Assembly to start on 1 January, 2021. This decision potentially opens a new era in oceanography, implying a major change in the way the ocean community works and how it is organized and supported, and how it can contribute to the future of our civilization.

This article presents motivations for the Decade, gives background information and describes goals, anticipated societal outcomes, main areas of research and development, and the approach to use them in achieving societal outcomes. The IOC must present an Implementation Plan for the Decade to the UN General Assembly of 2020. This work is in progress. The plan will be a living document and will be adjusted in the future to accommodate new needs and undertakings, and, importantly, partners. Engagement of the ocean community, including ocean observation specialists, in designing the Decade and its subsequent implementation is strongly encouraged.

MOTIVATIONS FOR THE UN DECADE OF OCEAN SCIENCE FOR SUSTAINABLE DEVELOPMENT

The ocean, the largest ecosystem on our planet, provides our civilization with a range of existentially important services (Stocker, 2015; Visbeck, 2018). To continue benefitting from them, a globally shared information and knowledge system is needed that would inform, on one side, actions for the restoration and maintenance of the ocean’s health (Duarte et al., 2018), and on the other side, use of the ocean space and resources to achieve global sustainable development. At present, such a consolidated system is not in place. However, many elements that could be connected in a more synergistic way to build such a system either exist, are being designed, or being worked on. These seeds of growth reside in the ocean observing systems, research and development activities, advances in the domains of technology and oceanographic information services, scientific assessments, national and international legislation and policies, best practices, standards, capacities, and resources—including human and economic resources available to industries,—and the private sector.

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. The 2030 Agenda with its 17 Sustainable Development Goals (SDGs), including the SDG 14 on the Ocean and its 10 targets, was unanimously endorsed in 2015 by the UN General Assembly¹. The Paris Agreement of 2015 under the UN Framework

Convention on Climate Change refers to “the importance of ensuring the integrity of all ecosystems, including the oceans.”² The Sendai Framework for Disaster Risk Reduction of 2015 intends to address, *inter alia*, the risks to countries’ coastlines. The UN Convention on Biological Diversity of 1992, with its Protocols and Implementation Plan components³—such as Aichi Targets—refers to the need to manage marine and other aquatic ecosystems scientifically. The 1995 Code of Conduct for Responsible Fisheries⁴ and the Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing of 2009⁵ are key global instruments under the UN Food and Agricultural Organization to make fisheries sustainable. The Regional Seas Conventions of the UN Environment Programme and regional fisheries management organizations provide regional framework for conserving the ocean health and its living marine resources. The International Maritime Organization monitors the implementation of the UN Convention for Safety of Life at Sea (SOLAS Convention of 1974)⁶ and a series of international conventions against marine pollution. The UN Convention on the Law of the Sea (UNCLOS) of 1982 http://www.un.org/Depts/los/convention_agreements/texts/unclos/unclos_e.pdf provides overall regulatory framework for the conservation and sustainable use of ocean and its resources.

An United Nations Intergovernmental Conference is being held in the years 2019–2020 to agree an international legally binding instrument under UNCLOS on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction. A number of important targets in relation to the sustainable use of the ocean are set in the Small Island Developing States (SIDS) Accelerated Modalities Of Action [S.A.M.O.A.] Pathway⁷, adopted at the Third International Conference on Small Island Developing States in Samoa in 2014. Since 1995, the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities⁸ has been working to identify the sources of land-based pollution or harmful activities and prepare measures to reduce them. It is even more relevant now as we know about the huge amount of plastics transported to the ocean from the shore. Taken together, all of these and other frameworks provide building blocks for the potential ocean information and knowledge system aimed at supporting policies and actions for ocean health and sustainable use of the ocean.

At present, there is tremendous goodwill in the global community to protect the ocean. It strongly manifested itself at the first UN Conference to Support the Implementation of Sustainable Development Goal 14 that took place at UN

¹<https://www.un.org/sustainabledevelopment/blog/2015/09/historic-new-sustainable-development-agenda-unanimously-adopted-by-193-un-members>

²https://unfccc.int/sites/default/files/english_paris_agreement.pdf

³<https://www.cbd.int>

⁴<http://www.fao.org/3/a-v9878e.htm>

⁵http://www.fao.org/fileadmin/user_upload/legal/docs/037t-e.pdf

⁶[http://www.imo.org/en/about/conventions/listofconventions/pages/international-convention-for-the-safety-of-life-at-sea-\(solas\)-1974.aspx](http://www.imo.org/en/about/conventions/listofconventions/pages/international-convention-for-the-safety-of-life-at-sea-(solas)-1974.aspx)

⁷<http://www.sids2014.org/index.php?menu=1537>

⁸<https://www.unenvironment.org/nairobiconvention/unep-global-programme-action-uneppga>

Headquarters in June of 2017 (the Ocean Conference⁹). More than 1,500 various commitments to that effect were received by the organizing committee of the Conference. Nine Communities of Ocean Action are following up on the implementation of those commitments. Another venue for seeking commitments is the series of Our Ocean annual conferences organized by national governments after the founding conference in 2014 called by the U.S. Ex-Secretary of State John Kerry. New networks and groups have been and will be created to conserve ocean health and promote sustainable means of using ocean resources. Engagement of the private sector holds a major promise in that respect and is stepping up.

The mobilization of the communities is the result of growing awareness and concern about the decline in ocean health. According to the First World Ocean Assessment conducted by UN¹⁰, due to the impact of multiple negative stressors, our civilization is running out of time to start managing the ocean sustainably. Symptoms of the decline in ocean health include warming of the ocean water at all depths, including submarine heat waves (Stocker, 2015), ocean acidification and its multiple consequences (Hoegh-Guldberg et al., 2014), reduced generation or depletion of oxygen, the massive scale of various types of ocean pollution including plastics and accidental pollution, dire consequences of the illegal, unreported and unregulated fishing and of fishing subsidies, ocean habitat destruction, harmful impacts of invasive species, and some other negative effects. The World Ocean Assessment lists some other impacts on the society: the sea-level rise, growing occurrences of more intense tropical (and, potentially extratropical) cyclones, harmful algal blooms, fish and human poisoning, inundation of the coasts by the Sargasso and some other factors. Migration of the population to the coast along with the continuing population growth exacerbate the risks to lives and property in the coastal zone, and earthquakes and tsunamis continue to represent a major threat.

According to the first Global Ocean Science Report, prepared by the IOC of UNESCO in 2017¹¹, the investment into ocean science is less than 4% of the global funding of natural sciences, with very large variations among countries. The current knowledge of the ocean, in terms of its physics and dynamics, might be close to sufficient for alerting the society and governments about many of the existing or emerging threats. However, there is a strong need for more specific knowledge and its systematic delivery and application to enable effective and efficient actions toward sustainability, at the global and regional levels. Mainstreaming oceanography and targeting it and ocean related components of natural and social sciences on practically assisting the sustainable development agenda were the main motivations for the IOC to develop the proposal to the UN to organize a Decade of Ocean Science for Sustainable Development (hereafter – the Decade¹²) in 2021–2030.

⁹<https://oceanconference.un.org>

¹⁰<http://www.worldoceanassessment.org/>

¹¹<https://en.unesco.org/gosr>

¹²<https://en.unesco.org/ocean-decade>

BACKGROUND AND MAIN GOALS OF THE DECADE

The proposal of the Decade came from a brainstorming meeting of the IOC Chair, Vice-Chairs and senior secretariat staff held in Gilleleje, Denmark in January 2016. Dr. Gunnar Kullenberg, a former IOC Executive Secretary, made significant contributions resulting in the meeting's success. During 2016 and first half of 2017, IOC Member States and many other interested parties were consulted on the concept and potential value of a Decade of Ocean Science. A proposal for the Decade was drafted for consideration by IOC Member States (IOC/INF-1341, 2 February, 2017) and a revised version of the proposal (IOC/INF-1341 REV) was presented to the twenty-ninth session of the IOC Assembly and subsequently endorsed through a Resolution (IOC Resolution XXIX-1, IOC-Unesco, 2017). In addition, recognizing the cross-cutting role of ocean science in SDG 14 of the 2030 Agenda, the Decade proposal was registered by the IOC as a voluntary commitment to the first UN Ocean Conference that took place in June of 2017 in New York⁹. In the middle of 2017, the IOC submitted the proposal for consideration of the 72nd Session of the UN General Assembly (UNGA).

It was proposed that the Decade start exactly fifty years after the International Decade of Ocean Exploration (IDOE) that took place in 1971–1980 (Holland and Pugh, 2010). IDOE was coordinated by the IOC and successfully stimulated oceanographic research and exploration, creating additional interest and support to the discipline. The IDOE was followed by several seminal developments in ocean management and sciences, including the preparation and signature of the UN Convention on the Law of the Sea (1982), the World Ocean Circulation Experiment (1990–2002) and several other major international undertakings in the domain of the ocean.

On 5 December 2017, the UNGA, within Part XI of the Omnibus Resolution for Oceans and the law of the sea (RES 72/73) relating to “Marine science,” decided (United Nations General Assembly, 2017, paragraph 292) to proclaim

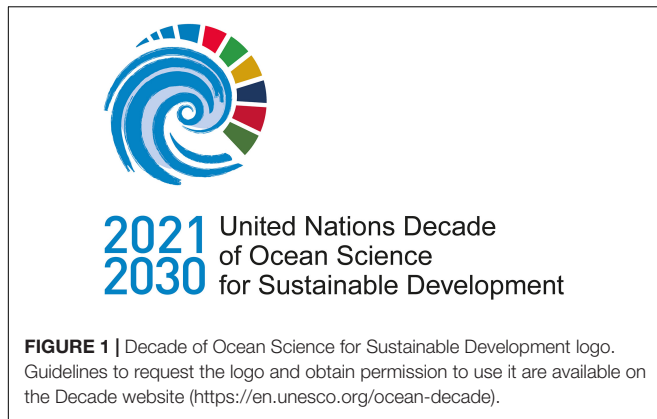
the United Nations Decade of Ocean Science for Sustainable Development for the 10-year period beginning on 1 January 2021, within existing structures and available resources.

The UNGA:

called upon the Intergovernmental Oceanographic Commission to prepare an implementation plan for the Decade in consultation with Member States, specialized agencies, funds, programmes and bodies of the United Nations, as well as other intergovernmental organizations, non-governmental organizations and relevant stakeholders.

Further, the UNGA:

- Requested that the Intergovernmental Oceanographic Commission provide information on the development of the implementation plan and regularly consult with, and report to, Member States on the United Nations Decade of Ocean Science and its implementation;
- Invited the Secretary-General to inform the General Assembly about the implementation of the United Nations Decade of



Ocean Science through his report on oceans and the law of the sea, on the basis of information to be provided by the Intergovernmental Oceanographic Commission;

- *Invited UN-Oceans and its participants to collaborate with the Intergovernmental Oceanographic Commission on the United Nations Decade of Ocean Science.*

The proclamation of the Decade by the UN General Assembly is an acknowledgment by UN Member States and their Governments of the importance, need for and role of ocean science, data and information exchange for sustainable development, and that science can play an important role in helping the ocean support the 2030 Agenda. The Decade requires response and delivery from the IOC and other UN bodies, the scientific community as a whole, working in close contact with governments, industry and business, as well as with the civil society.

The idea of the Decade is to achieve a major change in the knowledge and management of the ocean. It is reflected in the following two over-arching goals that provide the high-level motivation for the Decade:

Goal 1: To generate the scientific knowledge and underpinning infrastructure and partnerships needed for sustainable development of the ocean.

Goal 2: To provide ocean science, data and information to inform policies for a well-functioning ocean in support of all Sustainable Development Goals of the 2030 Agenda.

The design of the Decade should address both deep disciplinary understanding of ocean processes and solution-oriented research to generate the knowledge needed for reducing pressures on the ocean, preserving and restoring ocean ecosystems and safeguarding ocean-related prosperity for future generations. The Decade should turn the scientific knowledge and understanding into effective actions supporting improved ocean stewardship for sustainable development. The generation of societal outcomes of the Decade would trigger positive environmental and societal changes and would support peaceful cooperation of nations. The logo of the Decade (**Figure 1**) aims to demonstrate the role of ocean in all aspects of sustainable development.

SOCIETAL OUTCOMES

The Decade will aim to achieve considerable progress in a number of research and technology development areas with a view of generating the following six societal outcomes.

A clean ocean, whereby sources of pollution are identified, quantified and reduced and pollutants removed from the ocean in an efficient manner. Integrated research will assess the human and environmental shorter-term and long-term risks from ongoing and future types of ocean pollution and generate new ideas on how to reduce ocean pressures by recycling, improved waste management, and strengthening the governance regimes that encourage more sustainable production and consumption.

A healthy and resilient ocean, whereby marine ecosystems are mapped and protected, multiple impacts on them, including climate change, are quantified and, where possible, reduced and provision of ocean ecosystem services is maintained. The Decade will promote research aimed at elucidating impacts of cumulative stressors on the ocean, its seas, ecosystems and resources, hence providing required information to enable actions, which can reverse the ocean ecosystem degradation. Improved evaluation and appreciation of the economic and societal value of the ocean and its ecosystems will also be instrumental to stimulate marine spatial planning, marine protected areas, coastal zone management and other ecosystem-based management approaches.

A predicted ocean, whereby society has the capacity to understand current and predict future ocean conditions and their impact on human well-being and livelihoods. Under the Decade, sustained and systematic ocean observations would be expanded to all ocean basins and depths to document ocean change, initialize coupled models and facilitate improved ocean understanding. Knowledge of present and future conditions is a pre-requisite to the development of sustainable ocean economic policies and ecosystem-based management. More detailed and complete accounts of ocean processes can help to improve climate prediction in a significant way. The Decade will also build on advances in ocean robotics and the combination of remote and *in situ* ocean observations, which offer new opportunities and reduce operational costs; it will also promote multi-stakeholder contributions by governments, the private sector and citizens.

A safe ocean, whereby human communities are much better protected from ocean hazards and where the safety of operations at sea and on the coast is ensured. The Decade will promote research aimed at minimizing impacts of various changes and risk reduction through adaptation and mitigation. It will also support the development of integrated multi-hazard warning systems (MHWSs) in all basins, hence, contributing to enhanced preparedness and awareness of society with regard to ocean risks. Community resilience and adaptive capacity, with elevated education and awareness concerning the use of observations and data, will also contribute to reduced impacts and improved efficiency of early warning systems for natural and man-made hazards. This area of research will be of great interest for the insurance and reinsurance industries.

A sustainably harvested and productive ocean, ensuring the provision of food supply and alternative livelihoods. The Decade

should create a better understanding of the interactions and interdependencies of the ocean ecosystem and environmental conditions and processes, the use of resources and the economy. A major task in context of the development of the ocean economy will be in documenting the potential impacts from environmental changes on the established and emerging maritime industries and their ability to generate growth, especially for least developed countries and SIDS. Defining safe and sustainable thresholds for economic operations in the ocean will help policy-makers and stakeholders in implementing a truly sustainable blue economy (see for example, Smith-Godfrey, 2016; Visbeck, 2018). New research should develop and flesh out sustainable blue-green growth agendas and link it to efforts in ecosystem protection.

A “transparent and accessible” ocean, whereby all nations, stakeholders and citizens have access to ocean data and information technologies and the capacities to inform their decisions. The enormous need for more ocean information in the scientific, governmental, private and public sectors demands a step change in ocean education at all levels. New technologies and the digital revolution are transforming the ocean sciences; these will be harnessed to deliver data and information to all stakeholders. Science-policy interface for the ocean should be enhanced as well. Open access to ocean information, increased interactions between the academic and societal actor communities, and ocean literacy for all should capacitate all citizens and stakeholders to have a more responsible and informed behavior toward the ocean and its resources. Innovative capacity development schemes between south–south and north–south ocean actors as well as courses for ocean professionals will be key in raising ocean awareness and promoting better solutions.

The six societal outcomes of the Decade are holistic. In order to be achieved, most of them require actions by the society, governments, or by key stakeholders. However, there is no causal link to achieving them that would be entirely scientific. Nevertheless, progress in several thematic areas of ocean science is either necessary or very useful to achieve them. Scientific papers should not be the sole measure of success of the Decade. Impact to society, appropriately measured against clear objectives, should also be a measure of success. Such *initial* priority areas of research and technology development (R&D) are outlined below. There is no priority order among them. They are interconnected but allow focused design and planning. Progress in these areas is necessary to facilitate protection and the sustainable use of the ocean, on global and more localized scale.

R&D Priority Area 1: Comprehensive Map (Georeferenced Digital Atlas) of the Ocean

This R&D Area includes and goes beyond the domain of mapping the ocean bottom topography, and its importance can be illustrated by the deficiency of current global ocean depth maps. Current, largely satellite-based mapping of the global ocean renders a horizontal resolution between 2 and 5 km. At this resolution, many features are not detectable and result in only a coarse understanding of the ocean bottom. Technologies such as multibeam echo-sounders can deliver much higher

resolution, either as hull mounted on surface ships or on undersea vehicles that can be positioned closer to the seabed. At present the multibeam echo-sounder coverage of the world ocean is scarcely over 5%, leaving much work to be done and only a sketch of the true detail that exists under the ocean. The current map of the ocean does not represent therefore many important underwater features. If a parallel to the land surface is evoked, the equivalent resolution of terrestrial maps would level out almost all prominent topographic features. With the current level of knowledge, the recent searchers for missing aircraft simply did not know the true initial depth of water they were supposed to operate in.

Current efforts under the International Hydrographic Organization (IHO) and the IOC, particularly the IHO/IOC Project “General Bathymetric Chart of the Ocean” (GEBCO¹³) and its flagship Project Seabed 2030, sponsored by the Nippon Foundation, address the formidable task of mapping the ocean depth for most of the global ocean.

The task of mapping the ocean depth is being currently addressed through coordinated assembly of depth measurements made using various platforms, such as satellites, ship and autonomous underwater vehicle (gliders) echo sounding. It may be promising to review other sources of data, e.g., seismic information that is available from various seismic networks to enrich the volume of data, particularly for poorly covered regions. The feasibility of using new data and approaches needs to be studied.

A comprehensive map of the ocean should include much more information than just ocean depth. It requires other variables describing the physical, biological, chemical, and geological environments, ecosystems, cultural objects, boundaries, resources, etc. The shipping and transport community, weather and ocean forecasters, fishing industries and authorities, marine resource managers, and coastal cities and communities vulnerable to sea level rise, tsunami, and tropical cyclones are all dependent upon accurate ocean maps. Maritime spatial planning is a way of optimally putting many interdependent maritime activities on a single map. Establishment of marine protected areas is also based on mapping. Similar requirements exist in the coastal zone management. A common digital atlas of ocean information is necessary in order to address the prevailing and future societal pressures on the ocean. Advanced prototypes of such an atlas already exist in many regions of the world, sometimes encompassing high resolution maps.

Designing a digital georeferenced atlas of the ocean that would satisfy many of the future uses of the ocean and its protection is therefore a necessary and innovative scientific undertaking that requires consolidation of existing knowledge, review of requirements, new R&D, and comprehensive assemblage on regional and local scales.

R&D Priority Area 2: A Comprehensive Ocean Observing System

One cannot manage what one cannot measure. Ocean observations are the key to understanding weather, climate

¹³<https://www.gebco.net>

and the future state of marine ecosystems and resources. The Global Ocean Observing System (GOOS¹⁴) domain of competence is physical state variables in the upper 2 km of the water column and at the surface. It is expanding to include additional measurements in the deeper ocean and in the domains of biogeochemistry, biology, and ecosystems. The approach based on Essential Ocean Variables (Lindstrom et al., 2012) is effective and new variables should be taken on board, making the scope of observations capable to help monitoring and management of large marine ecosystems (LMEs) and coastal and offshore areas.

Global Ocean Observing System is a shared undertaking. All nations, even landlocked, benefit from the associated data products and services. United Nations Member States need to engage further to construct and sustain a global ocean observing system that covers all the world's major ocean basins and also addresses coastal and local interests. This system should be routinely maintained, with observations collected to a uniform and common standard of foundational or basic data, with information gathered made openly available to all and should be readily adaptive to both emerging circumstances and priorities as well as to local or regional needs, in addition to basic parameters. All the societal outcomes listed above would benefit from additional observations and parameters, and in particular, in the southern ocean and the Arctic that are currently under-observed. Efforts should also focus on expanding observations to the deep ocean in all ocean basins to characterize its physical state, biogeochemistry and ecosystems, and detect changes.

The Decade should produce a regime of international cooperation that fully monitors the major ocean basins of the world, at all depths, blending inputs into the GOOS, and maintained by the nations of the basin region, among others. It should synergistically use *in situ* and remotely sensed observations and strongly benefit from emerging observing technologies. The Decade should create conditions for involvement of downstream beneficiaries, such as the private sector, of the ocean observations (for example, as has been done for the tropical Pacific; Smith et al., 2019). Their input would provide very useful feedback on the quality and quantity of the observations information provided, and their interest in obtaining the data should create a “pull” and a better resource base for expanding and sustaining the ocean observations. It should be noted that such beneficiaries often operate on local scales and require information of high resolution.

R&D Priority Area 3: A Quantitative Understanding of Ocean Ecosystems and Their Functioning as the Basis for Their Management and Adaptation

The Census of Marine Life produced an inventory of species in the ocean, enhancing the scientific knowledge on what lived, lives, and will live in the ocean. This work is successfully continuing under the IOC Ocean Biogeographic Information System

(OBIS). The biological component of GOOS is approaching the pilot phase. Emerging technologies are becoming more mature and available, such as Environmental DNA sampling (eDNA; Ausubel et al., 2019). These new approaches will enrich more mature molecular methods and, combined, create a capacity for imaging life in the ocean in near real time. From viruses and plasmids to whales, and their interaction with each other, the new state of molecular and genetic science will reveal much of what has not been able to be measured or understood in the past. This knowledge will be instrumental to better understand the ecosystem services, including, for example, nitrogen fixation, primary production, nutrient cycling, and surface colonization (with thanks to the manuscript reviewer).

Increasingly, tools are available to replace the laboratory bound analysis with deployable laboratories that produce the resulting information, rather than simply collect the sample. A combination of methods exists to produce an ongoing measurement of micro- to the macro- and mega-sized components of the marine ecosystem inventory and assess its health. The new technologies will be able to help the researchers to better understand the functioning of deep-sea ecosystems, measure the cumulative impacts of ocean stressors and define the carrying capacity of ocean ecosystem to sustain human impacts and economic development. For the first time in history, this opens a possibility to meaningfully predict the evolution of ocean ecosystems, using biogeochemical and ecosystem models that are forced by modern climate prediction or projection models and are verified against a bulk of standardized *in situ* eDNA and other observations.

Availability of environmental predictions also offers potential to guide the adaptation to the new climatic and environmental conditions of certain valuable ecosystems (not only individual species), e.g., some coral reef ecosystems. The approach may consist of selective breeding of ecosystem components in a controlled basin of water with environmental conditions corresponding to the predicted regime of temperature (including estimates of its future variability and emergence of heat waves), salinity, water pH, oxygen, turbidity and, potentially, some other stressors. World aquariums possess significant potential to conduct such experiments.

Ecosystem monitoring with quantitative criteria of ecosystem health, enhancing knowledge of management solutions and availability of best practices and emerging predictive capacities hold promise to create a foundation for the science-based management of LMEs, with engagement of all key stakeholders, such as environmentalists and fisheries.

R&D Priority Area 4: Data and Information System

The IOC International Ocean Data and Information Exchange Programme (IODE¹⁵) focuses on the discovery, exchange of, and access to marine data and information including metadata, products and information. It sets international standards in that domain. The system, composed of an approximately 100 Data

¹⁴<http://www.goosocean.org>

¹⁵<https://www.iode.org>

Centers and associated data units, is capable of providing for long-term archival, preservation and documentation of marine data and information products, and facilitate related capacity development and the use of best practices.

Under the Decade, the oceanographic information system needs to be significantly expanded, upgraded and truly opened to the whole world to ensure flow of data and products between providers and users at different levels. The core of the future oceanographic data and information system is currently seen as a portal of ocean data that acts as a link between demand and supply and has a capacity to facilitate matching requirements for data and products. This engine is expensive to design and build, but it can be gradually created based on existing elements and advances in data processing and cataloging of data and product sources. Big data and cloud data processing and computing approaches offer additional perspectives to implement the portal. The initial steps toward creating the portal will likely consist of upgrading the current ocean data and information system while seeking resources and involvement of partners from IT industry and private sector to develop the future system in orderly manner, respecting the requirements of interoperability, the standards with acknowledgment of data originators. A Decade data policy will need to be developed and proposed. Compliance with the IOC data policy of free, unrestricted and open access to data should be considerably strengthened in the course of the Decade. A major international project on ocean data and information system development may be required, and, potentially, a global conference of the scale of OceanObs'19 to bring together known and new partners in the ocean data discipline, going beyond classical oceanographic data and starting to work with economic and social data.

R&D Priority Area 5: Ocean Dimension in an Integrated Multi-Hazard Warning System

Currently, there are a number of unconnected warning systems for ocean-related hazards. Some of them are operational, e.g., for tsunami generated by earthquakes, some are incomplete, e.g., for storm surges, and some emerging, e.g., for harmful algal blooms. Widely recognized and reflected in the Sendai Framework for Disaster Risk Reduction is the need to strengthen and harmonize the warning systems. An effective warning system has to be based on the knowledge of risks and corresponding emergency planning and warnings. The potentially affected communities need to be prepared to act appropriately on a warning. The hazard has to be detected, followed, and/or forecast. The warning then needs to be generated and timely, fully, and correctly transmitted, received, and acted upon.

This combination of actions and responsibilities necessarily involves more than one responsible agency. Experience shows a strong advantage of developing MHWSs able to act on more than one type of risk. During the Decade, a concerted effort should be made to incorporate ocean components into emerging or existing MHWSs and, as well, to more effectively use the ocean information for warnings of ocean-related hazards

at a variety of time scales, from immediate threats, such as tropical storms, to long-term, high-impact events like droughts, heat waves, forest fires, floods, etc. Until now, humankind has largely reacted too late to such hazards. There is significant progress in saving lives, but economic and infrastructural losses from natural disasters remain overwhelming and often strongly affect the capacity of a country or a region to recover after a natural hazard event.

The ocean-related warning systems, especially the one for tsunami, still require major methodological development, e.g., to embrace other sources of tsunami such as submarine landslides and volcanoes. Most importantly, the system needs to strengthen and upscale the preparedness of communities at risk. This quality of the system needs to be addressed during the Decade through involvement of appropriate governmental authorities and international mechanisms. The problem of “last mile” needs to be addressed so that the warning reaches the local community, which is prepared to act correctly, and community does so.

R&D Priority Area 6: The Ocean in an Earth-System Observation, Research, and Prediction

Ocean science is a part of the Earth system science. GOOS is a contributor to the Global Climate Observing System and, more widely, a part of the planet observing system of systems. To study and predict the future state of the ocean, one needs to incorporate it into various types of Earth system models. Industries, behavioral and societal changes, and economy all need to be eventually included in the observations and predictive modeling scope. As the time range of the prediction lengthens, more complexity is usually required to exploit the predictability of the interacting components of the Earth system. The longer the prediction range, the higher generally is the role of ocean processes in the prediction.

In addition, there exists an untapped potential in oceanographic observation and modeling that can help to improve a number of important services to humanity. This area of societal benefit includes many types and ranges of weather predictions, climate information services, various thematic assessments, and ocean space and resources management. Activities in the coastal zones and operations at sea are becoming more and more interdependent and need to be regulated accordingly. Activities require real-time decision making and anticipatory planning. Ocean modeling and prediction capacity that could meet such emerging requirements does not currently exist. Therefore, the Decade might engage at present unconnected modeling groups and industries into a design of a future multi-scale ocean observation and prediction system. Development of ethical principles of human interactions with the ocean, and short- and long-term economic analyses of ocean sustainability and the role of ocean science in it are urgently required. Quantitative assessments of tangible benefits and appreciation of intangible assets related to the ocean are needed for decisions to act on urgent issues including land-based sources of pollution, unsustainable ways of fishing and aquaculture and for ensuring protection of underwater cultural heritage.

R&D Priority Area 7: Capacity Building and Accelerated Technology Transfer, Training and Education, Ocean Literacy

All above R&D areas will move the cutting-edge of ocean science forward. They will augment the ocean science capacity and make it fit for the purpose of informing and even guiding sustainable development. The enabling elements for the progress are human potential, infrastructure, cooperation, resources and adequate social conditions of successful research and development. The IOC has started and will keep assessing the capacity of ocean science through the Global Ocean Science Report process. At present, the oceanographic capacities are highly uneven in the world, not only in terms of ability to contribute to the research but also in terms of ability to benefit from the scientific knowledge and technology, which is defined as also including ocean data and information. Based on ethical considerations and on the principle of common but differentiated responsibilities, all countries and communities should be able to benefit from the ocean life-supporting services, which requires capacity to act in a scientifically sound way. The Decade should strengthen the existing capacity development, training and education work and set in motion the transfer of marine technology (TMT) mechanisms. Infrastructure, training and teaching materials exist in many organizations. Their potential will be better sustained and potentially multiplied once the TMT Clearing House is put in place, linking supply and demand in capacity development, training and education.

One outcome of the Decade should be a major step forward in ocean literacy for various categories of people. The motivation for the Decade itself comes from the realization of the role of ocean for people and planet and from the understanding that the ocean is largely underexplored. A vigorous ocean literacy program of activities has to be designed. The major target audiences have to be students, which requires including ocean literacy in the school curriculum, decision makers—including governmental authorities—and the public at large (Santoro et al., 2017).

STRATEGIC APPROACH OF THE DECADE: TWO-WAY INTERACTION BETWEEN RESEARCH AND PRACTICAL APPLICATIONS

It is anticipated that progress in R&D will create new, more beneficial conditions for practical applications of new knowledge and technology. It is essential that ambitions of the private sector, governments and involved managers grow along with the progress in research. For that, active, intensive, and efficient communication of advances on ocean sciences will be a key enabling factor. The seven R&D priority areas listed above (or additional) will trigger accelerated development of the following means of using and protecting the ocean.

Protecting the ocean should employ the ecosystem-based approach, supported by observations and knowledge, with adequate regulation, and efficient and implemented policies including knowledge based establishment of marine protected areas in key locations.

The anticipation for the culmination year of the Sustainable Development Agenda, i.e., 2030, would be to have approximately 30% of the total area of the world Exclusive Economic Zones covered by scientifically-managed and governmentally approved maritime spatial plans¹⁶. This will bring multiple advantages for ocean “blue” economy and will facilitate management of ocean ecosystems and preserve ocean health. Similar progress is expected in the coastal zone management. It is essential that new MSP and coastal zone management approaches take into account not only the current state of the ocean and activities in it but are forward-looking, taking into account scenarios of future activities and appropriate environmental predictions.

Management of fisheries and aquaculture under the conditions of growing population, changing climate and the need to abate marine pollution, needs to fully capitalize on the multitude of ocean observations and on predictions of climate and ocean health and productivity. Observations and science can help increase transparency in managing the living marine resources and compliance with existing regulations, as well as stimulate countries to adopt progressive policies in the domain of fisheries and aquaculture.

Based on the analysis in the Intergovernmental Panel on Climate Change Special Report on the Ocean and Cryosphere in Changing Climate and gaps of knowledge and capacity to be identified in it, systematic work on adaptation solutions and search for climate change mitigation actions will be intensified.

WAY FORWARD, COMMUNITY AND UN ENGAGEMENT, RESOURCES

The Intergovernmental Oceanographic Commission was mandated by the United Nations General Assembly (UNGA) to lead the preparations of the Decade and develop its Implementation Plan in consultation with Member States, UN partners as well as other relevant stakeholders. The Implementation Plan must be submitted to the UN General Assembly in the second half of 2020. In the first part of 2018, a roadmap (IOC-Unesco, 2018b) was developed as an evolving document to guide the preparatory phase of the Decade by defining preliminary objectives, societal outcomes, governance and engagement processes.

In 2018, the 51st session of the IOC Executive Council welcomed the roadmap and decided to establish an Executive Planning Group (EPG) consisting of high-level experts to advise IOC governing bodies. The IOC convened the 1st meeting of the EPG from 17 to 19 December 2018 to brainstorm on scientific, governance, communications and engagement elements of the Decade. Beyond the scientific process itself, wide consensus was achieved within the EPG that the Decade must transform the way nations around the world invest in ocean science, both from the public and private sectors and how decision-makers use the available scientific knowledge to inform policies for ocean management. Experts also sought to lay out the basis for an effective strategy to communicate the objectives of the

¹⁶<https://en.unesco.org/mspglobal>

Decade, engage stakeholders, and ultimately influence behaviors and perceptions of scientists, decision-makers and the public around the value of ocean science for sustainable development. They stressed that capacity development and the TMT should be a key crosscutting priority, embedded deeply into the Decade planning process.

Executive Planning Group also agreed that early involvement of stakeholders in the planning phase would be key to achieving the objectives in an efficient manner and to secure broad and consistent implementation of the Decade. Stakeholders will be invited to contribute to the co-design of the Decade Implementation Plan through a consultation process that will be organized around Global Planning Meetings and a series of regional workshops foreseen in 2019 and early 2020 that will channel stakeholders' inputs into the preparatory process. Further to these consultative meetings, a Stakeholder Forum will be established and open to a broad range of communities (science, technology, ocean management, private sector, civil society) that are interested in contributing to the Decade.

UN partners with a focus on ocean are also associated to this consultation process. UN bodies were invited to contribute to the development of the Implementation Plan during a UN-Oceans' meeting (the UN inter-agency mechanism on ocean affairs) at UNESCO Headquarters in March of 2018. A dedicated task group was established at the UN-Oceans meeting held at the World Meteorological Organization in February 2019 to structure and reinforce its members' contributions to the Decade. The collaboration of the different UN bodies will also be encouraged through the development of both new and renewed partnerships with the IOC. It is essential to ensure that the UN agencies exercise leadership on aspects of the Decade that are relevant for their mandate. Communication and outreach efforts have intensified to present the objectives of the Decade and engage all these stakeholders.

The UNGA tasked the IOC with preparing the Decade Implementation Plan "within existing structures and available resources." Following the IOC Executive Council Decision, at its 51st session (IOC-UNESCO, 2018a), urging Member States to provide voluntary contributions for the preparation of the Decade, the IOC issued a Call for expression of interest in June of 2018. UN agencies and partners' organizations expressed strong support for the Decade and several Member States offered to host regional, global or thematic workshops scheduled during the Preparatory Phase of the Decade. More tangible support is still needed for the communication and outreach activities that will be developed for these consultative and planning meetings. Additional resources will be sought through alternative funding mechanisms such as public/private partnerships, as well as contributions of the philanthropic sector.

REFERENCES

Ausubel, J. H., Stoeckle, M. Y., and Gaffney, P. (2019). *Final Report of the 1st US National Conference on Marine Environmental DNA (eDNA)*. Available at: https://phe.rockefeller.edu/eDNAMarine2018/docs/MURU_eDNA_Conference_final_report.pdf; <https://undocs.org/en/A/RES/72/73> (accessed December 5, 2017).

CONCLUSION: DECADE AND OCEANOBS'19 COMMUNITY

The Decade is a major chance for oceanography to put in place a more complete and sustainable observing system and feed the resulting data into a science-based ocean management system satisfying the increasing reliance of our civilization on the ocean, its ecosystem services, and, at the same time, preserving ocean health. The OceanObs conferences are also decadal but periodic events intended to give momentum and direction to developing ocean observing systems. The Decade responds well to the main goal of this OceanObs'19, which is to establish the value chain from ocean observations through research to long-term societal benefits and key stakeholders. It is hoped therefore that the OceanObs'19 community will see the Decade as a key opportunity to propose ideas for making ocean observations even more societally relevant and, hence, better supported, and will actively participate and strongly contribute to preparatory phase of UN Decade. In summer 2020 IOC will need to submit the Implementation Plan to the 75th UN General Assembly of United Nations. The opportunities to contribute are multiple. The proceedings of OceanObs'19 will be carefully studied in crafting the Plan. Regional and global meetings will be organized to further develop ideas and digest them into the plan. The Decade stakeholder forum is a platform to collect ideas. The link to it is at <https://en.unesco.org/ocean-decade/get-involved>.

AUTHOR CONTRIBUTIONS

VR wrote the first draft of the manuscript taking into account various documents, to which JB, GK, NS, and some other authors made an input. PP and JR wrote some individual sections of the manuscript. All authors contributed to the manuscript revision, and read and approved the submitted version of the manuscript.

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Duarte, C. M., Poiner, I., and Gunn, J. (2018). Perspectives on a global observing system to assess ocean health. *Front. Mar. Sci.* 5:265. doi: 10.3389/fmars.2018.00265

Hoegh-Guldberg, O., Cai, R., Poloczanska, E. S., Brewer, P. G., Sundby, S., Hilmi, K., et al. (2014). "The ocean," in *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds

- V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, et al. (Cambridge: Cambridge University Press), 1655–1731.
- Holland, G., and Pugh, D. (2010). *Troubled Waters: Ocean Science and Governance. Geoff Holland and David Pugh*. Cambridge: Cambridge University Press.
- IOC-Unesco (2017). *Assembly Resolution XXIX-1*. Paris: UNESCO.
- IOC-Unesco (2018a). *Executive Council Resolution EC-LI.1*. Paris: UNESCO.
- IOC-Unesco (2018b). *Roadmap for the UN Decade of Ocean Science for Sustainable Development, Version 2.0*. Paris: UNESCO.
- Lindstrom, E. J., Gunn, A., Fischer, A., McCurdy, A., and Glover, L. K. (2012). *A Framework for Ocean Observing. By the Task Team for an Integrated Framework for Sustained Ocean Observing*. Paris: UNESCO.
- Santoro, F., Santin, S., Scowcroft, G., Fauville, G., and Tuddenham, P. (2017). *Ocean Literacy for All: a Toolkit*. Paris: UNESCO.
- Smith, N., Kessler, W. S., Cravatte, S., Sprintall, J., Wijffels, S., Cronin, M. F., et al. (2019). Tropical pacific observing system. *Front. Mar. Sci.* 6:31. doi: 10.3389/fmars.2019.00031
- Smith-Godfrey, S. (2016). Defining the blue economy. *Marit. Aff.* 12, 58–64. doi: 10.1080/09733159.2016.1175131
- Stocker, T. F. (2015). The silent services of the world ocean. *Science* 350, 764–765. doi: 10.1126/science.aac8720
- United Nations General Assembly. (2017). *Resolution A/RES/72/73, Part XI of the Omnibus Resolution for Oceans and the law of the sea*. Available at: <https://undocs.org/en/a/res/72/73> (accessed December 5, 2017).
- Visbeck, M. (2018). Ocean science research is key for a sustainable future. *Nat Commun.* 9:690. doi: 10.1038/s41467-018-03158-3
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