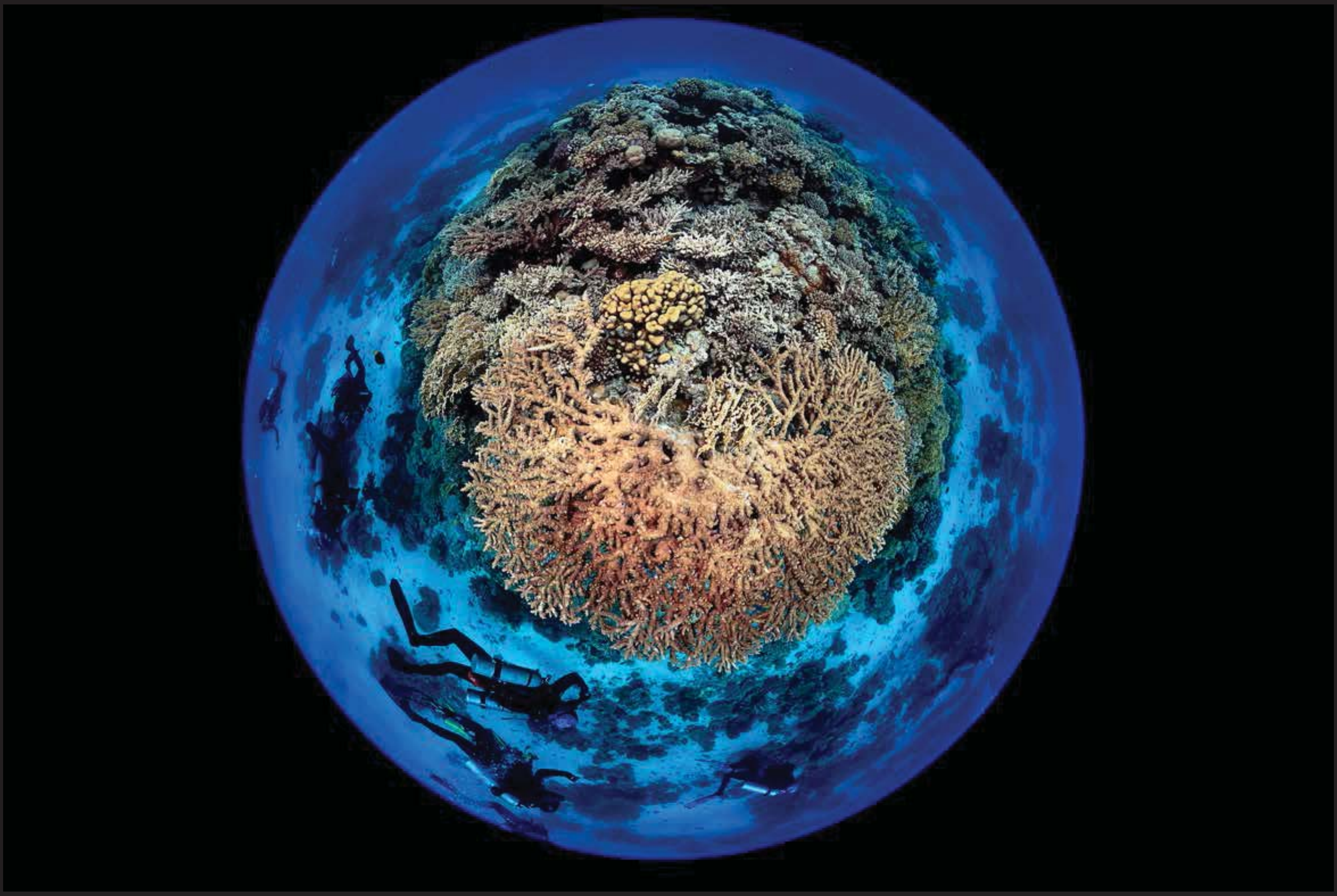
The Second World Ocean Assessment

WORLD OCEAN ASSESSMENT II

Volume I



United Nations

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Foreword

by the Secretary-General

The past year has presented unprecedented challenges. The coronavirus disease (COVID-19) pandemic has disrupted lives and livelihoods and exposed our societies' fragility. Sadly, the pandemic is not the only crisis that humanity faces. Climate change and biodiversity loss continue unabated, threatening sustainable development and our viability as a species. These challenges are particularly evident when we look at the state of our planet's life support system, the ocean.

In 2015, the first *World Ocean Assessment* warned that many areas of the ocean had been seriously degraded, the greatest threat to the ocean being the failure to deal with the many pressures caused by human activities. The message in the second *World Ocean Assessment* is that the situation has not improved, with the many benefits that the ocean provides at risk. The *Assessment* advises that, to ensure sustainability, we must work together to improve integrated ocean management, including through joint research, capacity development and the sharing of data, information and technology.

The ocean plays a crucial role in the achievement of the Sustainable Development Goals and the livelihoods of billions of people. We urgently need to change how we interact with it. The forthcoming United Nations Decade of Ocean Science for Sustainable Development and the United Nations Decade on Ecosystem Restoration provide opportunities for us to understand more and to reverse the damage that has already been done. The information in the second *Assessment* can assist in this process, as well as inform relevant intergovernmental conferences scheduled for 2021.

I urge leaders and all stakeholders to heed the warnings in the *Assessment* as we work to conserve and sustainably manage our planet's marine environment. Let us foster not only a green but also a blue recovery from the COVID-19 pandemic.

António Guterres

Summary

In its resolutions 57/141 and 58/240, the General Assembly decided to establish a regular process under the United Nations for global reporting and assessment of the state of the marine environment, including socioeconomic aspects, both current and foreseeable, building on existing regional assessments. In its resolution 71/257, the Assembly recalled that the scope of the first cycle of the Regular Process focused on establishing a baseline and decided that the scope of the second cycle would extend to evaluating trends and identifying gaps. The programme of work for the period 2017–2020 of the second cycle of the Regular Process includes the preparation by the Group of Experts of the Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects, of the second *World Ocean Assessment*, building on the baselines established by the First Global Integrated Marine Assessment (first *World Ocean Assessment*). In its resolution 72/73, the Assembly decided that the Group of Experts should proceed on the basis of a single comprehensive assessment. The present document was prepared by the Group of Experts in accordance with those decisions.

Preface

The goal for the General Assembly in creating the Regular Process for the Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects, was to ensure a comprehensive overview of the ocean and the relationships between the ocean and humans, covering all environmental, social and economic aspects. Such an overview would serve as a background to the many decisions that must be taken in that field at the international, national and local levels in pursuit of sustainable development. The first *World Ocean Assessment* was completed in 2015 and represents a major step towards that goal.

Inevitably, with such an ambitious goal, not only were some aspects not fully covered in the first output of the Regular Process, but also, as time passed, the assessment that was made up to 2015 needed to be updated. The General Assembly therefore provided for further global integrated marine assessments to record developments from the baseline provided by the first Assessment and, where possible, to show trends. In 2016, it decided that a second comprehensive assessment should be prepared by the end of 2020.

The present volume contains the second *World Ocean Assessment*. It provides more information on aspects of the ocean and its relationships with humans, including separate assessments of the abyssal plains and marine hydrates, and brings together in specific chapters matters that were addressed in different sections of the first Assessment, such as the state of fish species and marine infrastructure.

As with the first Assessment, the production of the present Assessment has been a major task, relying essentially on voluntary efforts of hundreds of experts in many fields, with support from the regular budget of the United Nations. As before, it has been a privilege for the Group of Experts of the Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects, to organize, contribute to and finalize the Assessment. Crucial support has again been provided by the Secretariat, including the Division for Ocean Affairs and the Law of the Sea, several international organizations and a number of States Members of the United Nations, as detailed in chapter 2. The Group of Experts is grateful to all those people and institutions but, under the terms of reference and working methods endorsed by the General Assembly, is ultimately responsible for the final text.

The bulk of the text was written before the outbreak of the coronavirus disease (COVID-19) pandemic. Some mention of the effects of that pandemic has been included (for example, in the sections of chapter 8A dealing with fisheries, shipping and tourism), but the full implications of the pandemic on human interactions with the ocean are still being worked out and will need to be explored fully in the third cycle of the Regular Process. Nevertheless, the ocean and the services that it provides will have an important role in the recovery from the pandemic. It is hoped that the information in the present Assessment will help with that process.

As with the first Assessment, the present document contains no policy analysis or recommendations, in line with the guidance endorsed by the General Assembly. It is therefore for national Governments and competent international authorities to decide what action should be taken in the light of the assessments under the Regular Process.

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Jörn Schmidt
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Chapter 3
Scientific understanding of the ocean

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Keynote points

- Innovations in technology and engineering regarding sensors and autonomous observation platforms have substantially increased observations of the ocean and allowed for those observations to be collected at finer temporal and spatial resolutions.
- The networking and coordination of regional observation programmes has been promoted and has enabled better the coordination and integration of efforts and the standardization and harmonization of observation methods.
- Global disparities in understanding and knowledge gaps at the continental regional level remain, in particular across Africa, Oceania and South America.
- Most observation networks do not incorporate the economic, social and cultural aspects of the ocean and, as a consequence, there is a lack of focused, publicly accessible observations of such aspects in standardized formats at the regional and global levels; such observations may be provided through work on supplemental national accounts.

1. Introduction

In the present chapter, changes related to the scientific basis for understanding the marine environment are described. Evidence-based science is considered to be the basis for understanding all aspects of the world. The natural sciences have been particularly important for the discovery and advancement of understanding of the environment, while social sciences and the humanities are important for understanding values placed on the marine environment and human behaviour in both using and valuing the ocean. Those disciplines, when combined, have been essential to understanding the challenges faced by humanity, from individuals to communities and societies, in achieving sustainable use of the marine environment that preserves those values and ensures that the marine environment is conserved. Interdisciplinary and transdisciplinary approaches are increasingly encouraged in marine sciences, and new funding schemes that support such approaches have been implemented by several international funding bodies, such as BiodivERsA,[1] JPI Oceans[2] and the Belmont Forum,[3] and national agencies, as well as through scientific diplomacy efforts and initiatives.[4,5]

The present chapter provides an overview of the advances in science that underly understanding of the ocean, as well as the changes in scientific capacity since the first *World Ocean Assessment* (United Nations, 2017c). It summarizes new developments in science and progress in relation to scientific capacity and builds upon chapter 3 of the first Assessment, on scientific understanding of ecosystem services (United Nations, 2017a), and chapter 30 of the first Assessment, on marine scientific research (United Nations, 2017b). However, it does not provide an update on the concept of ecosystem services or details of the new concept of nature's contributions to people as outlined in the recent report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)

1 See www.biodiversa.org.
2 See http://jpi-oceans.eu.
3 See www.belmontforum.org.
4 See https://allatlanticocean.org/main.
5 See https://meetings.pices.int.

(Pascual and others, 2017), as they are included in chapter 28 of the present Assessment.

The present chapter also covers more general developments since the first Assessment in relation to specific disciplines and how they have changed understanding of the ocean (see sect. 2). It summarizes key region-specific changes (see sect. 3), outlines changes that can be expected in the coming years (see sect. 4) and provides an overview of existing knowledge gaps (see sect. 5) and capacity-building gaps (see sect. 6).

2. Description of changes in data, technology and models since the first *World Ocean Assessment* and their consequences for overall understanding, including socioeconomic consequences

Following Valdés and others (International Oceanographic Commission (UNESCO-IOC), 2017a), changes and growth in scientific understanding are identified for eight global categories of marine scientific research disciplines, namely: (a) marine ecosystem functions and processes; (b) ocean and climate; (c) ocean crust and marine geohazards; (d) blue growth; (e) ocean health; (f) human health and well-being; (g) ocean technology and engineering; and (h) ocean observations and marine data. Innovations in technology and engineering related to sensors (e.g., Wang and others, 2019) and autonomous observation platforms (Zolich and others, 2019) have allowed for data collection at finer temporal and spatial resolutions and expanded those observations into remote areas (Camus and others, 2019). Cost-effective and user-friendly sensors, along with mobile applications, the enhanced participation of citizens (e.g., Simoniello and others, 2019) and the deployment of sensors on non-scientific ships are also facilitating the expanded collection of ocean observations (Jiang and others, 2019). That has increased understanding of physical and biogeochemical systems in the ocean (e.g., Moore and others, 2019) and benefited further development of capacity in the early warning and prediction of hazards (Luther and others, 2017). Data sets and methods for the accurate assessment of anthropogenic CO_2 emissions and their redistribution in the atmosphere, oceans and terrestrial biosphere have been developed (Le Quéré and others, 2018).

Advances in computing technology and in statistical approaches to analysing large data sets, such as through machine learning and artificial intelligence, have resulted in advances in remote sensing and the utility of ocean data sets, notably in the monitoring and surveillance of fisheries (Toonen and Bush, 2020) and bioinvasion management (Koerich and others, 2020). Advances in genomic approaches to ocean observation, such as through eDNA methods (Ruppert and others, 2019), are advancing understanding of the distribution and composition of species (Canonico and others, 2019) in the ocean and providing greater insights into food webs, trophic linkages and the connectivity of species throughout regions. New frameworks and tools that identify and assess the cumulative effects of multiple pressures on marine ecosystems (Stelzenmüller and others, 2018; see also chap. 25) and allow for the exploration of management options for the sustainable development of human society have been developed (Halpern and others, 2017; Audzijonyte and others, 2019). Projects such as the Seabed 2030 project[6] of

[6] See https://seabed2030.gebco.net.

the Nippon Foundation and the General Bathymetric Chart of the Oceans have been initiated, with ambitious goals to map 100 per cent of the ocean floor by 2030.

To further develop global ocean observations within an integrated system and ensure that ocean data are comparable, the networking and coordination of regional observation programmes has been promoted (Moltmann and others, 2019). Observation methods are being standardized and harmonized through international initiatives such as the Global Climate Observing System essential climate variables initiative (Bojinski and others, 2014) and the Global Ocean Observing System essential ocean variables initiative (Miloslavich and others, 2018). Findable, accessible, interoperable and reusable data services and principles have been proposed for the ocean (Tanhua and others, 2019a), and platforms for sharing best practices in ocean observing, data sharing and community dialogue have also been established (Pearlman and others, 2019), with the aim of improving the effective use of ocean data for the benefit of society.

3. Key region-specific changes and consequences

3.1. Arctic Ocean

The Arctic Council, including the Arctic Monitoring and Assessment Programme and the Conservation of Arctic Flora and Fauna Circumpolar Biodiversity Monitoring Program, regularly publishes reports on the state of the terrestrial, freshwater and marine environment of the Arctic. Recent reports on the state of Arctic biodiversity (Conservation of Arctic Flora and Fauna (CAFF), 2017), ocean acidification (Arctic Monitoring and Assessment Programme (AMAP), 2018) and climate change effects (AMAP, 2019) have provided new information on rapid changes in the Arctic marine environment, including increasing river discharges associated with low ice coverage that have resulted in an increase in carbon and nutrients and, thus, primary production in coastal regions. Such changes in production, as well as in the timing and intensity of marine algae blooms, are having profound impacts on the whole food web. Warming of the Arctic has also resulted in the introduction of 20 species, and changes in the distributional range of 59 others have been confirmed in the Chukchi Sea and the Beaufort Sea in the past 15 years. According to observations, ocean acidification is severely affecting the Arctic food web, including commercial species such as cod (AMAP, 2019). Despite significant changes in the Arctic Ocean, several regions and ecosystem components continue to be understudied and are lacking long-term monitoring (CAFF, 2017).

3.2. North Atlantic Ocean, Baltic Sea, Black Sea, Mediterranean Sea and North Sea

The joint Baltic Sea research and development programme, BONUS,[7] has made significant progress in improving understanding of the Baltic Sea. Some major trend reversals, such as the return of top predators, the recovery of certain fish stocks and the reduced input of nutrients and harmful substances in the Baltic, have been noted recently (Reusch and others, 2018). A spatially explicit end-to-end Atlantis ecosystem model was recently developed for the Baltic Sea with the aim of evaluating the effects of anthropogenic pressures on the

[7] See www.bonusportal.org.

marine ecosystem (Bossier and others, 2018). In the Second Holistic Assessment of the Ecosystem Health of the Baltic Sea, the Helsinki Commission showed that, although there were limited signs of improvement in the state of the Baltic Sea, the goals and ecological objectives of the Baltic Sea Action Plan had not yet been reached. The results of economic and social analyses were also included for themes for which information was available at the subregional level (Helsinki Commission, 2018).

The Commission for the Protection of the Marine Environment of the North-East Atlantic[8] publishes updates from time to time on the status of the marine environment. According to its assessment (Commission for the Protection of the Marine Environment of the North-East Atlantic, 2017), marine protected areas had expanded, and there had been a decrease in contaminants and radioactive discharge, in particular from oil and gas installations. However, eutrophication was still an issue, and an increase in marine litter, especially plastics, was noted. Although the population of some marine mammals, such as the harbour seal (*Phoca vitulina*) and the grey seal (*Halichoerus grypus*), was increasing, the population of others, including the harbour porpoise (*Phocoena phocoena*) and the bottlenose dolphin (*Tursiops truncatus*), was declining. More than a quarter of the marine bird species assessed were declining, and benthic habitats continued to be affected by bottom trawling.

Under the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean,[9] several well-elaborated action plans are being developed that target priority issues for the Mediterranean. They include pollution, the conservation of habitats and species, climate change, integrated coastal zone management and the sustainable use of resources.

Large numbers of local hypoxic "dead zone" vortices in the eastern part of the tropical North Atlantic have recently been discovered. North of 12° north, the vortices bring low-salinity seawater from the upwelling area of the eastern boundary of the North Atlantic to the high seas, while south of 12° north, the eddies appear to be generated in the open ocean (Schütte and others, 2016a). Increased chlorophyll concentrations associated with enhanced oxygen consumption within the eddy cores result in an increase in total oxygen consumption in the open eastern tropical North Atlantic Ocean. That is thought to contribute to the formation of the shallow oxygen minimum zone in the region (Schütte and others, 2016b).

3.3. South Atlantic Ocean and wider Caribbean

Significant progress has been made in the observation, understanding and prediction of multiple coupled climate change effects in the tropical Atlantic, such as continental rainfall, hurricane activity, marine biological productivity, heatwaves, atmospheric circulation with the equatorial Pacific, correlation with and impact on social phenomena, and freshwater input from the Amazon (Foltz and others, 2019; Rodrigues and others, 2019). The Prediction and Research Moored Array in the Tropical Atlantic[10] has been transitioned to the next generation of mooring to expand and enhance its capability for ocean and climate research and forecasting. More in situ observations have been obtained through repeated hydrographic and volunteer ship surveys. There has been a long-term relaxation of upwelling in the coastal regions of Senegal, resulting in diatom blooms. That is expected to result in anoxia and nitrogen loss in the region (Machu and others, 2019). Greater understanding of the cause, movement and ecological impacts

8 See www.ospar.org.
9 See www.unep.org/unepmap.
10 See http://pirata.ccst.inpe.br/en/home.

of sargassum blooms in the Caribbean Sea is required (Wang and Hu, 2017).

Progress has been made on the Coral Reef Early Warning System, in particular through new partnerships, including between the Caribbean Community Climate Change Centre and the National Oceanic and Atmospheric Administration. Under that agreement, the Atlantic Ocean and Meteorological Laboratory, which is partially funded by the Coral Reef Conservation Program, provides consultation and information systems support, including programming of the data-gathering buoy and transmission of the data to the Laboratory.

3.4. Indian Ocean, Arabian Sea, Bay of Bengal, Red Sea, Gulf of Aden and Persian Gulf

Advances in understanding of the Indian Ocean and its ecosystems since the first Assessment are largely due to the second International Indian Ocean Expedition, which has been operational since 2015 and was extended in 2020 for another five years (Hood and others, 2015; Hood and others, 2019). The multinational collaborative effort has observed that the subsurface depletion of oxygen is expanding along the western boundary of the Arabian Sea and has led to a dramatic shift in ecosystems in both the Arabian Sea and the Bay of Bengal (Gomes and others, 2014; Bristow and others, 2017). The expedition has also discovered new submarine canyons and provided enhanced understanding of the benthic habitats of the abyssal nodule field of the central Indian Ocean basin, the western continental margin of the Arabian Sea and the western regions of the Bay of Bengal (Hood and others, 2019). Massive changes in the biogeochemistry and ecosystems of the Persian Gulf resulting from human activities and the first reported measurements of primary production, nitrogen uptake and phytoplankton diversity across biogeochemical provinces in the central oligotrophic Indian Ocean have also been noted as part of the expedition (Hood and others, 2015).

A review of the Indian Ocean Observing System has led to the redesign of the Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction moorings to include new sites in the Arabian Sea and eight additional sites planned for just outside the exclusive economic zone of India. The moorings provide oceanographic and meteorological data in near real time and are directly available to climate and weather prediction centres for climate modelling and weather forecasting (Hermes and others, 2019). Growing numbers of Argo floats with biogeochemical sensors deployed under the system provide insights into key processes associated with plankton blooms and oxygen minimum zones (Hermes and others, 2019).

The Indonesian Throughflow, the leakage of western tropical Pacific water into the south-eastern tropical Indian Ocean through the Indonesian seas, is an important pathway for the transfer of climate signals and their anomalies in the global ocean (Fan and others, 2018; Feng and others, 2017; Iwatani and others, 2018; Lee and others, 2019; Maher and others, 2018; Zhou and others, 2016). A large amount of uncertainty still remains in measuring and modelling the physical and biogeochemical variability within the Indonesian seas.

3.5. North Pacific Ocean

The North Pacific components of the Integrated Ocean Observing System have expanded their capacity in coastal monitoring and started to include social science disciplines. That has led to a better understanding of the mechanism and ecological impacts of the Alaskan heatwave in 2014–2016 (Yang and others, 2019).

Since the first Assessment, the North Pacific Marine Science Organization[11] has enhanced

[11] See https://meetings.pices.int.

its role in coordinating regional observation networks in the North Pacific and serves as the platform for sharing knowledge among scientists and the bridge between science and policymakers. In the period since the first Assessment, it has released two special publications: one on ocean acidification and deoxygenation in the North Pacific Ocean (Christian and Ono, 2019); and another on the effects of marine debris caused by the 2011 tsunami in Japan (Clarke Murray and others, 2019). It has also furthered understanding of climate and ecosystem predictability, drivers of algal and jellyfish blooms, marine ecosystems and the services that they provide, human well-being and top predators (Watanuki and others, 2016; Makino and Perry, 2017; Trainer, 2017; Uye and Brodeur, 2017; Zhang and others, 2015; Jang and Curchitser, 2018). The organization periodically produces a North Pacific ecosystem status report aimed at reviewing and summarizing the status and trends of marine ecosystems in the North Pacific, in which it considers the factors that are causing or are expected to cause change in the near future. The third report, which will contain details of the trends of physical, chemical and biological properties of the North Pacific Ocean throughout the 2010s, is currently being prepared.

Intensive expansion of marine research capability and capacity, including remote sensing and in situ platforms and land-based infrastructure, by China (Chen and Lei, 2019), has enhanced monitoring capacity in waters off South-East Asia. The system has supported progress in regional cooperation in sustainable development and marine and climate research.

3.6. South Pacific Ocean

New understanding of the effects of climate change and ocean warming has helped to identify major hotspots within the South Pacific Ocean, including south-east of Australia, west of the Galapagos Islands, eastern Micronesia and the Drake Passage, where regions are warming at rates above the global average.[12] At the same time, descriptions and understanding of marine heatwaves and their impacts on marine ecosystems have progressed (Oliver and others, 2018; Fordyce and others, 2019). Assessments of coral atolls across the region have revealed no widespread signs of physical destabilization in the face of sea level rise, with land area remaining stable (Duvat, 2018). Observing systems in the region are now collecting time series of a variety of ocean observations, including the physical and chemical environment, biological productivity and marine animals for which trends and changes are being reported.[13]

New regional partnerships among the members of the Permanent Commission for the South Pacific (Chile, Colombia, Ecuador and Peru) have been developed with the aim of monitoring and forecasting oceanographic and climatic variability.[14] In the recent report on the Tropical Pacific Observing System,[15] recommendations were made for a redesigned moored array[16] that could improve observations in the tropical Pacific Ocean.

Every five years, the Government of Australia produces a report on the state of the Australian environment, the most recent of which was issued in 2016 (Clark and Johnston, 2016; Evans and others, 2016; Evans and others, 2018). It was concluded in the marine and coastal thematic reports that the overall state of the Australian coastal and marine environments could be regarded as good. However, the historical

12 See www.marinehotspots.org.
13 See www.imosoceanreport.org.au.
14 See www.met.igp.gob.pe/elnino/enfen.
15 See http://tpos2020.org.
16 See www.pmel.noaa.gov/gtmba/mission.

impacts of a number of pressures, such as commercial and recreational fishing, and ongoing pressures caused by activities that are currently inadequately managed, such as climate change and marine debris, have led to a deterioration in those environments and are continuing to have a negative effect on them. As a result, the outlook for the coastal and marine environment was regarded as mixed and largely depended on the escalating trajectory of climate-related pressures and the ongoing expansion of coastal and marine development.

New Zealand also regularly produces reports on the state of its marine environment; two have been released since the first Assessment, in 2016 and 2019.[17] The most recent report highlighted ongoing issues, including the fact that many species and habitats are under threat, pollution inputs are increasing, as is sediment accumulation of the marine environment, and boat activity and shipping are increasing, resulting in the spread of non-native species and pollution, increased coastal development and unprecedented change in the marine environment associated with climate change. It is worth noting that the report highlighted that the cumulative effect of such pressures was the most urgent problem faced by the ocean.

3.7. Southern Ocean

The Southern Ocean Observing System, a joint initiative of the Scientific Committee on Antarctic Research and the Scientific Committee on Oceanic Research established in 2011, facilitates the collection of essential physical, chemical and biological oceanographic observations in the Southern Ocean. Regional networks of observational activities operating under the framework of the Southern Ocean Observing System facilitate information exchange, technology transfer, the standardization of measurements and data sharing.[18] Tools developed by the system include an open-access interactive web-based platform, which allows users to explore circumpolar data sets and facilitate the exchange of scientific information. A database of upcoming expeditions to the Southern Ocean enables users to discover which expeditions, such as voyages, flights or traverses, are planned to help to facilitate the coordination of field activities (Newman and others, 2019). The system has supported progress in the number of observations collected since the first Assessment, in particular with regard to monitoring increases in ocean temperature (Roemmich and others, 2015), increases in westerly winds over the Antarctic circumpolar current (Gent, 2016) and freshening of the ocean, most notably close to the continent (Schmidtko and others, 2014). Deployment of biochemical sensors has increased measurements of chlorophyll *a*, nitrate, oxygen, light, optical properties and pH throughout the Southern Ocean (Newman and others, 2019). Ice-capable bio-Argo floats are now collecting information on biogeochemical cycles during ice-covered periods (Briggs and others, 2017), and gliders are adding to the collection of ocean observations (Newman and others, 2019). As ecosystems are changing, variable effects on marine predators have been observed; some populations of the Adélie penguin (*Pygoscelis adeliae*) and the chinstrap penguin (*Pygoscelis antarcticus*) have declined, while some populations of the gentoo penguin (*Pygoscelis papua*) have increased (Trivelpiece and others, 2011; Hinke and others, 2017; see also chap. 7K). Long-term monitoring of marine species, including penguins and seals, continues to be undertaken through the Convention on the Conservation of Antarctic Marine Living Resources as part of the management of krill fisheries and is increasing understanding of their foraging behaviour and demographics (Newman and others, 2019).

17 See www. mfe.govt.nz.
18 See http://soos.aq/activities/cwg/soflux.

4. Outlook for scientific understanding of the ocean

Further scientific research will help in assessing the achievement of targets under Sustainable Development Goal 14, especially during the United Nations Decade of Ocean Science for Sustainable Development.[19] As part of the Decade, innovative approaches to science, involving many disciplines and many sectors of society, are recognized as being necessary to achieve the 2030 Agenda for Sustainable Development. With regard to ocean and coastal observation in general, the OceanObs'19 Conference[20] has put forward a series of recommendations that are focused, inter alia, on sustaining ocean observations; connecting with users and stakeholders; identifying the benefits to society of observations; further developing indicators for the ocean; and fostering trans-disciplinary approaches to research. Work has begun on road maps to further the development of a global ocean observing system that includes and integrates abiotic and biotic observations and goes beyond traditional observation technologies (Speich and others, 2019). Together with advances in computing technology and analytical methods, the outputs of eDNA studies will help in the analysis of biodiversity observations, with a resulting improvement in the input of information into ecosystem models and their use in ecosystem-based management.

The International Convention for the Control and Management of Ships' Ballast Water and Sediments entered into force in 2017.[21] It is aimed at preventing the spread of harmful aquatic organisms from one region to another by establishing standards and procedures for the management and control of ships' ballast water and sediments. Further scientific work is needed to generate the required evidence and knowledge, including on the basis of observations and technology development, to assist managers and stakeholders, including government authorities, in implementing the Convention.

5. Key remaining knowledge gaps

The near-future scientific challenges are related to topics such as understanding and anticipating El Niño Southern Oscillation events and marine ecosystem tipping points, quantifying the cumulative effects of multiple pressures on marine environments, developing adaptive management approaches and making them more operational, and encouraging broader consideration and integration of local, traditional and indigenous knowledge in marine ecosystem assessment and management.

Global disparities in understanding and knowledge gaps at the continental regional level remain. The bulk of the research and the information readily available (based on the number of publications) relates to the North Atlantic Ocean, the North Pacific Ocean and the Arctic Ocean. For other areas, in particular Africa, Oceania and South America (UNESCO-IOC, 2017b), there is less information available.

Timely dissemination of collected measurements is very important for the effective usage

[19] See General Assembly resolution 72/73; see also www.oceandecade.org.
[20] See www.oceanobs19.net/sessions.
[21] International Maritime Organization, document BWM/CONF/36, annex; see also www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Control-and-Management-of-Ships'-Ballast-Water-and-Sediments-(BWM).aspx.

of data in today's connected ocean prediction and monitoring systems. That aspect of making data available and the software for quality control are essential to making the best use of ocean observations.

Currently, most global observation networks do not incorporate economic, social and cultural aspects of the ocean and, as a consequence, focused, sustained and publicly accessible observations of those aspects of marine systems in standardized formats at the regional and global levels are lacking (Evans and others, 2019). The compilation of economic, social and cultural information in useable formats for inclusion in an assessment framework for synthesis on a global scale requires considerable effort, often beyond the ability of those individuals or groups of individuals involved in contributing to present Assessment. It is an area in which an extension of current observation frameworks to incorporate sustained and standardized monitoring of economic, social and cultural aspects of the ocean would significantly improve assessments undertaken in the framework of the Assessment (Evans and others, 2019). IPBES has made clear the need to increase capacity not only to monitor biodiversity but also to understand its functions and the effect that human activities, including climate change, have on biodiversity (IPBES, 2019). One of the aims of the variables being developed under the Global Ocean Observing System is to expand observations of pressures placed on marine ecosystems by human activities to include ocean noise and marine debris, including plastics. The outputs of the Assessment could assist in guiding the process for identifying such variables and, in so doing, could provide a mutual pathway for further improvements to the observations that contribute to future assessments.

6. Key remaining capacity-building gaps

Advances in global understanding of scientific knowledge depend on uniformity in efforts to engage in research globally across the continental regions. The uniformity of research efforts globally further depends on how advanced infrastructure, specialized scientific human capacity and technology are distributed and shared through partnerships. Many natural science disciplines, such as physical, chemical and biological oceanography and marine geology, require research vessels or other specialized equipment and upgraded modern technology and the support of land-based laboratories equipped with modern equipment to support research surveys in the entire depth range of the global ocean. Further support needs to be provided through the use of satellites for remote-sensing studies of the ocean. Innovation for cost-effective in situ observation tools and methods is also needed.

Currently, the level of scientific understanding is regionally skewed because of disparities in the capacities of regional infrastructure and in specialized professional human capacity. Such disparities, therefore, affect possibilities for engaging in competitive ocean research and, in turn, lead to the observed disparities in scientific understanding of oceans at the regional level.

For improving the forecast capacities for the El Niño Southern Oscillation and other ocean-climatic variations, ocean observing systems need to be strengthened and partnerships with regional countries promoted in order to enhance local capacities.[22] In order to monitor

[22] See http://soos.aq/activities/cwg/soflux.

the significant changes in physical and biogeochemical environments and their impacts on ecosystems and society, further integration of multidisciplinary observations and a reduction in the uncertainty of prediction models are needed. Innovation in funding strategies is also required to sustain integrated observing systems.

The ocean science community has proposed action plans for the coming decade (Speich and others, 2019), which include efforts to increase the efficiency of the ocean information value chain (Tanhua and others, 2019b). To maximize the value of ocean data for societal use, the interface of each service, scientific observation, data assembly and management and policy should be smoothly streamlined. For example, the integration of observing systems and findable, accessible, interoperable and reusable data principals must be implemented in a harmonized manner. The aim of the present Assessment is to enable scientific knowledge to be conveyed as information that is usable and understandable for non-academic users and thus can serve as an important link in the ocean data value chain.

Local, traditional and indigenous knowledge needs to be further integrated, and concepts relating to facilitating collaboration to provide opportunities for recognizing synergies and for sharing and exchanging information (Wright and others, 2019) need to become best practices.

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