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Oceans and the law of the sea

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Report of the Secretary-General**

Summary

In paragraph 356 of its resolution 76/72, the General Assembly decided that the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea would focus its discussions at its twenty-second meeting on the theme "Ocean observing". The present report was prepared pursuant to paragraph 371 of that resolution with a view to facilitating discussions on the topic of focus. It is being submitted to the Assembly for consideration at its seventy-seventh session and to the States parties to the United Nations Convention on the Law of the Sea, pursuant to article 319 of the Convention.

* A/77/50.

** Owing to word limits for reports mandated by the General Assembly, references for the material contained in the present report are to be found in the advance, unedited version, which includes comprehensive footnotes and is available on the website of the Division for Ocean Affairs and the Law of the Sea (www.un.org/depts/los/consultative_process/consultative_process.htm).

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I. Introduction

1. Human health and well-being are intrinsically linked to the health of our ocean. The ocean regulates our climate, provides food security and livelihoods for billions of people, and underlies several economic sectors. It is, however, also under threat from cumulative human pressures, including from the impacts of climate change, pollution of the marine environment and destruction of marine habitats and biodiversity loss.

2. An integrated, science-based approach to the management of human activities in coastal and open ocean areas is needed to ensure that the ocean can continue providing the necessary ecosystem services that sustain life on Earth. Ocean-related data and information are crucial to understanding ocean processes and ecosystem functioning and to making informed decisions about human activities in the light of the present and estimated future state of the ocean. In particular, such data are essential for protecting and conserving marine ecosystems and their resources; understanding and forecasting weather patterns and predicting multi-hazard events; understanding the climate cycle and modelling future changes; managing human activities underpinning key economic sectors; and ensuring safety at sea. Data are also essential in evaluating progress towards meeting global sustainable development targets.

3. Data related to a vast array of ocean variables are currently collected through an extensive network of in situ and remote observational systems. However, despite significant progress in recent decades, challenges remain in meeting the increasing societal demands for ocean observation data and information across sectors, including due to gaps in observational data and difficulties in access, sharing and use thereof. Nonetheless, progress is being made and can be made in addressing those challenges. This is especially so at the present juncture, when there is a global impetus to improve the state of ocean science within the framework of the United Nations Decade of Ocean Science for Sustainable Development (2021–2030),[1] and in view of the upcoming 2022 United Nations Conference to Support the Implementation of Sustainable Development Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development, under the overarching theme "Scaling up ocean action based on science and innovation for the implementation of Goal 14: stocktaking, partnerships and solutions".[2]

4. The global recognition afforded to the importance of ocean observations in underpinning marine science and contributing to informed decision-making for sustainable development is also reflected in the decision of the General Assembly, in paragraph 356 of its resolution 76/72, that the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea would focus its discussions at its twenty-second meeting on the theme "Ocean observing".

5. To facilitate discussions of the Informal Consultative Process, the present report provides an overview of current tools and frameworks for ocean observation, types of data collected, and the existing and potential contributions of such data to science-based decision-making in support of sustainable development. It also outlines challenges in ocean observation, and opportunities to expand and strengthen the global ocean observation network through international cooperation and coordination. The report draws upon the contributions submitted by States and relevant organizations and bodies at the invitation of the Secretary-General,[3] as well

[1] Proclaimed in paragraph 292 of resolution 72/73.

[2] Convened pursuant to resolution 73/292, postponed by decision 74/548, and new dates decided by decision 75/578.

[3] The full text of the contributions is available on the website of the Division for Ocean Affairs and the Law of the Sea (www.un.org/depts/los/consultative_process/consultative_process.htm).

as upon other reports and studies related to the theme. Certain contributions showed differences in opinion, in respect of ocean observing, regarding the applicability of the provisions of the United Nations Convention on the Law of the Sea on marine scientific research. Potential impacts of such differences on the collection of data have been highlighted. The issues of a legal nature are, however, beyond the purview of the present report.

II. Ocean observation tools and their contributions to science-based decision-making

A. Tools and frameworks for ocean observation

6. Understanding ocean processes and ecosystem functioning requires tools for the collection of ocean observation data and information from various locations and for long-term monitoring. Existing ocean observation tools comprise both in situ and remote instrumentation. Examples of the former include moored and drifting buoys, sea level gauges, Argo profiling floats, autonomous underwater vehicles and gliders, animal-borne sensors, and ship-based instrumentation on research vessels and other ships, while the latter include satellites and remote sensing aircraft.

7. With regard to buoys, the Data Buoy Cooperation Panel, established in 1985 as a joint body of the World Meteorological Organization (WMO) and the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (IOC-UNESCO), manages around 1,500 drifting and 400 moored buoys, which measure variables including sea surface temperature, surface current velocity, air temperature, and wind speed and direction. For sea level gauges, a network of 290 sea level observing stations globally provide data relating to sea level. In respect of profiling floats, the Array for Real-time Geostrophic Oceanography (Argo) is a global network of around 4,000 such floats. The floats move between the surface and lower ocean depths while drifting with ocean currents and are used to sample temperature, salinity and other chemical properties.

8. Autonomous underwater vehicles, including gliders, provide opportunities to collect ocean observation data in remote areas that are difficult for other observation platforms to access, including in deep waters and under ice. Such vehicles have been used to conduct various measurements, including geochemical and oceanographic measurements, and to engage in seafloor mapping. A network of around 200 gliders transects key oceanic features and collects information on a range of variables. Animal-borne ocean sensors have been in use to collect essential ocean observations since 2004. Animal-borne sensors consist of a network of sensors deployed on marine mammals which provide measurements of temperature and salinity as well as behavioural data. These are used to collect data in regions that tend to be undersampled.

9. Ship-based measurements can be conducted by specialized research vessels but also include marine meteorological measurements conducted by voluntary observing ships, oceanographic measurements through the Ship of Opportunity Programme, including measurements of temperature, salinity and the partial pressure of carbon dioxide, and aerological measurements of upper-air profile data by voluntary ships. Despite technological advancements and the increasing use of other tools, observations from such vessels, together with dedicated research vessels, remain essential parts of the ocean observing system.

10. Certain variables can be measured, at current levels of technological development, only through in situ platforms, and such platforms also have the advantage of being able to calibrate other data and withstand certain weather

conditions. At the same time, data collection can be technically and logistically challenging and comes with limitations in terms of spatial coverage.

11. While in situ elements constitute the bulk of the ocean observing system, remote collection of oceanographic data has been made possible by using sensors on satellites and aircraft. Satellites gather complementary data on fundamental variables such as ocean surface temperature and salinity, sea surface height and sea level, winds, ice coverage and ocean colour. Numerous satellites support ocean observing.

12. Aircraft equipped with sensors, including helicopters, balloons, gliders and unmanned aerial vehicles, may also be used for collecting oceanographic information, including with respect to ocean colour, sea surface temperature and salinity, and near-shore topography. Aircraft remote sensing offers operational flexibility and, operating at lower altitudes, can provide better spatial resolution than orbital platforms. However, there are also disadvantages to the use of such tools, including limited spatial coverage, expense and weather restrictions.

13. These in situ and remote sensing instruments operate under frameworks for ocean observation. At the global level, the Global Ocean Observing System was established in 1991 to coordinate sustained ocean observing activities worldwide and to support the delivery of harmonized information to decision makers, especially relating to climate change, hazard warnings and weather prediction, management of marine resources, and marine transport. The System creates partnerships with and supports various stakeholders from the ocean observing network, including Governments, agencies of the United Nations system, international and regional organizations, academic institutions and scientists. It is a collaborative platform that aims to develop an integrated and sustained observing system that responds to user needs. Led by IOC-UNESCO and co-sponsored by WMO, the United Nations Environment Programme (UNEP) and the International Science Council, the System manages 12 global ocean observing networks, 12 additional biologically focused networks and 15 regional alliances, with active contributions from 84 countries.

14. The three key delivery areas of the Global Ocean Observing System are climate, weather and ocean prediction, and ocean health. Three expert Global Ocean Observing System panels have identified essential ocean variables, which are ocean observations that provide vital information across issues and platforms and are relevant, cost-effective and feasible to obtain. The panels also create and share recommendations on measurement, observing options and data management. Essential ocean variables cover physical (e.g. salinity, temperature), biochemical (e.g. dissolved organic carbon, oxygen), biological (e.g. plankton, seagrass and mangrove cover) and cross-disciplinary (ocean colour, sound) variables. Around 8,900 in situ observing platforms currently support the System and provide information on these variables.

15. At the regional level, the Global Ocean Observing System regional alliances support and coordinate implementation to address regional priorities, which differ according to needs, resources and culture. The regional alliances comprise governmental and non-governmental efforts coming together to complement the collective advancement of the System and both contribute to and benefit from efforts at the global level. The alliances have been active in coastal and open sea observation, employing, among other tools, high-frequency radar networks, ocean gliders and animal tagging programmes to meet societal challenges.

16. National ocean observation programmes and infrastructure, including both within and outside the framework of the regional alliances, have also been developed. Contributions to the present report highlighted, for instance, investments in observation facilities and networks, including through marine monitoring and sampling activities, satellite remote sensing, and research expeditions, as well as

investments in laboratories, operation support capabilities, analysis and modelling. Contributions also highlighted the establishment of national centres to collect oceanographic data and cooperate with other States and international organizations. In Europe, the European Marine Observation and Data Network was established to aggregate, process and make available marine data from in situ observations within Member States. The Copernicus programme of the European Union utilizes satellite technology to monitor ocean physics and biogeochemistry variables. The Global Ocean Observing System also receives contributions from national entities, such as the Système d'observation du niveau des eaux littorales, which is an integrated sea level monitoring system aggregating data from different observation networks and serves as the global navigation satellite system data assembly centre for the Global Sea Level Observing System, the global programme for overseeing and coordinating sea level networks.

B. Contributions to science-based decision-making for sustainable development

17. Ocean observation systems capture a multitude of ocean-related data that contribute to science-based decision-making for sustainable development, serve various stakeholders and provide relevant information for the benefit of society.

18. In particular, ocean observation data, including data from in situ instruments such as tide gauges, buoys and Argo floats, are essential to understanding climate change and to potential mitigation and adaptation actions. These data are used to monitor changes in the climate system and the role of the ocean in such changes and have contributed to the development of climate models necessary to understand future scenarios. At the intergovernmental level, this informs assessments and stocktakes and supports global decision-making. Evidence of ocean warming collected by the global Argo float array was, for instance, key in building the evidence base that led to the adoption of the Paris Agreement in 2015.

19. Ocean observation also supports regional and national decision-making with regard to mitigation of and adaptation to climate change. Contributions highlighted, for instance, research into geophysical oceanography, research into and participation in studies on ocean acidification and deoxygenation, and existing and planned coral reef ecological monitoring. In situ and satellite networks provide real-time ocean monitoring and data that are essential for weather forecasting and the operation of early warning systems for extreme weather events, such as tsunamis, hurricanes and storm surges, which have an impact on safety, property and the economy and are becoming more frequent as global warming heightens. A notable example of regional observation is the Indian Ocean Observing System, which consists of five in situ networks and plays an important role in providing oceanographic and marine meteorological measurements of the Indian Ocean, including sea level, salinity and sea surface temperature. Rapid warming of the Indian Ocean is affecting the weather and seasonal patterns in the countries of the region and may also affect the marine ecosystems and fisheries on which they depend. The System collects the data necessary for supporting, among other things, weather prediction, climate forecasting and fisheries management. In the Pacific, responding to the existential threat posed by rising sea levels, the Pacific Community maintains and operates a series of tide gauges in Pacific island countries and has developed the Digital Earth Pacific, an open-access operational Earth observation system, to assist in monitoring the impacts of sea level rise on countries and communities in the region, while also maintaining buoys for use in coastal inundation early warning systems. At the national level, countries have developed ocean observing capacity to measure key parameters, including sea level, undertake oceanographic and meteorological observations and enhance weather forecasting.

20. Ocean observation data also play a key role in the protection and preservation of the marine environment. For States, ocean observation data provide the scientific basis for the development of regulations for that purpose, as well as a means of monitoring the effectiveness of measures. More particularly, ocean observation tools are, for instance, used in the monitoring of ecosystems, including with regard to degradation of marine habitats and biodiversity loss. The biological oceanography research group of the Islamic Republic of Iran studies, for instance, factors endangering marine life and how best to protect it. Ocean observing also has an important role to play in monitoring the existence and impacts of millions of tons of marine litter and plastic pollution threatening human health and marine species. At present, 15 major operational monitoring programmes cover both macroplastics and microplastics, together with indicator processes and baseline data collection activities supported by various networks and processes. Ocean observation data are also used in monitoring oil spills and clean-up responses, in monitoring regarding the protection of the environment from the marine and atmospheric impacts of shipping operations, in providing information to facilitate the description of ecologically or biologically significant areas, for informing efforts to implement the post-2020 global biodiversity framework, and in assessing the effectiveness of those efforts and progress towards achieving the various goals and targets under that framework.

21. Ocean observation is important in supporting planning for the blue economy, in both emerging and established sectors. For example, the capture fisheries and aquaculture sectors utilize relevant information, such as that relating to oceanic primary production, variables influencing fish location, and the activities of vessels engaged in illegal, unreported and unregulated fishing, in supporting the implementation of sustainable practices. At the regional and national levels, for instance, the European Union and its member States use ocean observation data to support fisheries management and action under the Common Fisheries Policy, the Pacific Community has established a tuna tagging programme which provides information on tuna migration patterns and life cycles, and Togo has built marine stations along its coastlines to, inter alia, support fishery activities.

22. With regard to other sectors of the blue economy, ocean observation data are critical for shipping, in terms of routing and safety of navigation, and support integrated coastal zone management, the management of coastal harbours and ports, tourism, the development of marine renewable energy, including wind energy, and exploration for, and the exploitation of, non-living resources.

23. Finally, outputs from the ocean observing system also assist intergovernmental processes such as the Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects, including by informing priority areas for monitoring. The *World Ocean Assessments*, as the output of the Regular Process, can in turn serve as a vehicle for synthesizing and distributing data products resulting from ocean observation for policymaking in strengthening the science-policy interface. Ocean observation data flowing from observing networks also support assessments of progress towards the achievement of the Sustainable Development Goals, the United Nations Decade of Ocean Science for Sustainable Development and the United Nations Decade on Ecosystem Restoration, and other international frameworks relating to climate change, disaster risk reduction and biodiversity.

III. Challenges in ocean observation

24. Because of the important role played by ocean observation data in various fields, societal demand for such data is on the rise. At present, however, there are challenges

facing the existing framework, both observational and structural: the former include gaps in spatial coverage, in terms of capabilities to collect data in various regions and the measurement of particular categories of variables; the latter include capacity gaps regarding participation, infrastructure and engagement with users. The volume and variety of data collected also pose challenges to ensuring that data are findable, accessible, interoperable and reusable, while other challenges concern the effectiveness of data value chains, from the point of collection to science-based decision-making. More attention should also be paid to the potential impacts of ocean observation activities on the ocean, particularly as ocean observation capacity grows.

A. Gap filling and expanding measurement capabilities

25. While technological and engineering-related innovations and enhanced participation have reduced costs and facilitated more expansive collection of ocean observation data on both a quantitative and a qualitative level, concerns persist that current global ocean observations are insufficient to provide the necessary understanding of the ocean and current threats to its health. Gaps exist in the coverage of data relating to various ocean conditions and variables, including those necessary to understand climate change and the cumulative impact of human activities. More specifically, limitations have been noted, for instance with regard to the adequacy of data relating to sea state and waves, ocean circulation and boundary currents, sea surface temperature and pressure, surface wind vectors, surface heat flux, sea surface height anomalies, certain chemical concentrations, salinity changes, ocean acidification, sea ice, ecosystem health and quality, plankton abundance and diversity, stocks of marine species, deoxygenation, surface visibility and ocean colour, and for prediction and early warning systems for marine disasters, including extreme weather events, earthquakes, volcanic events and tsunamis. Data on ocean-related biology, ecosystem and biogeochemistry components are particularly lacking, including on marine life and biodiversity, as are data on marine debris, the ocean's carbon storage capacity and the ocean's economic, social and cultural aspects. More generally, the quantity and complexity of data collected vis-à-vis key variables differ, and concerns have been raised regarding the accuracy and frequency of certain measurements, as well as their temporal and spatial extent and resolution.

26. Gaps in global spatial coverage represent a key challenge, with data for significant parts of the ocean either limited or entirely absent. Gaps can arise in spatial coverage as a result of either an overall insufficiency in observational instrumentation or geographical disparities. Observations are particularly limited in regions where States lack capacity to develop or maintain observing systems. In addition, the harsh environment and limited accessibility in the polar regions make in situ observation difficult, resulting in quantitative limitations in measurement. Gaps have also been observed in the Southern Ocean, the south-eastern Pacific Ocean and some regional basins. Spatial coverage gaps can also arise from a failure to sustain data collection and management after projects have ended.

27. Limitations also exist vis-à-vis remote areas of the open ocean, notably the mesopelagic and deeper zones, including regions below 2,000 m, and deep-sea ecosystems. Much of the seafloor, including along the African and South American margins, has not, for example, been subject to biological surveys. Some coastal regions also remain undermeasured, with many observation programmes limited to the high seas and exclusive economic zones.

28. Addressing these observational gaps and meeting demands with data that are fit for purpose will require not only sufficient sustained investment in the existing global ocean observational system but also its expansion. There is a need for investment in more observational equipment and the incorporation of new technologies, the

development of deepwater sampling platforms, increased capacity to measure and utilize additional variables, and the incorporation of economic, social and cultural aspects into collection practices.

29. However, ocean observation requires human resources, laboratories, field stations, institutions, and platforms, equipment and tools for observation. Equipment is expensive to purchase and maintain, particularly in the long term, and with decreased reliance on academic and commercial resources, maintenance and deployment costs in remote areas have increased. A decreasing number of global and ocean-class research vessels is also negatively affecting global sampling and data collection in undersampled regions, such as polar regions. Changes in the number and location of shipping routes are posing challenges for underway observations and for collecting observations from voluntary observing ships. The coronavirus disease (COVID-19) pandemic has only exacerbated difficulties in data collection and equipment maintenance. Vandalism and damage to ocean data buoys are also of concern and increase maintenance costs.

30. Capacity gaps pose a particular challenge, including by preventing interested parties from joining and contributing to regional and global ocean observation initiatives. Many developing countries, in particular the least developed countries and small island developing States, lack capacity to effectively conduct ocean observations, which further impedes the expansion of the ocean observing network. These capacity gaps relate both to in-country human resources and to the financial resources necessary for instrumentation purchase, maintenance, deployment and recovery. Near real-time data collection reliant on Internet transmission can be difficult owing to limited connectivity or low bandwidth. Such capacity gaps contribute to an overall gap in observations, particularly surrounding small island developing States and coastal States vulnerable to ocean change. More broadly, there is a lack of long-term investment in developing and sustaining the expert workforce required for ocean observation. Given the importance of the participation of women in ocean observation, concerns have been raised regarding a lack of gender equality in ocean sciences.

B. Data findability, accessibility, interoperability and reusability and data value chains

31. Ocean observing generates value and impacts for society through a data value chain, supported by data management that enables unprecedented amounts of data from many sources to be discovered, combined and used. However, effective data management relies on ocean observation data being findable, accessible, interoperable and reusable (the “FAIR” principles). Notwithstanding the progress being made in this respect, significant challenges remain.

32. First, some ocean observation data are not easily findable. This is due, among other things, to data being collected and stored in siloed platforms and databases, data not being described with rich metadata, metadata held at different data centres not being connected to metadata aggregators or federations, and persistent identifiers lacking from metadata records. In addition, capacity gaps exist for finding existing data, including due to a lack of training and tools.

33. Second, while the importance of accessibility is increasingly recognized, open access to ocean observation data is still not the norm. States have reported that 60 per cent of data centres restrict access to “certain” data types, 58 per cent of those for a period of time, and only 16 per cent of data centres apply no restrictions on access. Furthermore, cultural, social, political and practical factors limit the accessibility of significant amounts of ocean observation data, including the perception that such data

are confidential, sensitive or of commercial value, access charges, or a lack of capacity or tools to access or share available data sets. A large amount of the ocean observation data, including those collected by individual scientists, students and the private sector, are never shared. Indeed, systematic sharing of collected data is lacking in specific regions. Other challenges relating to data accessibility include ensuring that data collected by different countries are made available in an open and timely manner; ensuring that ocean observation data can be accessed by relevant stakeholders, including by connecting ocean observers and the communities that they serve; ensuring user-friendly data-sharing platforms and processes; and guaranteeing safe and long-term storage of ocean observation data and metadata to allow access for future generations.

34. Third, challenges remain in ensuring that ocean observation data from multiple sources are compatible and interoperable, which is essential to their effective sharing and use. Developing and adopting common standards for data and metadata require time, as well as coordination and testing. Where standards, formats, applicable vocabularies and classifications do exist, and despite the increasing calls for their usage and for data and metadata to be shared through robust databases using interoperable data delivery systems, their implementation may be beyond the capabilities of scientific communities. Efforts are also necessary to address the lack of harmonization of reporting procedures and the need for standardized information systems for data collection, validation, monitoring and reporting at the national, regional and global levels. There is a particular need to improve data interoperability in relation to ocean model forecast products.

35. Fourth, the reusability of ocean observation data beyond its original purpose continues to be affected by the lack of clear data licensing policies, and the lack of rich contextual metadata in some cases. The development and application of domain-relevant community standards will also allow for easier reuse of such data within various science communities.

36. Data findability, accessibility, interoperability and reusability (data “FAIR-ness”) are particularly underdeveloped in certain domains, including in relation to biological and ecological observations, on which the development of ecosystem models at operational scales depends, despite the urgent need for findable, accessible, interoperable and reusable data. This is partially linked to biological observations being more fragmented. It is critical to encourage open and extensive international cooperation in this respect, focusing on structuring the collection, harmonization and sharing of biological information, including by leveraging multidisciplinary and multisectoral partnerships and integrating biology with physical and biogeochemical data.

37. To maximize the value of ocean observation data in support of sustainable development of the ocean and marine resources, besides achieving data findability, accessibility, interoperability and reusability, it is also important to address challenges facing the different stages of the ocean observation data value chain, from collection to science-based decision-making. The increasing diversity of ocean observations, driven by the growing demand for ocean observation data and tendency for new programmes to fill only specific gaps in measurement or coverage, can lead to a lack of coordinated focus on priorities and to challenges in accessing, sharing and using data. Therefore, there is a need to invest in an integrated and responsive ocean observing framework to serve a variety of users, rather than creating different systems to meet different challenges facing the ocean. This requires focusing on how ocean observation systems can be used in a cross- and transdisciplinary way, thereby ensuring multiple effective uses. In this regard, challenges in integrating observations between disciplines over local, regional and global scales are noted.

38. Integrating ocean observation systems also requires strengthened engagement with multiple partners and stakeholders from different communities, sectors and disciplines across the ocean observation data value chain. A strong connection between data collectors, data managers and scientific experts is needed for assembling both data and metadata. Co-designing through engagement with increasingly diversified users of ocean observation data, including in end-to-end initiatives and at the level of intermediate users or downstream service providers, is essential to ensuring that ocean observations are sustainably implemented and useful to users. The incorporation of indigenous peoples and local communities into such processes is central, given their contribution to ocean observing activities and their region-specific knowledge that assists in understanding the ocean and its importance to communities. The inclusion of data from a wider variety of sources needs to be further enhanced, including from the private sector, from the knowledge systems of indigenous peoples and local communities, and from citizen science. To this end, relevant stakeholders need to be empowered to better contribute and share more valuable observations and to utilize data for their specific needs, including through capacity-building and the transfer of marine technology, in particular for the least developed countries and small island developing States. Backing and expertise from the private sector, which is both a major data user and an increasingly important contributor to ocean observation, are particularly needed, including fostering the sector's collaboration with the regional ocean observing community.

39. To bridge the gap between raw ocean observation data and the information required for sustainable development, ocean observation data need to be combined, using science-based and integrated approaches, including through various data synthesis and modelling efforts. This is computationally demanding and affected by capacity constraints. The storage, management and use of "big data" require new strategies, procedures, workflows and technologies, including cloud computing and artificial intelligence. Challenges also lie in compiling, synthesizing and analysing output data and information from multiple sources, the use of coupled data assimilation and other emerging assimilation approaches, and improving connectedness between observing systems and numerical models.

40. Furthermore, as an important link in the ocean observation data value chain, it is critical to ensure that ocean observation data, analysis and products are translated into useful information and communicated adequately to decision makers and the general public, including through integrated assessments and the integration of ocean observational data and instruments into more educational and outreach activities. Efforts are needed, in this regard, to develop tools to assess the cumulative impacts of multiple anthropogenic pressures and to promote the use of other tools, such as ocean accounting, which provides integrated records of ocean-related environmental, economic and social data.

C. Managing interactions with the environment and with other uses of the ocean

41. Despite the limited research in this area, it is important to note, particularly as global ocean observation networks expand, that in situ ocean observation methods may have negative impacts on the marine environment in which they operate, and on the environment more generally.

42. Certain concerns relate to the release of pollution. For instance, the more than 4,000 existing Argo floats release a few milligrams of tributyltin oxide into the water column during each 10-day profile to prevent biological fouling of salinity sensors. While tributyltin oxide has been found to cause severe adverse effects on some marine

species, it has nonetheless been noted that the amounts used in the Argo array are a small percentage of the estimated total amounts of tributyltin oxide being used as a biocide in paint for ship hulls.

43. In addition, since it is considered economically prohibitive to recover certain equipment such as Argo floats, these are left to break down and fall to the ocean floor, releasing small quantities of potentially toxic materials. In the case of Argo floats, this includes tributyltin oxide, copper, zinc, lithium and lead, as well as plastic float components. Similar end-of-life environmental impacts might be expected from the approximately 1,500 drifting buoys, operating as part of the Data Buoy Cooperation Panel, which are not usually recovered, although published data on their impact are not readily available.

44. While dedicated research vessels, which are the main alternatives to floats and buoys, are not left in the ocean, they must also be scrapped on land and suffer from large carbon footprints, with a typical research vessel releasing roughly 75,000 kg of carbon dioxide per day. Carbon dioxide emissions from floats tend to be small in comparison, since they operate on batteries and most are deployed by ships of opportunity already engaged in other missions.

45. Other concerns relate to impacts of ocean observation on marine species. For instance, sonar and vessel propulsion, which can be used in ocean observation, are some of the main causes of ocean noise. The introduction of anthropogenic sound into the marine environment may interfere with the use of sound by marine species for various functions, resulting in effects ranging from mild or significant behavioural responses to physical injury or death. However, while some research has been conducted on potential disturbances to animals caused by visual and acoustic stimuli from ocean observation methods, more is needed. Floats may also interact with marine species, although such interaction tends to be limited in modern times.

46. With regard to the use of animal-borne sensors, under the Animal Borne Ocean Sensors network, an emerging network of the Global Ocean Observing System, an Ethical Advisory Board provides oversight on the use and welfare of animals. However, the likely expansion in the use of animal-borne sensors, including to new species, as well as developments in new sensors, will warrant further research into the effects of capture, handling and attachment methods on animal behaviour and vital rates.

47. Other than ocean observing buoys being caught on fishing nets and lines, little has been reported on interactions between ocean observation systems and other uses of the ocean. However, as observations systems expand, such interactions may arise in the future.

IV. Opportunities to expand and strengthen the global ocean observation framework

A. Cooperation, coordination and collaboration at all levels

48. Ocean observation is a shared undertaking from which all countries, including landlocked countries, benefit, and whose impact depends on effective cooperation, coordination and collaboration at all levels. Cooperation and coordination are critical throughout the ocean observing process, from planning, research, maintenance and data collection to data analysis, sharing and distribution and the development and sharing of best practices. Contributions to the present report highlighted many issues in respect of which enhanced cooperation and coordination could strengthen the value of ocean observation.

49. As noted in section II, the primary platform for enabling coordination and collaboration at the global level is the Global Ocean Observing System, which creates and supports the frameworks and infrastructure that coordinate ocean observing activities globally. The System and its Framework for Ocean Observing, adopted in 2012, encourage voluntary collaboration across the ocean observation community, seeking to address the increase in ocean observing activities worldwide and differing degrees of responsibility, coordination and data-sharing. The Framework has, notably, been the bedrock for designing regional and basin-wide ocean observing systems, including the All-Atlantic Ocean Observing System and the Tropical Pacific Observing System.

50. Building on the Framework for Ocean Observing, the Global Ocean Observing System 2030 Strategy is aimed at building a fully integrated ocean observing system through, among other objectives, deepening engagement and partnership from the collection of observations to end users. Other regional and global observing networks, such as the WMO Integrated Global Observing System, the European Marine Observation and Data Network, the Global Ocean Acidification Observing Network, the Joint WMO-IOC Collaborative Board, and the UNEP Global Environment Monitoring System for the Ocean and Coasts Programme, also employ a collaborative partnership approach that includes global, regional and national observing systems, data providers, civil society and knowledge asset holders in order to optimize resources, avoid duplication and meet the needs of a wide range of users.

51. At the regional level, it is reported in the second *World Ocean Assessment* that, since 2015, improved networking and coordination of regional observation programmes have enabled better integration of efforts as well as the standardization and harmonization of observation methods. However, as noted in section III, ocean observing capacity at the regional level remains uneven, presenting opportunities to improve technological capacity and infrastructure and to reduce differences among the Global Ocean Observing System regional alliances in terms of governance, scope, attitudes to data-sharing, and maturity of activity. Possibilities also exist for expanding geographic coverage by increasing the number of countries and partners actively participating to create a wider alliance of contributors.

52. At the national level, there are opportunities to formalize the coordination of ocean observing through national focal points or ocean committees, as well as to establish permanent national organizations involving both scientists and funders. At present, responsibilities and financing for national ocean observing are often distributed across a number of bodies, creating opportunities to improve sustainability, integration and sharing beyond distinct research agendas. In addition, a key challenge is to fully embed and better coordinate national efforts with regional and global initiatives. In this respect, it is worth noting that part XIV of the United Nations Convention on the Law of the Sea envisages the development of national and regional marine scientific and technological centres, which could strengthen ocean observing capacity in the least developed countries and small island developing States. In the Samoa Pathway, the importance of dedicated regional oceanographic centres for developing the technological capacity of small island developing States is also recognized.

53. Opportunities for increasing the coverage, data quality and multidisciplinarity of ocean observing systems also exist at all levels through increasing collaboration with underrepresented groups and communities, such as women and indigenous peoples, and local communities. While such systems are increasingly designed to collect multidisciplinary data, many still neglect the economic, social and cultural aspects of the ocean, which results in a lack of standardized, publicly accessible observations of such aspects at the regional and global levels. However, there is a growing awareness of the importance of indigenous and local ocean knowledge for

sustaining ocean management and observing, including in Pacific island countries. Incorporating such knowledge into ocean observing systems can enhance both their coverage and multidisciplinarity. Indeed, recognizing that ocean observing networks have not always engaged with indigenous peoples, indigenous delegates to the OceanObs'19 conference issued a declaration, Aha Honua, in which they called upon the ocean observing community to formally recognize the traditional knowledge of indigenous peoples and to establish meaningful partnerships with indigenous communities, organizations and nations. In this respect, partnerships between ocean observing networks and indigenous knowledge holders are evolving to create tools to make traditional knowledge accessible, including participatory geographic information systems, as well as to collaborate in community-based ocean observing.

54. Collaborations with the private sector and through citizen science are also increasingly being used as cost-effective ways of increasing ocean observing coverage. Through its Ship of Opportunity Programme, the Global Ocean Observing System has networks that equip and coordinate professional but non-scientific vessels with instruments for ocean observing, with further opportunities to use vast networks of untapped but willing ocean professionals to benefit ocean observation. Given that public sector funding will be insufficient to meet increasing societal demand for ocean observations, private sector financing will be required at all levels.

55. Together with the Global Ocean Observing System 2030 Strategy, the United Nations Decade of Ocean Science for Sustainable Development provides a framework for enhancing ocean observation. The Decade, as a whole, is aimed at bringing together diverse actors in collective efforts to design, implement, resource and use transformative ocean science for sustainable development. One of the 10 challenges around which the Decade is structured is challenge 7, on expanding the Global Ocean Observing System, which identifies the need to ensure a sustainable ocean observing system delivering accessible, timely and actionable data and information to all users. The Decade has already increased levels of partnership and provides further opportunities to deepen existing partnerships within the scientific community and strengthen engagement with new partners, including emerging national ocean observing programmes and existing users not connected to the Global Ocean Observing System, to develop strong connections across the ocean observation value chain. Having already increased levels of interest from beyond the scientific community, it can also create the conditions for the involvement of downstream donors and beneficiaries, such as industry and philanthropists. To support the realization of the vision of the Decade, IOC-UNESCO proposes the establishment of a Global Ocean Observing System Decade Coordination Office for Ocean Observing.

B. Innovation and best practices

56. Innovation and the employment of advanced technologies enabling low-cost, large-scale, automated and multidisciplinary observations can also strengthen the global ocean observation framework. For example, advances in modelling together with enhanced ocean observations have improved weather predictions, including of tropical cyclones, supporting community preparedness; data from autonomous buoys and smart sound analysis software are detecting the presence of whales and informing voluntary shipping slowdowns; and automated underwater microscopes are being used to monitor and quickly respond to harmful algal blooms. New software tools enhance access to data sets and statistical monitoring, and artificial intelligence offers exciting possibilities to further advance ocean observing. Steps are being taken to integrate sensors into undersea telecommunications cables, including through the Joint Task Force on Science Monitoring and Reliable Telecommunications (SMART) cable systems, established by the International Telecommunication Union, WMO and

IOC-UNESCO. The resulting data could facilitate early detection of earthquakes and tsunamis and a better understanding of the impacts of climate change on the ocean. The European Union and its member States are pursuing several technological developments, including a new generation of sensors and autonomous underwater vehicles. The Digital Twin of the Ocean initiative of the European Commission will integrate existing and new data sources to create digital interactive high-resolution models of the oceans, allow continuous, timely monitoring of the ocean and advance ocean knowledge. The Pacific Community is creating "smart" fish aggregating devices by adding ocean sensors for waves, temperature and sonar, and the Commonwealth Blue Charter Action Group on Ocean Observation is developing low-cost, low-maintenance technology for areas that have limited resources and difficulty in gaining access thereto.

57. Alongside new technologies, existing observation tools and methods can be used in innovative ways. For instance, in addition to traditional ocean observing methods, OSPAR status assessments are informed by data collected for other purposes, or "proxy information", such as vessel monitoring system data on bottom trawling fishing activities being used to inform benthic habitat indicator assessments. The International Atomic Energy Agency similarly reports that combining and visualizing existing data sets in the Marine Radioactivity Information System extracts value added from publicly funded projects, facilitates contextualization and improves research planning.

58. Numerous initiatives to facilitate data-sharing are under way. The International Oceanographic Data and Information Exchange aims, inter alia, to facilitate the discovery and exchange of marine data and information, as well as to develop or use existing best practices with respect thereto. Alongside the IOC Oceanographic Data Exchange Policy, the new WMO Unified Policy for the International Exchange of Earth System Data further supports the free exchange of ocean observation data and information and facilitates sharing and coordination at the national level.

59. The International Seabed Authority holds centralized data on marine mineral resources and environmental baseline data acquired from exploration activities, which are publicly accessible through the Authority's Deep Seabed and Ocean Database. The OSPAR Commission reports that its portals, as a freely accessible one-stop shop for data storage and access, adhere to the "FAIR" principles for scientific data management and stewardship, as well as the INSPIRE Directive of the European Union, which is also based on principles to optimize data collection, access and sharing.

60. The utilization of best practices can improve the quality and consistency of observations, promote interoperability and improve efficiency across the ocean observing system. The ocean observing community is contributing to the development of such best practices regarding the collection and use of data. Having identified essential ocean variables that provide vital ocean information, Global Ocean Observing System expert panels are developing recommendations on measurements, observing options and data management practices, moving towards adopting common standards and maximizing data utility. The 15 regional alliances also share best practices in implementing observing systems. The European Commission is developing an ocean observation initiative with the aim of achieving a common approach to ocean observation that allows for "measuring once and using the data for many purposes", including by improving transparency in ocean observing information and its dissemination. The Food and Agriculture Organization of the United Nations (FAO) is strengthening monitoring and information systems for aquatic genetic resources, including by developing and institutionalizing standardized information systems. By sharing its experiences and lessons learned from developing data and assessment portals, the OSPAR Commission notes that the sharing of its

experiences can assist in building capacity, avoiding data silos, maximizing data reuse and limiting duplication. Seeking to improve the accessibility of ocean observation data, knowledge and best practices, the Commonwealth Action Group will release an open-source analysis package for downloading and analysing Argo float data.

61. More generally, the Ocean Best Practices System is an open-access repository of best practices documentation under the auspices of IOC-UNESCO. The System aims for a future in which there are agreed and broadly adopted methods for all ocean observing activities and operates as a collaboration of the International Oceanographic Data and Information Exchange and the Global Ocean Observing System. In addition to its permanent repository, the Ocean Best Practices System facilitates the sharing of best practices through a peer-reviewed journal, training resources and community engagement activities.

C. Infrastructure development

62. As our understanding of the ocean continues to evolve, so too do opportunities to advance ocean observing infrastructure. Contributions to the present report indicated ongoing efforts to improve the density, range of variables, geographical reach and real-time reporting capability of observation networks, both in situ and through remote sensing applications. Ocean observation infrastructure could further be enhanced by mobilizing private vessels through citizen science schemes, and by finding novel applications for established observing infrastructure, for example by integrating carbonate chemistry sampling into existing marine monitoring programmes or by applying land-based technologies at sea, such as the FAO Ex Ante Carbon Balance Tool. Newly identified challenges call for the development of new observation capabilities, for example through an integrated marine debris observing system and in relation to anthropogenic underwater noise.

63. Opportunities for advancing biological observing networks and marine biodiversity observations, which remain underdeveloped compared with marine physical and biogeochemistry observation systems, lie in strengthening existing programmes and networks, including the work of the Global Ocean Observing System Biology and Ecosystems Panel and the Ocean Biodiversity Information System, as well as supporting emerging projects such as Marine Life 2030, the Global Ocean Ship-Based Hydrographic Investigations Program (GO-SHIP) Evolve project and the emerging Animal Borne Ocean Sensors network. Advances in biomolecular observation through other emerging networks, such as the Ocean Biomolecular Observing Network, and the application of genomics technologies, including the use of environmental DNA (eDNA), hold promise in scaling marine biological observations globally.

64. Since the amount of data collected from the ocean is expected to increase, advances in integrating, combining, synthesizing and visualizing information, including through open-source tools, will be imperative to ensure that data are fit-for-purpose for user beneficiaries, including those in developing countries. Global initiatives such as the WMO-IOC Joint Centre for Oceanography and Marine Meteorology in situ Observations Programmes Support (OceanOPS) and Ocean+, regional schemes including the European Union Digital Twin of the Ocean project, the European Marine Observation and Data Network, and the Digital Earth Pacific of the Pacific Community, as well as national programmes such as the graphic visualization project of Ecuador, aid in improving interfaces to be responsive to more users. The sharing of technologies, expertise and analytical capacity will further improve the accessibility of ocean observational data.

65. Co-design of observing systems and programmes, such as those pursuant to the Ocean Observing Co-Design programme under the Global Ocean Observing System, and under the Global Environment Monitoring System for the Ocean and Coasts Programme, can help to avoid the duplication of monitoring initiatives, enable observing systems to better serve stakeholders, and facilitate decision-making on infrastructure investment. The development of low-cost, low-maintenance technologies, such as modular or portable observation platforms or monitoring kits, can increase participation in ocean observation, including by developing countries. The United Nations Decade of Ocean Science for Sustainable Development offers an impetus for infrastructure advancement through endorsed ocean observation programmes. Continued infrastructure development will, however, also depend on support from private sources.

D. Managing interactions with the environment and with other uses of the ocean

66. While it is recognized that observation is fundamental to informing ocean science and to supporting the sustainable management of the oceans, identifying and managing the potential impacts of ocean observing activities highlighted above are essential. To this end, ocean observing activities must be effectively managed with a view to minimizing detrimental impacts on the marine environment, in accordance with applicable international law, including the United Nations Convention on the Law of the Sea.

67. Environmental impacts of ocean observing activities are already being taken into consideration by research institutions, and steps taken towards limiting those impacts. For example, guidelines in relation to anthropogenic underwater noise have been developed at the national, regional and global levels. In respect of the Argo floats, solutions have been proposed to address their potential environmental impacts, including transporting several Argo units together in order to reduce the individual impact of their transportation and placement; avoiding the use of tributyltin oxide; revising construction materials to use less polluting components; and designing floats to spend more than 90 per cent of their lifespan in the deep sea, thus limiting interaction with marine life as far as possible. Carbon dioxide emissions from ocean observation vessels are being minimized through employment of the Ship of Opportunity Programme and the use of voluntary observer ships to collect data under the Global Ocean Observing System Ship Observations Team without recourse to additional dedicated research vessels. With regard to the use of animals for ocean observation, one of the four objectives of the Animal Borne Ocean Sensors network is to ensure best animal handling practices that minimize negative effects on animal welfare, overseen by an Ethical Advisory Board. To the extent that some potential impacts generated by ocean observing activities remain unknown, further research, continued monitoring and a precautionary approach may be necessary. The development and dissemination of best practices would also be beneficial.

68. Measures should also be put in place to minimize potential impacts on other legitimate uses of the oceans, or user conflicts, including by increasing transparency and awareness of ocean observing activities and strengthening cross-sectoral cooperation and coordination.

V. Conclusions

69. The alarming state of degradation of our world’s oceans is well known. Action on various fronts is necessary to restore the health and resilience of the marine

environment, to mitigate and adapt to the effects of climate change and to protect and preserve marine ecosystems and sustainably use their resources. The well-being and livelihoods of so many depend on it. Central to these efforts must be the collection of ocean observation data, which allows us to understand the state of the ocean and marine resources, to predict future impacts and to manage human activities in a way that ensures that the ocean continues to support the sustainable development of present and future generations.

70. Technological innovation in ocean observing systems, together with cost-effective instrumentation, have enabled the generation of a vast network of in situ and remote sensing capabilities, including under the auspices of the Global Ocean Observing System, which capture critical ocean observation data for informed decision-making at the global, regional and national levels. However, gaps and challenges remain, both in the coverage of existing networks, spatially and in terms of variables, and in the form of barriers to accessing, sharing and using the acquired data.

71. While it is both infeasible and unnecessary to measure absolutely everything, more needs to be done, and more efficiently. Ocean observation will benefit from expansion and continued infrastructure development, including through the co-design of observing systems and programmes, in particular regarding biological observing networks and marine biodiversity observations, as well as from the enhancement of data management systems and the optimization of the ocean observation value chain. Further innovation and technological developments also present opportunities to strengthen the global ocean observation network by enabling lower-cost, larger-scale and multidisciplinary observations.

72. The aim must be to address critical financing gaps and work together to make the best use of available resources. In this respect, opportunities exist at all levels to increase collaboration between networks and with citizens and the private sector to increase the coverage, data quality and multidisciplinarity of ocean observing systems. Opportunities must also be taken to work more closely with underrepresented groups, for example by drawing inspiration from emerging partnerships between ocean observing networks and indigenous knowledge holders. Capacity must be built to ensure not only that ocean observation data attain global coverage but also that such data are able to be accessed, interpreted and effectively used. In the latter respect, the role of such processes as the World Ocean Assessments in bridging the science-policy interface, by translating ocean observation data and research into meaningful and understandable information for decision makers, cannot be underestimated.

73. The year 2022 will be a year for the ocean as the international community takes action on several fronts to address the threats facing this invaluable part of our planet. We must, in doing so, recognize and support the critical importance of ocean observation. The United Nations Decade of Ocean Science for Sustainable Development and its challenge 7, on expanding the Global Ocean Observing System, together with various ocean-related processes, provide opportunities to stimulate the creation of new partnerships in ocean observation while deepening existing relationships within the scientific community. This includes the upcoming 2022 United Nations Conference to Support the Implementation of Sustainable Development Goal 14, which will seek to bring to the fore science-based and innovative solutions for a sustainably managed ocean. I encourage States to embrace all of the opportunities in 2022 and beyond to take ocean observation to the next level in support of sustainable development.