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Item 9 of the provisional agenda*
Interactive dialogues

Interactive dialogue 3: Minimizing and addressing ocean acidification, deoxygenation and ocean warming

Concept paper prepared by the Secretariat

Summary

The present concept paper was prepared pursuant to paragraph 23 of General Assembly resolution 73/292, in which the Assembly requested the Secretary-General of the 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 to prepare concept papers on each of the themes of the interactive dialogues, taking into account the relevant ocean-related processes of the Assembly and other possible contributions. The present concept paper relates to interactive dialogue 3, entitled "Minimizing and addressing ocean acidification, deoxygenation and ocean warming". In the paper, the status, trends, challenges and opportunities for the achievement of relevant targets of Sustainable Development Goal 14 are set out, under the overarching theme of the Conference: "Scaling up ocean action based on science and innovation for the implementation of Goal 14: stocktaking, partnerships and solutions".

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I. Introduction

1. The ocean, its diverse ecosystems, the marine life and the many key services the sea provides are under heightened pressure from diverse threats. First among these are climate change impacts, which are exacerbated by other human-induced stressors, such as pollution, eutrophication, habitat destruction, invasive species and unsustainable use of marine resources. Climate-related impacts on the global ocean and its coastal waters include events that occur often incrementally over a long duration, such as ocean warming, acidification, deoxygenation, sea level rise and glacial retreat. However, these threats should not be viewed as a slow menace, as immediate effects can be swift, extreme and local.

2. Alongside more rapid events, increased frequency and intensity of extreme events, such as heat waves or storms, are happening. These are all driving shifts in the marine environment in multiple ways, affecting resilience and biodiversity, as well as the provision of essential ocean services. It is shown that sudden and severe periods of climate-related stress can result in profound impacts on marine ecosystems, such as large-scale mortality, bleaching in corals and impacts on local fisheries and aquaculture. The combined impact of ocean acidification, deoxygenation and warming on marine ecosystems is already observed and yet difficult to predict with accuracy, as it reflects an integration of events and processes at various spatial and temporal scales.

3. Observations and models show that approximately 25 per cent of carbon dioxide is released into the atmosphere each year and more than 90 per cent of the extra heat trapped on the planet by greenhouse gases owing to anthropogenic activities is absorbed by the ocean, considerably helping to attenuate global warming. But this essential service is not without consequence and has led to three major threats affecting ocean health: acidification, warming and deoxygenation. These three stressors often affect marine ecosystems simultaneously, resulting in cumulative effects, and their interaction and the underlying mechanisms are complex. Lack of understanding related to these interactions and mechanisms hinders (a) prediction of the risks they pose, and (b) the development of counteractive measures needed to ensure a sustainable ocean.

4. Mobilizing action to limit global greenhouse gases emissions and climate change impacts is paramount for protecting the ocean and its dependent communities from the threats described above and maximizing adaptation opportunities. Actions to respond to these stressors, alongside non-climate stressors, such as eutrophication and habitat destruction, will enhance the resilience of ecosystems to climate change impacts and maintain key processes.

5. Understanding these stressors better and how they interact also helps prepare for, respond and adapt to changes in the future. Owing to their global and broad range of effects, ocean acidification, deoxygenation and warming directly affect efforts to attain Sustainable Developments Goals 13 and 14, in addition to the other Goals, as well as the mission of the United Nations Framework Convention on Climate Change to limit climate change and its impacts.

6. The present concept paper provides background and key questions to be considered during the interactive dialogue on the theme “Minimizing and addressing ocean acidification, deoxygenation and ocean warming”. It is based on inputs received from Member States, United Nations system entities and other stakeholders.

II. Status and trends

Ocean acidification

7. Carbon dioxide dissolves in seawater forming carbonic acid, altering the ocean's carbonate chemistry, resulting, among other changes, in an increase in seawater acidity (i.e. a decrease in pH). Even small changes in carbonate chemistry can have significant biological and ecological impacts, especially when occurring over long periods of time, such as on the construction of calcium carbonate shells and skeletons of many marine organisms. Since the industrial revolution, the mean surface ocean pH has dropped from 8.2 to 8.1, corresponding to an increase in acidity of 26 per cent. If the emission of carbon dioxide into the atmosphere continues at the present rate, global mean surface ocean pH is predicted to fall by another 0.3 to 0.4 pH units (equivalent to a 100–150 per cent increase in acidity) by the end of this century, though variability at the spatial level is high and some places will suffer much faster from rapid change, while others will be less severely affected. While projections on the concrete impacts that acidification has on marine life could be improved, it has been shown that marine ecosystems and marine biodiversity will be negatively affected, as pointed out, for example, by the recent reports by the Intergovernmental Panel on Climate Change.[1,2,3]

Ocean deoxygenation

8. It is virtually certain that climate change has made a substantial contribution to ocean oxygen decline, with a warming-induced solubility decline accounting for about 15 per cent of the observed changes, whereas changes in stratification and ventilation of the ocean interior with freshly oxygenated surface waters are expected to be the dominant driver in the open ocean. In particular, in coastal regions, anthropogenic nutrient input and associated increases in the production and respiration of organic matter contribute to net oxygen losses and enhanced accumulation of respiratory carbon dioxide, and hence to ocean acidification. Ocean oxygen decline, or deoxygenation, is another major threat to global ocean ecosystems and ocean services, as well as human well-being. Since the mid-twentieth century, there has been an estimated 1–3 per cent decrease in the global ocean oxygen content.[4] The projected expansion of the natural pre-industrial low oxygen zones (areas with less than 80 µmol kg^{-1}) by 7 per cent through 2100 is expected to fundamentally alter the diversity, composition, abundance and distribution of marine life.[5,6]

Ocean warming

9. Global temperatures are rising because of climate change. This is primarily owing to the greenhouse effect caused by greenhouse gas emissions. The greenhouse effect causes more solar radiation to be trapped in the Earth's atmosphere, which is

[1] Intergovernmental Panel on Climate Change, Global warming of 1.5°C. Available at: https://www.ipcc.ch/sr15/.

[2] Intergovernmental Panel on Climate Change, Special report on the ocean and cryosphere in a changing climate. Available at: https://www.ipcc.ch/srocc/.

[3] Intergovernmental Panel on Climate Change, Climate change 2022: impacts, adaptation and vulnerability. Available at: https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/.

[4] Sunke Schmidtko, Lothar Stramma and Martin Visbeck, "Decline in global oceanic oxygen content during the past five decades", Nature, vol. 542, No. 7642 (February 2017), pp. 335–339.

[5] Global Ocean Oxygen Network. The ocean is losing its breath: Declining oxygen in the world's ocean and coastal waters. Intergovernmental Oceanographic Commission-United Nations Educational, Scientific and Cultural Organization, IOC Technical Series, No. 137, 2018.

[6] D. Laffoley and J. M. Baxter, eds., Ocean deoxygenation: everyone's problem. Gland, Switzerland, International Union for Conservation of Nature, 2016.

converted into thermal energy and therefore also absorbed by the ocean. In fact, more than 90 per cent of excess heat resulting from greenhouse gas emissions is absorbed by the sea. Global warming has led to ocean warming, with an increase of 0.7°C in the mean sea surface temperature already occurring over the past century and direct consequences on many fundamental chemical, physical and biological processes, often exacerbated by other stressors, have been detected.

10. Sea level is rising owing to thermal expansion of water and melting of sea ice and glaciers and the speed of sea level rise has been increasing since at least 1960.[7] It is important to note that the impacts of ocean warming are unevenly distributed across regions. Marine ecosystems in tropical areas are projected to have generally negative impacts; as far as fisheries production is concerned, a drop of up to 40 per cent in maximum catch potential is expected in tropical areas, whereas areas in high latitudes are projected to have a 30 per cent to 70 per cent increase in catch potential, leading to some new opportunities (e.g. new fisheries).[8] This large difference has significant ramifications for poverty reduction and food security for the global South, much of which lies in these tropical regions.

Cumulative effects of ocean acidification, deoxygenation and warming

11. While ocean warming is the cause of coral bleaching, the recovery of coral reefs is impeded by increasing ocean acidification. Ocean warming also accelerates deoxygenation both directly, through declining solubility, and indirectly, through a slowdown of ocean ventilation. The thermal expansion of water owing to warming is a primary cause of sea level rise, alongside terrestrial input of freshwater from ice sheets and glaciers. Rising temperatures, coupled with ocean acidification and deoxygenation, affect marine species and ecosystems and, consequently, the fundamental benefits humans derive from the ocean. The change in seawater temperatures also leads to shifts in species distribution, one example is the geographical expansion of the naval shipworm (*Teredo navalis*), putting cultural heritage sites, such as ancient shipwrecks, in danger.

Support by intergovernmental processes

12. Following the first United Nations Ocean Conference, held in June 2017, over 1600 voluntary commitments were submitted by stakeholders from around the world. Expectedly, many of these voluntary commitments cover multiple targets related to Sustainable Development Goal 14. As at March 2022, 280 of the registered voluntary commitments addressed ocean acidification, 31 ocean warming and 21 the loss of oxygen in the ocean.

13. It is important to note that the Sustainable Development Goal and their targets are fully integrated, interlinked and indivisible, with strong connections to the United Nations Framework Convention on Climate Change. The achievement of target 14.3 (Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels), depends on the implementation of Goal 14 as a whole and of the other related Goals and targets in the 2030 Agenda for Sustainable Development, in particular Goal 13. [9] The development and

[7] M.D. Palmer, C.M. Domingues, A.B.A. Slangen and F. Boeira Dias. “An ensemble approach to quantify global mean sea-level rise over the 20th century from tide gauge reconstructions”, Environmental Research Letters, Vol. 16, Num. 4, April 2021.

[8] Food and Agriculture Organization of the United Nations. *Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options*. Rome, 2018.

[9] At the Partnering for Green Growth and the Global Goals 2030 Summit, held in Seoul in May 2021, a special session on oceans was held and included a discussion on strengthening the linkage between Sustainable Development Goals 13 and 14.

implementation of mitigation and adaptation measures can only be successful when the individual mechanisms behind the impacts, as well as the cumulative effects of ocean acidification, deoxygenation and warming, are considered. As a result, these three stressors need to be addressed in a truly integrated manner, both in the context of sustainable development, climate change and ocean governance.

14. Furthermore, two United Nations Decade of Ocean Science for Sustainable Development (Ocean Decade, 2021–2030) programmes are now addressing ocean acidification, Ocean Acidification Research for Sustainability, and ocean deoxygenation, Global Ocean Oxygen Decade (see section IV below).

15. With respect to the international framework for oceans, the United Nations Convention on the Law of the Sea sets out the legal framework within which all activities in the oceans and seas must be carried out (General Assembly resolution 76/72, preamble). The Convention contains many provisions of relevance for action in mitigating and responding to the impacts of ocean acidification, deoxygenation and warming. In particular, Part XII of the Convention contains extensive obligations on States to protect and preserve the marine environment. Likewise, the United Nations Framework Convention on Climate Change and the Paris Agreement provide the framework for intergovernmental efforts on climate change. There are strong linkages between responding to climate change and Sustainable Development Goal 14. Under article 4 of the Convention, all Parties are called upon to promote sustainable management, conservation and enhancement of the oceans as sinks and reservoirs of greenhouse gases and to conserve and enhance coastal and marine ecosystems.

16. Building on the United Nations Framework Convention on Climate Change, the Paris Agreement aims to strengthen the global response to the threat of climate change by holding the increase in average temperature to well below 2°C above pre-industrial levels, while pursuing efforts to limit average temperature increase to 1.5°C; increase adaptation and foster resilience and lower greenhouse gases emissions without threatening food production; and make finance flows consistent with a pathway towards low greenhouse gases emissions and climate-resilient development. The Paris Agreement requires all Parties to put forward their best efforts, identified through nationally determined contributions and to strengthen these efforts in the years ahead. As at March 2022, about 60 per cent of all nationally determined contributions mention ocean-related issues.

17. The special report of the Intergovernmental Panel on Climate Change on global warming of 1.5ºC,[10] and the Panel's report on the ocean and the cryosphere in a changing climate,[11] and the recently published Intergovernmental Panel on Climate Change Working Group I and Working Group II contributions to the Sixth Assessment Report, provide the scientific evidence that underscores the urgency to minimize further damage to the ocean and to maintain key ocean services, directly threatened by ocean acidification, deoxygenation and warming.

18. The Panel's report on the ocean and the cryosphere in a changing climate also highlighted that the implementation of existing tools under the current governance arrangements (e.g. management systems, marine protected areas and marine spatial plans) is often too fragmented across administrative boundaries and sectors to provide integrated responses to the increasing and cascading risks from climate-related changes in the ocean. Furthermore, the Working Group II contributions to the Sixth Assessment Report state that marine governance is impeded by increasing numbers

[10] Intergovernmental Panel on Climate Change, Global warming of 1.5 °C. Available at: https://www.ipcc.ch/sr15/.

[11] Intergovernmental Panel on Climate Change, Special report on the ocean and cryosphere in a changing climate. Available at: https://www.ipcc.ch/srocc/.

of often-competing users and uses, sector-led and fragmented efforts; and a legal framework that lacks clarity compared with land governance.[12]

19. Fragmentation and multi-stakeholder interest to protect and utilize ocean resources were the reasons for Parties to the United Nations Framework Convention on Climate Change at the 26th Conference of the Parties to establish a new instrument, the annual Ocean and Climate Dialogue under the Subsidiary Body on Scientific, Technical and Technological Advice, to foster ocean-based action and call for Convention constituted bodies and work streams to consider how they can strengthen ocean-climate action in their work. Marine ecosystems are also recognized as "carbon sinks",[13] highlighting the importance of the protection, conservation and restoration of marine ecosystems in the reduction of greenhouse gas emissions, all of which are topics directly related to ocean acidification, deoxygenation and warming. This is an important step towards the recognition of the intricate links between the ocean, climate and biodiversity and the need to address them jointly in global sustainable development, climate and biodiversity processes, in particular the 2030 Agenda.

20. The United Nations Ocean Conference held in 2017 truly fulfilled its objective to raise ambition and promote collaboration across multiple organizations, institutions, programmes, networks and other international efforts towards assisting States in their efforts to reverse downward trends in ocean health, including as a result of ocean acidification, deoxygenation and warming.

21. It is expected that the Ocean Conference in 2022 will take stock of and further enforce research and capacity-building activities on ocean acidification, deoxygenation and warming, as well as stakeholder involvement, implementation of mitigation and adaptation strategies across the globe. Continued and enhanced international cooperation and coordination will be essential to achieve the Sustainable Development Goal target 14.3 and to reduce the impact of ocean warming and deoxygenation.

III. Challenges and opportunities

Knowledge gaps to be filled to reduce the impacts of ocean acidification, warming and deoxygenation

22. Challenges and opportunities related to ocean acidification, deoxygenation and warming are numerous and include detecting and understanding those changes, related mitigation aspects, adaptation measures and resilience of ecosystems.

23. During the preparation of the Ocean Decade, 10 major challenges were identified, among which challenge 2 addresses the protection and restoration of ecosystems and biodiversity and challenge 5 refers to how to unlock ocean-based solutions to climate change.[14] Science has proven that reducing greenhouse gas emissions is the single most important aspect to reducing the impacts of ocean acidification, deoxygenation and warming, achieving target 14.3, meeting the goals of the 2015 Paris Agreement and addressing the Ocean Decade challenges. Moreover, in the most vulnerable communities relying on coastal areas for their living, adaptation is a priority. However, co-designed science and its application within Ocean Decade programmes and projects targeting these challenges can provide the

[12] Intergovernmental Panel on Climate Change, Climate change 2022: impacts, adaptation and vulnerability. Available at: https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/.

[13] See Glasgow Climate Pact, FCCC/CP/2021/12/Add.1, decision 1/CP.26.

[14] See https://www.oceandecade.org/challenges/.

basis for Member States to scale up mitigation and adaptation strategies and campaigns related to ocean acidification, deoxygenation and warming.

24. Observations already clearly indicate that ocean and human health are compromised by climate and anthropogenic change impacts. Action to adapt and respond is urgently needed now and while some general actions aimed at increasing ecosystem health and resilience can already be implemented (e.g. increase surface of marine protected areas), more specific actions require accurate scientific knowledge with observations at relevant spatial and temporal resolution to discover variabilities, which are important for improving predictions and guiding actions.

25. Countries may lack the technical expertise to maintain long-term monitoring programmes, or the capacity to obtain information on societal and human vulnerabilities to ocean acidification, deoxygenation and warming. There are significant global coverage gaps in the observing network, with many under-sampled areas, in particular the coastal ocean, regions with narrow shelves and the Southern Ocean. The availability of resources for sustained ocean observations in combination with experimental studies is often subject to short-term funding.[15]

26. Capacity development and new technologies for less expensive measurements of ocean acidification, oxygen and temperature are needed. An increased focus on biological observations to improve current understanding about marine ecosystems is required in concert with physical and chemical ocean acidification, oxygen and temperature measurements.

27. Countries face challenges in benefiting fully from the knowledge gained through capacity-development activities when it comes to converting this knowledge into tangible action. This is often owing to limited financial, human and technical resources, inadequate support from national institutes, as well as limited policy and regulatory frameworks. Furthermore, equal access to ocean data of known quality is a major goal in years to come. To date, much of ocean acidification, deoxygenation and warming data are not freely available, or are limited to metadata. Also, marine research in the past often focused on species-level response or on responses from single stressors, making it difficult to understand and project community and ecosystem response, which is the foundation for adaptation to and mitigation of ocean acidification, deoxygenation and warming.

28. Innovative applications of remote technologies allowing observation of ocean change from space is another approach which might be able to meet the ocean observation challenge. Furthermore, the developments of reliable sensors will be required to use the wide range of coastal and open ocean infrastructures which could be used to close previously identified scarcely observed areas. Co-design and implementation of observing system developments that include oxygen and ocean carbon dioxide system measurements are essential for the Ocean Decade.

29. Current estimates based on the Earth's energy imbalance suggest that more than 90 per cent of the excess heat produced since industrialization has been absorbed by the ocean. Several methods exist to estimate the Earth's energy imbalance, but only ocean in situ data, for example collected by buoys and ships, provide the required accuracy on decadal timescales. Ocean data still do not provide the means to understand hiatus periods, Earth's energy imbalance response to mitigation policies and the linkages with acidification and deoxygenation. Significant improvements in the ocean observing system are needed to better quantify Earth's energy imbalance, with the top priorities being sustained observations, full spatial and temporal

[15] Global Climate Observing System. The Status of the Global Climate Observing System 2021: Executive Summary. (GCOS-239), World Meteorological Organization, Geneva, 2021.

implementation of Argo,[16] with deep Argo[17] implemented, improved measurement coverage in data sparse areas (ice zones, boundary currents, shelf regions) and improved uncertainty estimates.

30. Similarly, the ability to accurately model sea surface temperature changes on multiple time scales is critical to understanding upper ocean mixing and its impacts on biogeochemical cycles in a changing climate. Current models are unable to adequately resolve the structure of the upper ocean required for seasonal to decadal prediction because they do not include sufficiently high-resolution data about the ocean-atmosphere processes that we now know are critical for understanding and predicting upper ocean structure even on longer timescales. Until those processes are better constrained, any future assessment of ocean acidification and deoxygenation is not possible.

31. Examples for refined scientific research and modelling, as well as monitoring and observing, were identified as being specifically useful at national and subnational scales. For example, the effective protection of coral reef areas in a changing climate requires implementation of an observing and modelling system at appropriate scales to understand how the changing environmental conditions are impacting reef growth and response.[18] The results are needed to underpin the assessment of adaptation responses, including coral reef restoration techniques and technology, which are in their infancy with regard to scalability and effectiveness. The changing environmental conditions are also already affecting wild and aquaculture-based fisheries in some regions and the observing system requirements are needed to first identify exposure and predict future conditions, but also to strengthen the development of mitigation and adaptation strategies.

32. In the second World Ocean Assessment, the gaps in the current understanding of ocean chemistry were also summarized and it was noted that more research was needed to better inform models and improve predictions of the earth system response to ocean acidification, deoxygenation and warming, along with their impacts, including socioeconomic impacts.

Measures and interventions to fill existing knowledge gaps and to assist Member States in scaling up ocean action

33. To achieve a sustainable ocean and to lower the rates of ocean acidification, deoxygenation and warming, and their impacts, science projects must be co-designed and conducted with scientists, ocean users and beneficiaries.

34. Steps to that end must include (i) long-term funding for national and regional networks of monitoring and observing activities; (ii) investment in future research and development to enhance knowledge about the mechanisms behind cumulative effects of multiple stressors and data curation; (iii) increased support to develop human and technical capacity to broaden and democratize data generation, access and application; (iv) augment efforts to use newly generated knowledge of ocean acidification, deoxygenation and warming to support policy decisions effectively.

35. Addressing climate change, deoxygenation and ocean acidification in the different marine regions through ocean-based solutions and adaptive governance in the future will be imperative.

[16] Argo are free-drifting profiling floats measuring different parameters characterizing the physical and chemical state of the ocean.

[17] Argo floats characterizing the whole water column down to 6,000 metres.

[18] David Obura and others “Coral Reef Monitoring, Reef Assessment Technologies, and Ecosystem-Based Management”, *Frontiers in Marine Science*, Vol. 6, Art. 580. 19 September 2019. Available at: https://www.frontiersin.org/articles/10.3389/fmars.2019.00580/full.

36. The following are some concrete measures to be taken by stakeholders:

(a) Investing in the development of ocean-based climate solutions, to decrease annual greenhouse gas emissions to keep global temperature rise below 1.5°C, is a major opportunity for the private sector to work hand in hand with Governments and scientists. Ways to support ocean-based climate solutions rooted in ocean observation and research can be:

(i) Investing in nature-based climate solutions (e.g. so-called blue carbon investments, such as restoration and protection of mangroves, saltmarshes and seagrasses);

(ii) Scaling up offshore and ocean-based renewables;

(iii) Rapidly decarbonizing ocean industries, in particular international shipping;

(iv) Promoting sustainable, resilient and low-carbon sources of food from the oceans;

(v) Advancing the science behind carbon capture and storage below the seabed and other geoengineering technologies.

(b) Supporting the Ocean Decade programmes addressing ocean acidification, deoxygenation and warming (e.g. Ocean Acidification Research for Sustainability and Global Ocean Oxygen Decade);

(c) Increasing support and augmenting capacity to report towards Sustainable Development Goal indicator 14.3.1: average marine acidity (pH) measured at agreed suite of representative sampling stations;

(d) Supporting resilience-based management and the identification of potential climate refugia for coral reefs to address the effects of coral bleaching and prepare for response to other stresses like ocean acidification and deoxygenation;

(e) Developing and strengthening capacity-building activities in and transfer technology to developing countries and encourage States and international organizations to pursue further research on ocean acidification, especially programmes of observation and measurement (General Assembly resolution 76/72, paras. 22 and 219);

(f) Building and supporting ocean- and coastal-zone-related adaptation and resilience, based on the best available science to co-produce solutions. This includes the building of opportunities for Member States under the Paris Agreement through nationally determined contributions. Currently less than 10 per cent of nationally determined contributions specifically reference ocean acidification or deoxygenation. The process of revising and updating nationally determined contributions also provides Parties with an opportunity to highlight the interlinkages between climate and ocean, including through cooperation at all levels on scientific, technical, technological and financial aspects and capacity-building;

(g) Considering ocean acidification, deoxygenation and warming in the national adaptation plans (process under the United Nations Framework Convention on Climate Change), to enable countries to identify medium and long-term adaptation needs, including those related to ocean and coastal risk and impacts, and developing and implementing strategies and programmes to address those needs. As at March 2022, 85 per cent of national adaptation plans reference topics related to the ocean, while only 40 per cent specifically reference ocean deoxygenation or acidification;

(h) Engaging in the Marrakech Partnership for Global Climate Action, which continues to highlight action on ocean and coastal zones as a key theme of the United

Nations Framework Convention on Climate Change global climate action agenda helping to increase ambition to achieve the objectives set in the Race to Zero[19] and the Race to Resilience by 2030[20] campaigns, and has provided a platform for stakeholders to collaborate on ocean and climate change action on an annual basis at the Conference of the Parties to the United Nations Framework Convention on Climate Change;

(i) Supporting marine protected areas, which can be sentinel sites to track environmental change and climate change impacts in order to help us better understand climate impacts. Sentinel sites are areas in coastal and marine environments that have the operational capacity for intensive study and sustained observations to detect and understand changes in the ecosystems they represent. Sustained observations of indicators of impending change within ecosystems may allow for effective control or mitigation through management action. A fully functioning sentinel monitoring programme consists of a continuum of activities that include observing, applied research, modelling and predictions, data analysis and visualization, information-sharing, support for management decisions, and education and outreach;

(j) Improving national, regional and global legislation and governance of ocean action, addressing ocean acidification, deoxygenation and warming, e.g. through ocean action plans.

37. The summary above shows that individuals and independent networks, activities and actions can make a change. Commitments and enforcements by Member States to expand carbon dioxide measurements above and below the ocean surface, to improve and sustain measurements of ocean carbon parameters, ocean heat and oxygen, as well as to develop new technologies to close spatial and temporal gaps will be indispensable during the next decade.

IV. Existing partnerships

38. Many regional and international partnerships address ocean acidification, deoxygenation and warming. Below are some of the major initiatives.

39. The United Nations Decade of Ocean Science for Sustainable Development (Ocean Decade, 2021–2030) is a new unifying framework across the entire United Nations system, which will enable countries to achieve elements of their ocean-related Agenda 2030 priorities, including Sustainable Development Goal target 14.3. The activities and coordination of the Ocean Decade are expected to mobilize support towards small island developing States, which are at the forefront of many ocean-related challenges, such as ocean acidification, deoxygenation and warming. The Ocean Decade is coordinated by the Intergovernmental Oceanographic Commission of the United Nations Education, Scientific and Cultural Organization (UNESCO), the United Nations body responsible for supporting global ocean science and services. The Commission hosts part of the Global Ocean Acidification Observing Network secretariat, supports the Global Ocean Oxygen Network, the two Ocean Decade programmes, Ocean Acidification Research for Sustainability and Global Ocean Oxygen Decade and a working group focusing on multiple ocean stressors. The Commission is committed to continuing its efforts in advancing the science towards reducing the impacts of ocean acidification and deoxygenation. To that end, the Commission's role as custodian agency for Sustainable Development Goal indicator 14.3.1 provides researchers with guidelines for measuring ocean acidification in a

[19] See https://climatechampions.unfccc.int/the-race-to-zero/.
[20] See https://racetozero.unfccc.int/join-the-race-to-resilience/.

coordinated manner. In addition, ocean acidification data now have a home in the Sustainable Development Goal 14.3.1 data portal.

40. Within the framework of the United Nations Framework Convention on Climate Change, [21] opportunities to build and support ocean-and coastal-zone related adaptation and resilience based on the best available science to produce collaborative solutions includes opportunities for Member States under the Paris Agreement through nationally determined contributions and national adaptation plans, as well as the ocean and coastal zone climate action group under the Marrakech Partnership for Global Climate Action and activities related to the Nairobi work programme on impacts, vulnerability and adaptation to climate change. While about 63 per cent of nationally determined contributions overall as at March 2022 include topics related to ocean or coastal zones, less than 10 per cent specifically reference ocean acidification or deoxygenation. The process of revising and updating nationally determined contributions provide Parties with an opportunity to highlight the interlinkages between climate and ocean, including challenges, and countries' plans and/or contributions to responding to those challenges, such as cooperation on scientific, technical, technological and financial aspects and capacity-building.

41. There is a significant focus under the Convention on Biological Diversity on issues related to climate change and marine biodiversity. Under the Convention, the post-2020 global biodiversity framework, which will contain a new set of global goals and targets, is presently being negotiated and expected to be adopted at the second part of the fifteenth Conference of the Parties to the Convention on Biological Diversity, to be held in 2022. The framework provides an opportunity to catalyse further actions and partnerships to address the onset and effects of ocean acidification, deoxygenation and ocean warming.

42. Equally, the UNESCO Convention on the Protection of the Underwater Cultural Heritage, adopted in 2001, in its article 5 calls upon each State Party to use the best practicable means at its disposal to prevent or mitigate any adverse effects that might arise from activities under its jurisdiction incidentally affecting underwater cultural heritage.

43. The United Nations Environment Programme (UNEP) supports efforts to identify climate refugia for coral reefs around the world using down-scaled climate projections to understand which coral reef areas may be more resilient, or more vulnerable, to bleaching events in the future. Under a business-as-usual scenario, annual severe bleaching is projected to occur for 99 per cent of the world's coral reefs this century.

44. In parallel, the General Assembly has adopted annual resolutions on oceans and the law of the sea and sustainable fisheries, which address ocean acidification, deoxygenation and ocean warming. The resolution is accompanied by an annual report by the Secretary-General on oceans and the law of the sea. The Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects (Regular Process), [22] is a mechanism established by the General Assembly, to regularly assess the state of the world's oceans and enhance the scientific basis for policy-making. The Second World Ocean Assessment, published in 2021, assesses the impacts of ocean acidification, deoxygenation and ocean warming on the marine environment. Also established by the General Assembly is the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea. The Division for Ocean Affairs and the Law of the Sea of the United Nations Office of Legal Affairs supports the work of these bodies.

[21] See https://unfccc.int/topics/ocean.

[22] See: https://www.un.org/regularprocess/.

45. The Global Ocean Observing System is co-sponsored by Intergovernmental Oceanographic Commission, the World Meteorological Organization, UNEP and the International Science Council. The Framework for Ocean Observing, a guide to meeting the needs of multiple stakeholders, addresses concerns about ocean health, serves users across climate zones, operational services with an increasing focus on coastal areas and regional seas. The Global Ocean Observing System-Global Climate Observing System-World Climate Research Programme Ocean Observations Physics and Climate Panel is working to fill gaps in observing and understanding ocean surface air-sea fluxes and heat through its working groups. This work will lead to improved models of the ocean conditions and their impacts on acidification and deoxygenation, thereby directing future adaptation or mitigation measures.

46. The International Atomic Energy Agency (IAEA) helps to coordinate global ocean acidification efforts through its Peaceful Uses Initiative project Ocean Acidification International Coordination Centre, as well as through its research and development and technical cooperation programmes. The Ocean Acidification International Coordination Centre has a threefold approach to coordinate, promote and facilitate international activities on ocean acidification through science, capacity-building and communication. The network of marine and coastal stressors of Latin America and the Caribbean, also sponsored by IAEA, has been strengthening the analytical capabilities, necessary to report on Sustainable Development Goal indicator 14.3.1, of 18 countries in the region. Currently, IAEA has involved more than 850 scientists from 83 countries to work on ocean acidification through its capacity-building activities. The Global Ocean Acidification Observing Network is also supported by IAEA.

47. The World Meteorological Organization (WMO), with the Intergovernmental Oceanographic Commission and the International Science Council, through its World Climate Research Programme, coordinates ocean research activities to improve our understanding of the distribution and trends of greenhouse gases in the atmosphere to better understand ocean acidification. WMO also coordinates global observations of greenhouse gases in the atmosphere for estimating air-sea carbon dioxide fluxes. WMO releases the annual Global Statement on the State of the Global Climate, which is the authoritative reporting on the yearly variations and long-term trends in climate change, including ocean acidification, deoxygenation and ocean warming, as well as annual Greenhouse Gas Bulletin.

48. Climate change is increasingly threatening food production from freshwater, coastal and open ocean marine ecosystems. The activities of the Food and Agriculture Organization of the United Nations (FAO) are aimed at supporting Member States and partners to effectively mitigate and adapt to the impacts of climate change. Activities include a review of the impacts of climate change on fisheries and aquaculture and guidance on policy development for mitigation and adaptation, as well as a number of field programmes and projects implemented in collaboration with governments and with the full involvement of local communities in over 30 countries. FAO also combines disaster risk reduction and management and climate change adaptation approaches to develop a suite of actions that aim to build the resilience of the fisheries and aquaculture sector to climate and non-climate risks and impacts.

49. The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection functions under the auspices of 10 United Nations entities with maritime and ocean interests. Different working groups within the Joint Group are addressing issues related to ocean acidification, deoxygenation and ocean warming. For example, Working Group 41 works on Ocean Interventions for Climate Change Mitigation (lead by the International Meteorological Organization and supported by Intergovernmental Oceanographic Commission and WMO) and Working Group 45 addresses Climate Change and Greenhouse Gas Related Impacts on Contaminants in

the Ocean (sponsoring agencies are IAEA, UNEP, Intergovernmental Oceanographic Commission, WMO and the International Meteorological Organization).

50. The Global Ocean Acidification Observing Network, a partnership of more than 970 members from 104 countries, is committed to achieving three goals related to ocean acidification: (a) to document its status and trends in diverse locations around the world; (b) to understand impacts; and (c) to enable forecasts and early warning capabilities. The Network established a data portal that contains metadata, links to downloadable data and near real-time data visualizations from ocean acidification monitoring platforms around the world. Network members contributed to the establishment of the Sustainable Development Goal 14.3.1 methodology, under the leadership of the Intergovernmental Oceanographic Commission. The Global Ocean Acidification Observing Network supports nine regional hubs.

51. The Global Ocean Acidification Observing Network spearheaded the development of the Ocean Decade programme entitled Ocean Acidification Research for Sustainability, which provides the road map for the next 10 years, identifying the major outcomes needed to focus efforts towards delivering the ambitions of Goal 14.3. The final objective of this global initiative is providing society with the observational and scientific evidence needed to sustainably identify, monitor, mitigate and adapt to ocean acidification from local to global scales. It builds on the work of Global Ocean Acidification Observing Network to further develop scientific knowledge by enhancing ocean acidification capacity, increasing observations of ocean chemistry changes, identifying the impacts on marine ecosystems at different scales and providing society and decision makers with the information needed to mitigate and adapt to ocean acidification.

52. The international working group Global Ocean Oxygen Network is committed to providing a global and multidisciplinary view of ocean deoxygenation, with a focus on understanding its multiple aspects and impacts. The Network's research, outreach and capacity-building efforts include facilitating communication with other established ocean science and observation networks and programmes. The Global Ocean Oxygen Decade is an endorsed programme of the Ocean Decade led by the Global Ocean Oxygen Network. The Global Ocean Oxygen Decade will raise global awareness about ocean deoxygenation, provide knowledge for action and develop mitigation and adaptation strategies and solutions to ensure continued provision of ecosystem services and minimize impacts on the ocean economy through local, regional and global efforts, including transdisciplinary research, innovative outreach and ocean education and literacy.

53. The Division for Ocean Affairs and the Law of the Sea partners with the Nippon Foundation and other partners, including approximately 40 academic institutions, in the context of the United Nations/Nippon Foundation Fellowships, Alumni Network and the Hamilton Shirley Amerasinghe Memorial Fellowship on the Law of the Sea. Those programmes are aimed at training ocean professionals from developing States, including on the links between climate change and oceans and ocean acidification, deoxygenation and warming, with a view to assisting in the development of ocean governance frameworks that integrate necessary climate-related responses.

54. The non-profit organization Ocean Conservancy, based in the United States of America, leads the Pacific Rim Ocean-Climate Action Partnership, a voluntary initiative of stakeholders focused on reducing greenhouse gas emissions, maximizing sustainable ocean-related mitigation measures and building climate resilience of ocean and coastal ecosystems, as well as communities and economies, on the front lines of ocean and climate change.

55. The International Alliance to Combat Ocean Acidification, which Ocean Conservancy helped launch at the "Our Ocean" Conference in 2016, brings together

Governments and organizations from across the globe dedicated to taking urgent action to protect coastal communities and livelihoods from the threat of ocean acidification and other climate-ocean impacts.

56. The Global Coral Reef Monitoring Network was established by the International Coral Reef Initiative in 1995. Its role is to provide coral reef data, aggregated from national to regional levels, and then to a global level. It has produced a range of reports focusing on the status and trends of coral reefs, helping to understand the changes and to inform appropriate responses. As coral degradation is occurring at the global level driven by global, as well as local, processes, coherent coral reef observation is required in addition to outreaching efforts.

V. Possible areas for new partnerships

57. The areas identified for new partnerships are informed and directed by the challenges and measures identified in section III above and the already existing partnerships referred to in section IV above.

58. First and foremost, new partnerships across Ocean Decade programmes, projects and contributions are encouraged, e.g. the Ocean Acidification Research for Sustainability and the Global Ocean Oxygen Decade programmes. Further stakeholders not yet active in these communities are invited to join the efforts to achieve related objectives and outcomes. Specific collaborations to encourage are:

(a) Alignment of biological and chemical observing initiatives, providing information to multiple ocean relevant intergovernmental processes, e.g. the 2030 Agenda, the Convention on Biological Diversity and the United Nations Framework Convention on Climate Change;

(b) Partnerships between science and industry (both financial and manufacturing) to search for innovation solutions (at all scales, to solve local and global problems);

(c) Support exchanges between science and communication professionals to increase global climate change literacy across society.

59. Action on ocean acidification, deoxygenation and warming is vital as part of the commitments to achieving Sustainable Development Goal 14, as well as being crucial to Sustainable Development Goal 13, the United Nations Framework Convention on Climate Change and the Paris Agreement. Globally, there are strong linkages between responding to climate change and Sustainable Development Goal 14, in particular with regard to protection of ecosystems (targets 14.2 and 14.5), responding to ocean acidification, deoxygenation and warming (target 14.3) and increasing scientific knowledge (target 14.a). Developing new partnerships among voluntary commitments already in place, as well as future commitments addressing more than one goal or target, will increase the benefits as a whole and assist Member States in achieving the set targets in Sustainable Development Goals 13 and 14 by 2025 and 2030, as well as the Paris Agreement.

60. Another area for new partnerships is the open access to data and information on ocean acidification, deoxygenation and warming. Examples are:

(a) Partnerships supporting the effort led by the Intergovernmental Oceanographic Commission and Ocean Acidification Research for Sustainability to establish a federated system for ocean acidification data (a special type of distributed database management system) with the focus on information necessary for Sustainable Development Goal indicator 14.3.1 are required to be able to minimize the effects of ocean acidification. Potential partners are national oceanographic data

centres, international data centres, such as the World Ocean Database, the Integrated Carbon Observation System, SeaDataNet, European Marine Observation and Data Network; product oriented efforts, like the Surface Ocean Carbon Dioxide Atlas and the Global Ocean Data Analysis Project, as well as the International Oceanographic Data and Information Exchange, the International Ocean Carbon Coordination Project, the Group of Seven, IAEA, WMO and national statistical offices;

(b) Efforts to implement the Global Ocean Oxygen Data Atlas in the framework of Global Ocean Oxygen Decade, supported by the Global Ocean Oxygen Network. The Global Ocean Oxygen Data Atlas will help to meet the need for a standardized, well-documented, high-quality and comprehensive database integrating oxygen data and other environmental variables from multiple sources is growing rapidly with the increasing threat of ocean deoxygenation for marine ecosystems and delivery of their associated services to society;

(c) Private-public partnerships to support and increase the availability of information derived from data for both stakeholder groups but also allow the use of the latest technologies developed in the field of data management for the commercial sector;

(d) Initiatives to encourage implementation of data policies supporting open access to ocean data, e.g. the data policy of the International Oceanographic Data and Information Exchange[23] and the WMO unified data policy.[24]

61. Establishment of and support to regional networks is crucial, e.g. in the framework of the Global Ocean Acidification Observing Network, which currently supports nine regional networks: the Latin American Ocean Acidification Network, the Mediterranean Ocean Acidification Hub, the North American Ocean Acidification Hub, the North East Atlantic Ocean Acidification Hub, Ocean Acidification-Africa Network, the Pacific Islands and Territories Ocean Acidification Network, the Western Pacific Hub, the Arctic Hub and the South Asia Regional Hub on Ocean Acidification. Those networks foster cooperation, mentoring and knowledge exchanges among scientists and help them address the regional issues stemming from ocean acidification at geographically relevant scales. New regional networks associated with the Global Ocean Acidification Observing Network, especially in areas highly vulnerable to ocean acidification and climate change in general, such as the Southern Ocean, will not only increase the scientific capacity, but also promise to raise the adaptation potential of local communities to future change.

62. The need for more effective monitoring of ship emissions is another area for new collaboration between the private, scientific and government sectors. Countries have requested more activities related to technology transfer that can help them reduce emissions from ships and at the port level. Specific efforts should be made to provide more assistance with the identification of appropriate technology, both tried-and-tested, as well as innovative developments. Monitoring and decreasing greenhouse gas emissions from shipping is only one of many important steps to assure sustainable management of the ocean and its services.

63. In addition, partnerships with the International Coral Reef Initiative and Regional Seas Programmes are important for implementing action on resilience-based management for coral reef ecosystems in the face of climate change. Partnerships with academic institutions are important for researching coral bleaching events and refining models that can help us understand where climate refugia may exist. Another

[23] IODE data policy, https://www.iode.org/index.php?option=com_content&view=article&id=51&Itemid=95.

[24] WMO Unified Data Policy, https://public.wmo.int/en/our-mandate/what-we-do/observations/Unified-WMO-Data-Policy-Resolution.

type of partnership in coral reef research, the collaboration between science and the private sector, has been shown to be extremely effective when it comes to innovative communication.

64. Collaboration with the United Nations Food Systems Summit Coalition for Aquatic/Blue Foods should be strengthened in order to mobilize support and cooperation to enhance sustainable climate resilient fisheries management and aquatic food farming to avert climate change impacts on aquatic ecosystems and aquatic food production, which will affect many of the most vulnerable regions and populations, especially in the tropics.

65. The geographical shift owing to ocean acidification, deoxygenation and warming of species with commercial interest reinforces the need for international cooperation. The shared knowledge of consumption habits will be of great importance to enable and educate consumers on new species. This international cooperation must include official communication channels, fishermen associations, state laboratories, academics and associations of fish product buyers or chefs.

66. New partnerships between ocean energy companies and scientists, including oceanographers, engineers and economists to investigate the potential of energy by the ocean, e.g. waves, contributing to the decarbonization of energy supply and thus reducing the emission of carbon dioxide are also important. More broadly, fostering alignment between the United Nations Framework Convention on Climate Change and the 2030 Agenda related processes addressing ocean and climate will be another avenue to proceed. The triple threat of ocean acidification, deoxygenation and warming are important topics within both processes.

VI. Conclusions and recommendations

67. Over the past decade, science addressing ocean warming, acidification and deoxygenation has substantially advanced our understanding of the complex response of the ocean to climate and anthropogenic change. We have learned that these stressors occur and affect ocean health at multiple levels, in an interactive way, and this is complicated to model and to project, in particular in high latitude areas, the southern hemisphere and coastal areas. As a result, networks, partnerships and countries must commit to investing in ocean science now, to advance our understanding of the cumulative global effects of ocean acidification, deoxygenation and warming on the ocean and the provision of its ecosystem services. This can only be accomplished if the global oceanographic community rallies together in new and unprecedented ways. Collective action has to be co-designed by information producers and users, informed by science that is fit for purpose, anchored within the framework of the United Nations Decade of Ocean Science for Sustainable Development. Inclusive, supportive and advocative partnerships established and joined by diverse stakeholders representing the academic, governmental and private sectors are needed to equip Member States with the knowledge and tools to combat the effects of ocean acidification, deoxygenation and warming, tailored to satisfy their unique needs, required for ambitious action within the 2030 Agenda, the United Nations Framework Convention on Climate Change and the Paris Agreement and in conformity with the United Nations Convention on the Law of the Sea.

68. For example, bilateral, regional and global cooperation programmes, technical partnerships and fellowships need to be created to develop and strengthen ocean science capacity-building activities. Integrated multisectoral solutions and effective adaptation options can reduce risks to people and nature while addressing social inequalities, differentiate responses based on climate risks and increase the feasibility and effectiveness of adaptation in multiple sectors.

69. In addition, multidisciplinary research to fill gaps in the understanding of biological, ecological and socioeconomic impacts of ocean acidification, deoxygenation and warming would be critical. Efforts are needed to improve knowledge and evidence base of vulnerabilities and socioeconomic impacts and particular attention should be given to the most vulnerable, including small-scale fishing and fish farming communities living in low-income countries and islands, drawing on the experience and existing best practices in many countries and of existing partnerships. Public-private partnerships are necessary to increase the data and knowledge accessibility and application of new technologies to address the three global threats to ocean health.

70. It is important, however, to take a more comprehensive and integrated approach to address the challenges described above. Action is required on cross-cutting issues, such as capacity-building, ocean literacy and awareness-raising in relation to the destruction of key marine environments and the additional stress of pollution added to ocean acidification, warming and deoxygenation. New measures and tools will need to be developed streamlining the often-fragmented governance arrangements across administrative boundaries and sectors to provide integrated responses to the increasing and cascading risks from climate-related changes in the ocean. New avenues to increase the commitments by Member States will need to be explored leading to ambitious action to combat the impacts of climate change and to achieve a sustainable ocean.

VII. Guiding questions

71. The topic of the interactive dialogue is cross-cutting. The success or failure of activities related to combating the impacts of ocean acidification, warming and deoxygenation will affect the meeting of the targets laid out in Sustainable Development Goal 14 and Sustainable Development Goal 13, the United Nations Framework Convention on Climate Change and the Paris Agreement. The questions of what to do, how to do it and where to act, are still under development and many questions remain. The following guiding questions may be used to inform the dialogue:

(a) How can multidisciplinary science, including natural and social sciences, support strengthened action on climate, biodiversity and marine planning?

(b) How can capacity-building programmes be enhanced to ensure that existing ocean, climate, ocean acidification ocean warming and deoxygenation frameworks are implemented in mutually supportive and coordinated ways?

(c) What options, strategies and new partnerships could benefit ocean users, particularly aquaculture and fisheries and countries at large, to minimize the impacts of ocean acidification, warming and deoxygenation on these sectors and the livelihoods that depend upon them?

(d) What kind of processes and institutions are needed to facilitate the translation of scientific understanding into behavioural change, improved legal frameworks and increased resilience?

(e) How can the United Nations Decade of Ocean Science for Sustainable Development help to increase actionable knowledge in the areas of ocean acidification, warming and deoxygenation and their cumulative effects?

(f) How can open data and information access for research on ocean warming, acidification and deoxygenation be improved?