

Brief on the second *World Ocean Assessment* and climate change in the ocean

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Considerations for the third cycle of the Regular Process

Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects

The Regular Process is a global mechanism established by Members States of the United Nations after the World Summit on Sustainable Development, held in Johannesburg, South Africa, in 2002¹. Its aims are to regularly review the environmental, economic and social aspects of the state of the world's ocean, both current and foreseeable, and identify current knowledge gaps and capacity needs. Its purpose is to contribute to the strengthening of the regular scientific assessment of the state of the marine environment in order to enhance the scientific basis for policymaking. The Regular Process is in its third cycle (2021–2025), with the first and second World Ocean Assessments published in 2016 and 2021, respectively.

The Regular Process is mandated by the General Assembly to provide scientific information that supports, inter alia, the 2030 Agenda for Sustainable Development², the development of an international legally binding instrument under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction³, the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea⁴ and the United Nations Framework Convention on Climate Change⁵.

The main output of the first and second cycle of the Regular Process was a global integrated marine assessment (also known as the World Ocean Assessment), with the first World Ocean Assessment focused on establishing a baseline and the second on building on that baseline, evaluating trends and identifying gaps.

The first World Ocean Assessment, published in 2016, indicated that growing population, economies and agricultural and industrial requirements for feeding, clothing and housing the world's population were seriously degrading parts of the marine environment, especially near the coast. The assessment concluded that, without an integrated, coordinated, proactive, cross-sectoral and science-based approach to coastal and marine management, the resilience of coastal and marine ecosystems and their ability to provide vital services would continue to be reduced.

The second World Ocean Assessment, published in 2021, is structured around a slightly modified drivers-pressures-state-impact-response framework. It identifies the following overarching drivers influencing the marine environment: (a) population growth and demographic changes; (b) economic activity; (c) technological advances; (d) changing governance structures and geopolitical instability; and (e) climate change. The second assessment highlighted that although some improvements in some sectors and some regions had been made, ongoing decline in many aspects of the ocean as a result of the many unabated pressures humans were placing on the ocean had occurred.

The programme of work set out for the third cycle of the Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects, developed by the Bureau of the Ad Hoc Working Group of the Whole on the Regular Process and to be conducted during the period 2021–2025, consists of three main outputs. Output II is focused on supporting and interacting with

¹www.un.org/regularprocess/content/about

²<https://sustainabledevelopment.un.org>

³www.un.org/bbnj

⁴www.un.org/Depts/los/consultative_process/consultative_process.htm

⁵<https://unfccc.int>

ocean-related intergovernmental processes. The activities associated with this output include the preparation of policy relevant briefs specifically tailored to meet the requests and needs of a number of international agreements, intergovernmental initiatives and processes relevant to the Regular Process.

Four briefs have been produced, addressing Climate Change, Biodiversity, the Sustainable Development Goals and both the UN Decade of Ocean Science for Sustainable Development and the UN Decade of Ecosystem Restoration, respectively.

Purpose and preparation of the four briefs

The briefs provide a synthesis of relevant information from the second *World Ocean Assessment* related to two key global topic areas (climate change and marine biodiversity) and three United Nations processes (the Sustainable Development Goals of Agenda 2030, the United Nations Decade of Ocean Science for Sustainable Development and the United Nations Decade on Ecosystem Restoration). These key global issues and processes have been identified as priorities by the Group of Experts and the secretariat of the Regular Process, in consultation with the Bureau. The briefs have been prepared by the Group of Experts, with the assistance of the secretariat of the Regular Process. Outlines of the briefs have been reviewed by relevant UN agencies and intergovernmental processes. The briefs have been reviewed by member states, the Bureau of the Ad Hoc Working Group of the Whole on the Regular Process and considered by the Working Group at its sixteenth meeting.

In the case of the brief on climate change, the intergovernmental processes include the United Nations Framework Convention on Climate Change (UNFCCC), the Intergovernmental Panel on Climate Change (IPCC), the Sustainable Development Goals (SDGs) and the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea (UNICPOLOS), which focused its discussions on the themes “The effects of climate change on oceans” in 2017 and “Sea level rise and its impacts” in 2021.

Note from the writing team: *the paragraphs in the two sections above (i.e., “the Regular Process Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects” section and the “Purpose and preparation of the four briefs” section) will be numbered later by the copy-editing team.*

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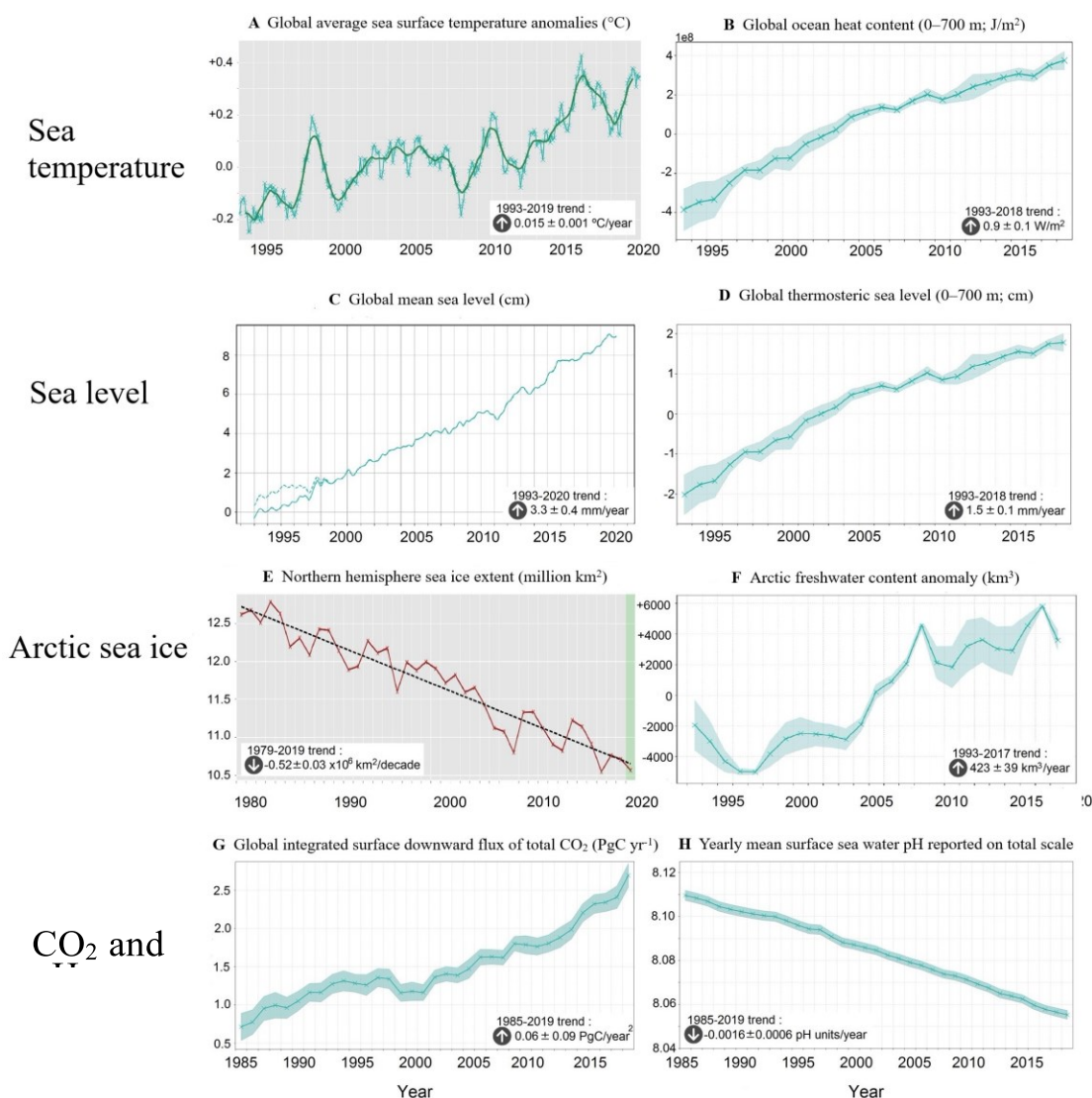
I. Introduction: visual summary of global ocean climate change indicators

1. The ocean is currently experiencing a phase of significant impacts of climate change, and it is of the utmost importance to evaluate the rate of the changes. As an introduction to this brief, two figures providing a visual summary of trends during recent decades in key ocean climate change indicators have been included. Figure 1 shows the global trends of sea temperature, sea level, Arctic Sea ice and ocean pH (ocean acidification) indicators during the period 1993 to 2019/2020 elaborated by the Copernicus Marine Environment Monitoring Service (CMEMS). Figure 2 presents key aspects of the global dissolved oxygen decline; (a) the extent of the oxygen minimum zones, (b) the decreasing trends over five decades (1960-2010), (c) the vertical distribution of deoxygenation and (d) the percentage of deoxygenation due to warming of the water column. These indicators are recognised as Essential Climate Variables (ECVs) by the Global Climate Observing System (GCOS; <https://gcos.wmo.int/en/global-climate-indicators>) and provide an overview of recent rates of change of key components of the global ocean.

2. The section below provides greater details about the following major points: (II) physical and chemical impacts; (III) changes in extreme events; (IV) impacts in marine ecosystems; (V) impacts and adaptation measures in marine coastal communities, (VI) knowledge gaps and capacity development needs and (V) further reading.

3. It is hoped that this information will allow for decisive and urgently needed decision-making at all levels.

Figure 1. Global ocean trends during the recent decades, elaborated by the Copernicus Marine Environment Monitoring Service (CMEMS): (A) Global Sea Surface Temperature (SST) anomalies ($^{\circ}\text{C}$) during the period January 1993–December 2019, (B) Global Ocean Heat Content (OHC; 0–700 m; J/m^2) for the period January 1993–December 2018., (C) Global Mean Sea Level (cm) during the period January 1993–October 2019., (D) Global thermosteric sea level (0–700 m; cm) for the period January 1993–December 2018., (E) Northern Hemisphere annual mean sea ice extent (millions of Km^2) during the period January 1979–December 2019 (40 years). (F) Arctic ocean freshwater content annual anomalies (Km^3) during the years 1993–2017. G) Global area integrated annual surface downward flux of total CO_2 (PgC/year) during the period January 1985–December 2019. (H) Annual global mean surface sea water pH over the period January 1985–December 2019.

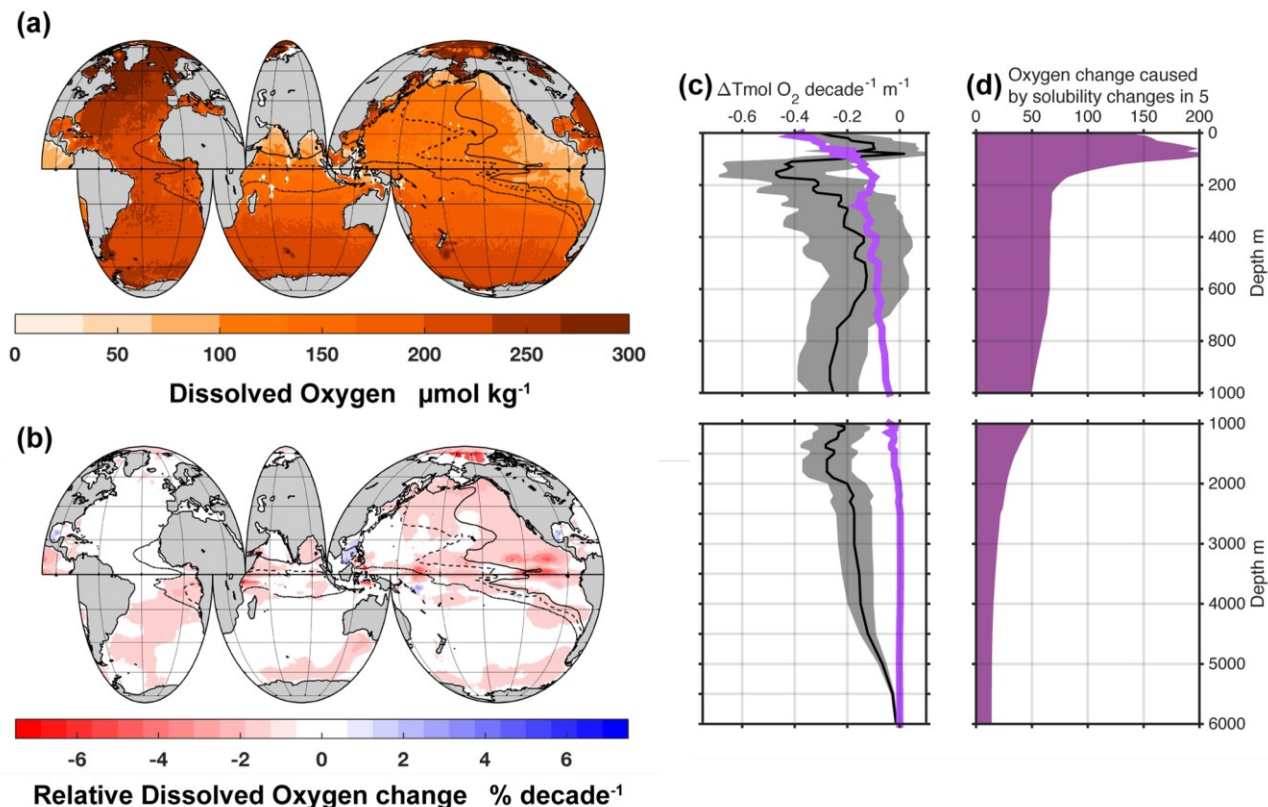


Source: Garcia-Soto, C., and others, 2021⁶ The article was written by members of the drafting

⁶Garcia-Soto, C., L. Cheng, L. Caesar S. Schmidtko, E. B. Jewett, A. Cheripka, I. Rigor, A. Caballero, S. Chiba, J. C. Báez, T. Zielinski and J. P. Abraham “An overview of ocean climate change indicators: sea surface temperature, ocean heat content, ocean pH, dissolved oxygen concentration, Arctic sea ice extent, thickness and volume, sea level and strength of the AMOC (Atlantic Meridional Overturning Circulation)”, *Frontiers in Marine Science*,

team of Chapter 5 of WOA2 and represents an update with respect to the WOA2 content.

Figure 2. Spatial and temporal trends of dissolved oxygen concentration. (A) Mean oxygen concentration, lines indicate the maximum extent of the oxygen minimum zone with 40, 80, and 120 mmol kg^{-1} dissolved oxygen anywhere in the water column. (B) Trend of oxygen over five decades 1960–2010 (A, B data from Schmidtko et al., 2017)⁷. (C) Vertical distribution of deoxygenation (black curve) and error (gray area), the purple line indicates the loss expected from oceanic warming detected in the same data set. (D) Percentage of deoxygenation due to warming for the water column, values above 100% indicate that processes counter acting solubility deoxygenation are at play (C, D reworked from Schmidtko et al., 2017).



Source: Garcia-Soto, C., and others, 2021⁸The article was written by members of the drafting team of Chapter 5 of WOA2 and represents an update with respect to the WOA2 content.

vol. 8, art. 642372 (September 2021). <https://www.frontiersin.org/articles/10.3389/fmars.2021.642372/full>

⁷Schmidtko, S., Stramma, L., and Visbeck, M. (2017). Decline in global oceanic oxygen content during the past five decades. *Nature* 542, 335–339. doi: 10.1038/nature21399.

⁸Garcia-Soto, C., L. Cheng, L. Caesar S. Schmidtko, E. B. Jewett, A. Cheripka, I. Rigor, A. Caballero, S. Chiba, J. C. Báez, T. Zielinski and J. P. Abraham “An overview of ocean climate change indicators: sea surface temperature, ocean heat content, ocean pH, dissolved oxygen concentration, Arctic sea ice extent, thickness and volume, sea level and strength of the AMOC (Atlantic Meridional Overturning Circulation)”, *Frontiers in Marine Science*, vol. 8, art. 642372 (September 2021). doi: 10.3389/fmars.2021.642372

II. Physical and chemical impacts of climate change

Sea surface temperature and ocean heat content (chapters 5 and 7)⁹

4. Globally averaged sea surface temperature data in the period from 1900 to 2018 show a warming of 0.62 ± 0.12 °C per century. Of temperature measurements collected across 1900-2018, the 10 warmest years on record have all occurred since 1997, with the 5 warmest occurring since 2014. The recent decade (2009–2018) shows a rate of warming approximately four times higher (2.56 ± 0.68 °C per century) than the long-term trend (0.62 ± 0.12 °C per century).

5. Ocean temperature increases corresponds to an uptake of over 90% of the excess heat accumulated in the Earth system. Increases in ocean heat content are observed throughout practically the entire ocean, down to 2,000 m¹⁰. Recent estimates of ocean heat content based on observations show highly consistent ocean warming since the late 1950s with a linear rate of 0.34 ± 0.06 W m⁻². After 1990 the rate of ocean warming in the upper 2,000 m has doubled (0.62 ± 0.05 W m⁻²). The past 10 years are the 10 warmest on record as ocean heat content is less affected by natural variability.

6. Marine species distributions are shifting to the poles as a result of warming waters. The physical structure, spatial extent and ecological function of many coastal ecosystems are also impacted by global warming. Warm-water corals are expected to decline with 1.5° warming leading to systems with reduced [biological](#) diversity and reduced ability to provide [ecosystem](#) services including food and coastal protection (see also section IV Marine ecosystems).

Sea level rise (chapters 5 and 9)

7. Since 1993, the global mean sea level has been rising at a mean rate of 3.15 +/- 0.3 mm per year, with a clear superimposed acceleration of approximately 0.1 mm per year². By 2010, the global average sea level was 52.4 mm above the 1993 level and, by 2018, it had increased to 89.9 mm above the 1993 level.

8. Thermal expansion from a warming ocean, together with land and polar ice sheet melt, are the main causes of the acceleration in the global rise in mean sea level. Satellite altimetry has also revealed strong regional variability in rates of sea level change, with regional rates up to 2–3 times above the global mean in some regions over the altimetry era (1993 onwards). Regional sea level has increased fastest in the Indo-Pacific, Northwest Pacific and Subtropical North Atlantic. Differences from the global mean and trend sign can result from land ice loss and variations in ocean warming and circulation.

9. In coastal areas, additional processes, including land subsidence, are added to the global mean and regional sea level components and can make coastal sea level deviate substantially from open ocean sea level rises.

10. Sea level rise poses a significant threat to coastal systems and to low-lying areas around the world through inundations, the erosion of coastlines and the contamination of freshwater reserves and food crops. Entire communities on low-lying islands have nowhere to retreat within their islands. Due to projected global sea level rise extreme sea level events that are historically rare will become common by 2100. Sea level rise

⁹In the present brief, chapters references are to chapters of the second World Ocean Assessment.

¹⁰The text does not imply that the ocean below 2000 m is not warming. The 2000 m depth is the standard limit of the reported measurements. Deep sustained observing systems (GoSHIP and OceanSITES) document deeper warming.

will continue for centuries, even if mitigation measures of Greenhouse Gases are put in place. (See also section V Coastal communities).

Salinity (chapter 5)

11. Global satellite observations of salinity have only been available since 2010 but, considering all available analyses, it is extremely likely that near-surface and subsurface salinity changes have occurred across the globe since the 1950s.

12. Studies provide clear evidence, when comparing historical (approximately 1950s) salinities to present-day salinities, that the near-surface, high-salinity subtropical ocean and the entire Atlantic basin have become more saline and that the low-salinity regions, such as the Western Pacific Warm Pool, and high latitude regions have become fresher. The pattern of change indicates an amplification of the Earth's hydrologic cycle.

Ocean circulation (chapter 5)

13. Independent proxies seem to indicate that the Atlantic Meridional Overturning Circulation is at its weakest for several hundreds of years and has been weakening during the past century.

14. The Atlantic Meridional Overturning Circulation is crucial for meridional heat transport and therefore strongly influences the climate. Its slowdown can reduce ocean carbon uptake among other [environmental](#) consequences.

Deoxygenation (chapters 5, 7 and 9)

15. The global overall oxygen budget has decreased by 2 per cent in the past five decades, which equates to a loss of 4.8 ± 2.1 petamoles since 1960. Temperature-driven solubility decrease is dominating the oxygen loss in the upper most water layers from a global perspective. A warming ocean is gaining less oxygen from air sea gas exchange. 50% of the oxygen loss is attributed to solubility changes in the upper 1,000 m. This number drops to about 25% for the upper 2,000 m and only on the order of 13% of the overall full water column oxygen loss. This solubility driven deoxygenation is attributed to the time period 1960–2010, assuming linear warming. For an accelerating warming process these numbers will likely increase.

16. The area of oxygen minimum zones has typically been expanding in recent decades, although regional variability exists. Oxygen minimum zones are generally defined as oceanic volume with less than 80 mmol l^{-1} dissolved oxygen concentration. In areas where the dissolved oxygen levels are close to or completely depleted oxygen minimum zones have potential impacts on greenhouse gas driven climate warming, since they can emit large quantities of nitrous oxide, a potent greenhouse gas, owing to denitrification processes under anoxic conditions. Such areas can be found in the Pacific and Indian Ocean and have been found expanding.

17. Climate change is projected to cause further oxygen declines in many coastal systems where deoxygenation is currently driven primarily by an oversupply of anthropogenic nutrients. Ocean warming is acting to increase the number of coastal areas that become hypoxic, and causing earlier onset, longer duration and more intense oxygen loss in seasonally hypoxic coastal settings.

18. Deoxygenation is of great concern because oxygen is a limiting factor for productivity and biodiversity, regulates global cycles of nutrients and carbon and is required for the survival of individual organisms (see also paragraph 46 on Fish biodiversity and distribution). In deep (bathyal) regions oxygen loss results in

biodiversity loss and habitat compression among other ecosystem consequences (see paragraphs 49 to 51 on Deep-sea ecosystems).

Ocean acidification (chapters 5 and 9)

19. Global surface ocean pH (a measure of acidity) has declined on average by approximately 0.1 pH units since preindustrial times, an increase in acidity of about 30 per cent. Ocean pH is projected to decline approximately by an additional 0.2–0.3 pH units over the next century unless global carbon emissions are significantly curtailed. These changes can be observed in extended ocean time series, and the rate of change is likely unparalleled in at least the past 66¹¹ million years.

20. The interactions of ocean acidification in coastal zones with coastal processes, such as the upwelling of undersaturated water and land-based nutrient influxes, has become a high-priority area of research. Natural variability in carbonate chemistry, such as coastal upwelling and seasonal fluctuations in primary productivity, is compounded by anthropogenic changes to create particularly extreme ocean acidification conditions in some regions of the global ocean.

21. It has now been documented that ocean acidification is making it harder for some marine organisms, such as corals, oysters and pteropods, to form calcium carbonate shells and skeletons. In some cases, ocean acidification has also been shown to lower fitness in species such as coccolithophores, crabs and sea urchins (see also paragraphs 36 and 46 on corals and marine invertebrates).

Arctic sea ice (chapters 5 and 7)¹²

22. Sea ice melt in the Arctic has been one of the most iconic indicators of climate change. The extent of the Arctic sea ice area is declining by -2.7 ± 0.4 per cent per decade during the winter (March, 1979–2019) and -12.8 ± 2.3 per cent per decade during the summer (September, 1979–2018). While the decreasing trends during the winter are more evenly distributed around the pole, summer trends are almost twice as high in the Eurasian sector of the Arctic Ocean.

23. The thickness of sea ice in the Arctic has decreased by at least 40 per cent. The observed trends in sea ice area and thickness together indicate that the volume of Arctic sea ice has decreased by one-third in winter (April) and over two-thirds in summer (September) since 1979. This estimate is coincident with many modelling studies.

III. Extreme events

Marine heatwaves (chapter 9)

24. Marine heatwaves are periods of extremely high ocean temperatures that persist for days to months and can extend up to thousands of kilometres and can penetrate many hundreds of meters into the deep ocean. Satellite observations reveal that marine heatwaves doubled in frequency between 1982 and 2016 and became longer-lasting, more intense and more extensive. Over the past two decades, they have had a negative impact on marine organisms, ecosystems and fisheries in all ocean basins, including on critical foundation species such as corals, seagrasses and kelps. Early warning systems, producing skillful forecasts of marine heatwaves, can further help

¹¹In AR6 WG-I by IPCC (2021), the period of long-term trend of pH as reconstructed using boron isotope is the last 65 million years.

¹² See also paragraphs 48 and 69 on Polar wildlife and Knowledge gaps in scientific information.

to reduce vulnerabilities in fishing, tourism and conservation, but are yet unproven on a large scale.

25. With future global warming, marine heatwaves are expected to further increase in frequency, duration, spatial extent and intensity, pushing some marine organisms, fisheries and ecosystems beyond the limits of their resilience, with cascading impacts on economies and societies. Globally, it is very likely that the frequency of marine heatwaves will increase approximately 50 times by the period 2081–2100 under the high-emissions Representative Concentration Pathway 8.5 scenario¹³ and approximately 20 times under the low-emissions Representative Concentration Pathway 2.6 scenario. These future trends in the frequency of marine heatwaves can largely be explained by ocean warming. The largest changes in frequency are projected to occur in the Arctic Ocean and the western tropical Pacific Ocean.

El Niño Southern Oscillation (chapter 9)

26. The strongest El Niño and La Niña events since the pre-industrial era have occurred over the past 50 years, and that variability is unusually high when compared with the average variability during the past millennium. There have been three occurrences of extreme El Niño events during the modern observational period (1982–1983, 1997–1998 and 2015–2016), all characterized by pronounced rainfall in the normally dry equatorial eastern Pacific. There have been two occurrences of extreme La Niña events (1988–1989 and 1998–1999). At a more regional level ~~we note that~~ the influence of ENSO events on rainfall is more heterogeneous and depends on the confluence with other climatic oscillations of different periodicity acting simultaneously. In addition to rainfall ENSO influences on other ocean-atmospheric variables such as sea temperature, and positive anomalies in the Southeast Pacific have great consequences on ~~marine mammals, sea birds, especially guano birds, and cold-water fish populations, also affects different economic sectors such as~~ fishing, ~~agriculture and tourism affecting the economy~~ of ~~many~~ countries ~~like Peru~~.¹⁴

27. Extreme El Niño and La Niña events are likely to occur more frequently with global warming and intensify existing impacts, with drier or wetter responses in several regions across the globe, even with relatively low levels of future global warming.

Tropical and extratropical cyclones (chapter 9)

28. Anthropogenic climate change has increased precipitation, winds and extreme sea level events associated with a number of observed tropical cyclones.

29. An increase in the average intensity of tropical cyclones and the associated average precipitation rates is projected for a global temperature rise of 2°C, although there is low confidence in future frequency changes at the global scale. Projections suggest that the proportion of tropical cyclones that reach the strongest levels (category 4 and 5) will increase.

30. Rising sea levels will contribute to higher extreme sea levels associated with tropical cyclones. Such changes will have an impact on coastal infrastructure and mortality (see also the sections on marine infrastructure and human society).

31. Investment in disaster risk reduction, flood management (ecosystem and engineered) and early warning systems decreases economic losses from tropical cyclones that occur in most lying coastal areas, including islands. However, such

¹³For definitions of the Representative Concentration Pathways scenarios, see www.ipcc-data.org/guidelines/pages/glossary/glossary_r.html.

¹⁴The text provides additional information to the content of WOA2 suggested by the States that reflects general scientific consensus.

investments may be hindered by limited local capacities (see also the sections on sea level rise and cities, coastal erosion, marine infrastructure and human society).

IV. Marine ecosystems

Plankton and food webs (chapters 6 and 7)

32. Owing to global warming, the timing of the seasonal spring maximum of plankton biomass is shifting to earlier in the year at an average rate of 4.4 days per decade and the leading edges of a number of species distributions have extended poleward by, on average, 72 km per decade. The phenological changes (changes in timing) are projected to increase the frequency of occurrence of temporal mismatches that could lead to fish recruitment failures.

33. In the subtropical gyres, phytoplankton net primary production has decreased between 1998 and 2006 owing to climate-driven upper ocean warming and associated decreases in nutrient supply, while net primary production increased in coastal ecosystems as a result of increases in land-based nutrient inputs. This has led to a global spread of hypoxia in the ocean, a decline in the spatial extent of seagrass beds and increases in the occurrence of toxic phytoplankton events.

34. Global warming increases the importance of microbial food webs decreasing the export of biological production to the deep ocean. The ability of the ocean to absorb carbon dioxide can be reduced, accelerating global atmospheric warming.

35. The observed decrease in summer sea ice extent since 2016 presages a long-term shift from a food web dominated by Antarctic krill (*Euphausia superba*) to one dominated by salps (benefiting from warming), with unknown cascading effects on the abundance of vertebrate predators.

Corals (chapters 6 and 7)

36. Climate change threatens coral reef ecosystems. Coral bleaching due to global warming, the erosion and inundation of islands, ocean acidification and the effects of extreme events such as tropical storms and marine heatwaves are of particular significance. Consequently, coral cover continues to decline globally, with negative effects on biodiversity, and is also affected by extractive activities, pollution, diseases, physical destruction, outbreaks of several species and the increasing time required to recover after major disturbances such as storms.

37. Cold water corals, that are common features along continental margins, mid-ocean ridges and on seamounts worldwide, are highly sensitive to elevated temperature and deoxygenation (see also points 49, 50 and 51 on deep-sea ecosystems).

38. Future projected declines in the abundance of corals will reduce the habitat available to commercially significant species, reduce carbon sequestration in deep waters and eliminate potential genetic resources.

Mangroves, saltmarshes and seagrass (chapters 6 and 7)¹⁵

39. The global distribution, diversity and abundance of mangroves are affected by climate change owing to alterations in temperatures and rainfall regimes, affecting their reproductiv cycle and survive. Warmer winters and sea level rise are expected to allow for expansion towards mid latitudes and landwards at the expense of salt

¹⁵Mangroves, saltmarshes and seagrasses are known as the coastal blue carbon ecosystems. Coastal blue carbon ecosystems provide climate regulatory services through their carbon removal and storage.

marshes. However, habitat availability constraints may hinder expansion near certain range limits. Mangroves have been decreasing annually. Increasing human population density, [overexploitation of mangrove fauna](#), and unplanned development in coastal zones, are however, the main threats to mangrove forests today.

40. Saltmarshes have declined as a consequence of sea level rise. Decreasing water quality and changes in sediment delivery rates associated with human activity continue to affect the world's remaining wetlands, including saltmarshes.

41. Seagrass meadows continue to decline, in particular where they are in conflict with human activities. These marine ecosystems are being reconfigured as a result of climate-driven changes in species distributions, with some species projected to be functionally extinct by 2100. The combination of the poleward shift of habitat-modifying species as a result of climate change and fishing pressure can result in reduced ecosystem resilience.

Marine mammals, seabirds and reptiles (chapters 6 and 7)

42. Climate change and associated changes to marine ecosystem dynamics are now emerging as influencing a broader range of marine mammal species. Changes in circulation owing to climate warming in the North Atlantic have resulted in a northward shift of the copepod (*Calanus finmarchicus*), the main food source for the endangered northern right whale (*Eubalaena glacialis*). The changes have led to the whales altering their seasonal foraging pattern to follow the copepods.

43. Climate change has been reported to have already caused declines in almost 100 seabird species. For example, changes in sea surface temperature during late winter were associated with declines in the population growth rate of the black-browed albatross (*Thalassarche melanophris*), primarily through effects on prey availability and subsequent juvenile survival.

44. Rising temperatures associated with climate change are hypothesized to increase the feminization of the sea turtle population and embryonic mortality. Climate change impacts, from sea level rise (and associated habitat loss) to increased incidence of cyclones leading to nest inundation and coastal erosion, are also of concern for turtle populations

Fish biodiversity and distribution (chapter 6)

45. Overfishing and habitat loss and degradation in combination with climate change have been identified as major threats to marine fish biodiversity. Novel threats, for instance microplastic pollution, are also attracting increased research interest, even though considerable uncertainty remains about the population-level effect. The impacts of climate change and thermal stress on marine fish, in particular coral reef fish communities, have become more severe. Range shifts have been observed in response to global warming with most shifts being poleward or to greater depths towards previously cooler waters. Rates of range shifts are influenced by local rates of warming, ocean currents and ecological traits, with long-lived and highly migratory species changing slowest and shorter-lived species changing fastest.

46. There is concern that low-oxygen areas and their expansion make fish and mobile shellfish more susceptible to overfishing by concentrating populations in high-density aggregations above and at the edge of low-oxygen waters, making them more accessible for fishing gear, with consequences for food security.

Marine invertebrates (chapter 6)

47. Climate-induced changes in the distribution of benthic invertebrates are likely to affect the functioning and diversity of marine ecosystems. Several studies report changes in the poleward distribution of invertebrates, even at a slower rate than fish, but also consider benthic invertebrates more likely to respond directly to changes in temperature and acidification. In the Arctic -the Barents Sea, other seas to the north of Eurasia and the Far Eastern seas in the North Pacific, marine invertebrates are shifting northwards as a result of warming waters. Invertebrate biomass has declined in areas of the Alaska seas with consequences for higher trophic levels; native elders link this change to decreased sea ice coverage, the movement of sand bars and alterations in ocean currents. In the North Atlantic, climate warming has enabled the arrival of warm-water species in inshore areas of the United Kingdom influenced by the Gulf Stream.

Polar wildlife (chapter 7)

48. High-latitude ice habitats are characterized by high, but geographically variable, declines in sea ice extent as a consequence of climate change. The loss of Arctic Sea ice habitat and Antarctic ice shelves allows expansion of both pelagic and benthic species into the newly open water environments. In general, however, many ice-dependent species are decreasing in abundance and their spatial distributions may also be reducing, in particular in the Arctic. The impact of the decreasing ice on populations of marine mammals and seabirds is species-specific and depends on the extent to which individual species rely on the sea ice habitat. There is some evidence that, as prey habitats are changing, species such as the beluga whale (*Delphinapterus leucas*) are exploiting expanded marine habitats and are generally showing flexible feeding responses to environmental change. In contrast, the reduction in sea ice has reduced the abundance of the ringed seal (*Pusa hispida*) in Hudson Bay, and their distributional range in the Svalbard Archipelago has also contracted, which is leading to a major reduction in range overlap in those islands with the Arctic's top predator, the polar bear (*Ursus maritimus*). In response, polar bears have been observed feeding increasingly on ground-nesting birds and whale carcasses, with a concomitant increase in energy expenditure.

Deep-sea ecosystems (chapter 7)

49. Climate change will likely affect the abyssal plains. Projections suggest increased abyssal ocean temperatures and acidification, and decreased oxygen concentrations and downward flux of organic matter. Other oceanographic processes will likely respond, increasing stratification and reducing water mass exchange. Given the narrow environmental niches of abyssal biota, such changes could produce geographic shifts and increase the vulnerability of abyssal organisms to other anthropogenic impacts. Ocean warming triggering gas hydrate dissociation is a major stressing factor to cold seepage activity and ecosystems.

50. Climate change projections for the deep sea indicate substantial effects in bathyal habitats (200–3,000-m depths), including ridges, and their communities. Recent model projections indicate that bathyal depths worldwide will experience significant reductions in pH (0.29 to 0.37 pH units) in all oceans by 2100, and oxygen concentrations will decline by as much as 3.7 per cent in the bathyal North-East Pacific Ocean and the Southern Ocean. The flux of particulate organic matter (marine snow) to the sea floor will decline significantly in most oceans, most notably in the bathyal Indian Ocean, with a predicted decrease of 40–55 per cent by the end of the century.

51. Naturally occurring oxygen minimum zones reveal that biodiversity in continental slopes and submarine canyons is highly sensitive to oxygenation;

expansion of low oxygen zones will reduce biodiversity; projected declines in pH and food supply are likely to affect cold water coral ecosystems. Climate change also remains a major threat to seamount communities, with rising temperatures, declining oxygen concentrations and the shallowing of the aragonite saturation horizon. Some seamount fauna, such as cold water corals are vulnerable to changes in water mass characteristics.

V.Coastal communities

Sea level rise and cities (chapter 9 and 13)

52. Cities are becoming increasingly susceptible to sea level rise. Many comprise large areas of reclaimed land, which are retained and protected from erosion by hard-engineered structures such as seawalls and rock armouring. Many of these engineered coastlines will likely need to be adapted and upgraded to keep pace with rising sea levels. The impacts of climate change on coastal infrastructures are described in a dedicated section below (paragraphs 56 to 60).

53. As an alternative to hard-engineered coastal defences, which are complex and expensive, natural coastal ecosystems such as mangroves and saltmarshes can be used as natural barriers or combined with hard infrastructure using hybrid approaches. The retention and restoration of these ecosystems can protect the land and provide valuable ecosystem functions and services, including local livelihoods and food security. Recent developments in coastal protection strategies have involved supplementing structural engineering approaches with these “softer” or “greener” forms of coastal stabilization, which aim both to increase ecological co-benefits and to utilize the resilient attributes of natural systems, such as the adaptive capacity displayed by coastal dunes or the disturbance-recovery behaviour demonstrated by coastal wetlands and mangrove forests.

Coastal erosion (chapter 13)

54. Changes in coastal erosion and sedimentation patterns are likely to occur globally as a result of climate change, especially with projected rises in sea level and increased frequency and severity of storms. Human activities affecting the incidence of coastal erosion and sedimentation include the substantial growth in the number and scale of dams on major waterways, land-use changes leading to catchment deforestation and increased human occupation of the coastal zone, coincident with proliferation of coastal structures.

55. With sea level rise and an increase in the frequency and intensity of extreme climate events owing to climate change, coastal erosion will be more severe for islands where riverine sediment does not exist.

Coastal and marine infrastructure (chapters 9 and 14)

56. The causes of coastal defence structure degradation owing to climate change include wave forces on structures, wave overtopping and sea level rise. Newly developed or upgraded structures are needed to adapt to climate change in some regions, such as the South Atlantic Ocean, the wider Caribbean and the Mediterranean.

57. Responses to threats from climate change are varied and include a mix of hard and soft coastal defences. Forms of built infrastructure, such as seawalls or dykes, are

widely used but tend to be more costly and maintenance-dependent than nature-based solutions¹⁶, such as [the restoration of](#) marshes, mangroves, reefs or seagrass.

58. Climate change may influence the hazard risk to telecommunications cables by affecting storm frequency and intensity, as submarine landslides and sediment flows can be triggered by storms.

59. Coastal infrastructure in Pacific Island nations is mainly aimed at supporting economic development, preventing damage due to natural hazards, especially extreme storms and sea level rise, and adapting to climate change.

60. Coastal infrastructure development in the Arctic Ocean is challenged by rapidly changing weather, ice conditions and waves regime due to climate change. Declining sea ice cover is leading to an increase in shipping and related infrastructure though greater efforts to preserve facilities situated or dependant on frozen grounds.

Human society (chapter 8)

61. The vulnerability of coastal communities to the impacts of climate change is of increasing concern, in particular in small island developing States.

62. Small coastal communities are not just physically vulnerable to the impacts of climate change, but also socially vulnerable, in particular in rural areas. Rural coastal communities are vulnerable to extreme weather events and flooding owing to their geographic location and limited access to health care, goods, transportation and other services.

63. Coastal communities located in the Arctic, in low-lying (often deltaic) States, on paths frequented by cyclones or hurricanes and in densely populated coastal megacities are especially vulnerable to climate change.

64. Climate change-related increases in the frequency and severity of riverine and coastal flooding leading to the release of raw sewage and the run-off of vector animal faeces may also represent a health problem through the transmission of emerging infectious agents, such as in the context of the coronavirus disease (COVID-19) pandemic.

VI. Knowledge gaps and capacity development needs

Scientific observations (chapters 5 and 9)

65. Temperature records are regulated by, inter alia, the Pacific Decadal Oscillation, the El Niño-Southern Oscillation and the Atlantic Multi-decadal Oscillation. The caveat of observation-based analyses is that the record is still too short. The typical period of the Atlantic Multi-decadal Oscillation and the Pacific Decadal Oscillation is 30 to 70 years, similar to the length of the reliable ocean heat content record (approximately 60 years since the late 1950s). In addition, there is insufficient knowledge of El Niño Southern Oscillation mechanisms and feedback as well as its diversity related to global warming.

66. Coastal zones are highly under-sampled by sea level tide gauges and currently unsurveyed (within 10 kilometres of the coast) by conventional altimetry missions because of land contamination on radar signals. Future satellite missions will soon make it possible to estimate sea level change very close to the coast. In addition to the

¹⁶ The ~~concept~~ [expression](#) “nature-based solutions” has been used in the resolution on Implementation of the Convention on Biological Diversity and its contribution to sustainable development approved in 2021 in the GA. Additionally, a resolution on Nature-based Solutions for Supporting Sustainable Development was approved in the UNEA <https://www.unep.org/news-and-stories/press-release/un-environment-assembly-concludes-14-resolutions-curb-pollution->

lack of tide gauges in the coastal zone and the limitations of altimetric observations in the coastal zone, it is also necessary to consider that subsidence and liquefaction processes, among others, can alter the reference level with respect to land, and have a quantitative and qualitative impact on the identification of possible long-term changes in sea level at a local scale.

67. The current ocean observation network remains limited, in particular for coastal regions, marginal seas and deep ocean regions below 2,000 m. It is important to establish a deep ocean system to monitor ocean changes below 2,000 m to provide a complete estimate of the Earth's energy imbalance. There is a need to develop and maintain various platform observations for cross-validation and calibration purposes, including for the validation of climate models.

68. Marine ecosystem modeling is very useful and helpful to understand the biochemical impact due to climate change. More research is needed to enhance models and improve predictions of the Earth system's response to ocean acidification, its impacts on marine populations and communities and the capacity of organisms to acclimate or adapt to changes in ocean acidification-induced ocean chemistry. There remains a strong need for more extensive monitoring in coastal regions and high-quality, low-cost sensors to do the monitoring. There is also a clear need for expanded observations and increased understanding of effects of both acidification and deoxygenation and a need for a multi-stressor framework.

69. Maintaining in situ observation networks in the polar regions by means of autonomous buoys and manned platforms is challenging owing to the harsh environment and to access for deep water profiling typically being limited to the spring and summer seasons. Retrievals of geophysical parameters by satellite are improving, but in situ observations are required to validate these retrievals. In situ measurements of sea ice, snow on sea ice and ocean surface layer variables are invaluable to advancing understanding of physical processes in the polar regions. Density of these measurements is growing but is still highly insufficient in the Arctic, and even more so in the Antarctic¹⁷. The recently extreme change of Antarctic ice sheets should clearly influence global mean sea level, but the impacts to Global Mean Sea Level by Antarctic ice loss have very low confidence by rare observations¹⁸.

70. Combined analyses of models and observations are the proposed way to better understand climate change and variability on different time-scales. Current observation and research efforts of some parameters (e.g. ocean acidification and deoxygenation) are concentrated in a relatively small number of countries leaving large knowledge and capacity gaps around the world. ~~It is necessary to propose a~~ Numerical modelling ~~as~~ a complementary solution, and ~~at the same time present a real panorama comparison of a range~~ of numerical simulations, ~~showing possible~~ has the potential to identify current strengths and weaknesses in process understanding and modelling.¹⁹

Coastal erosion (chapter 13)

71. More information is needed on the extent of coastal erosion for the identification of appropriate management strategies for coastal erosion and sedimentation, including the management of riverine sediment supply and other management strategies, such as protection, accommodation and retreat.

¹⁷WMO Integrated Global Observing System (WIGOS), <https://community.wmo.int/activity-areas/wigos>

¹⁸The following footnote has been added "The text provides additional information to the content of WOA2 suggested by the States that reflects general scientific consensus."

¹⁹The text provides additional information to the content of WOA2 suggested by the States that reflects general scientific consensus.

72. The evaluation of global coastal change is not sufficiently mature to establish metrics for human-induced change to secular trends. Improved understanding about the interaction of coastal dynamic processes and sediment transport is needed. The accuracy of models for sediment transport and coastal erosion and/or sedimentation is still limited. It is essential to have more information aimed at a deep understanding of the wave conditions (sea and swell) and the marine currents at a local scale, considering their importance in the sediment transport. The importance of studying the impact of the climate change signal and of the ENSO events on variables such as waves is still underestimated.²⁰ With sea level rise and an increase in the frequency and intensity of extreme climate events owing to climate change, coastal erosion will be more serious for islands where riverine sediment does not exist.

73. The availability of satellite data remains immature in developing States for local and regional decision-making, with many data sets requiring substantial further interpretation and better worldwide spatial resolution.

74. A better understanding of how to attribute driving processes and determine responses and of how those processes will change with sea level rise and climate change is required.

75. Quantification of erosion or sedimentation rates needs to be placed in the context of thresholds for coastal ecosystems or morphological systems.

Marine infrastructure (chapter 14)

76. At the global level, not enough is known about the extent of coastal infrastructure, especially built coastal defence infrastructure, and its ecological and socioeconomic impacts.

77. Scientific understanding of the interactions between coastal dynamics, sediment transport and the environment and between ecological processes and marine and coastal infrastructure is still lacking.

78. A lack of proper knowledge and data also hinders correct design and construction and increases the environmental and ecological damage of coastal and marine infrastructure. The challenge of optimizing existing data (GIS, disaster loss and damage, economic, etc.) need to be addressed as well²¹.

Human society (chapters 5 and 8)

79. With regard to human society, and especially for communities of indigenous peoples, better information is needed on the climate change threats that they face and their economic and social situation. There are limitations in the knowledge about climate variability and risks which is a great constraint for decision-making at national and regional levels. Accurate climate extremes/disasters early warnings need to be disseminated timely to the coastal communities especially for the most vulnerable groups²².

80. Increased understanding of the health and environmental impacts of climate change, including food and water scarcity, is needed. Efforts to address those issues must include interdisciplinary research, which, in turn, requires the building of capacities to carry it out and apply the results. That necessitates both the training and retention of expert staff and the provision and financing of the necessary infrastructure. Efforts to tackle the causes of ill health linked to the ocean must also

²⁰The text provides additional information to the content of WOA2 suggested by the States that reflects general scientific consensus.

²¹The text provides additional information to the content of WOA2 suggested by the States that reflects general scientific consensus.

²²The text provides additional information to the content of WOA2 suggested by the States that reflects general scientific consensus.

include the provision of adequate infrastructures and skilled personnel, in particular with regard to the environmentally sound management of chemicals and all wastes throughout their life cycle, integrated water resources management and the testing of harvested food.

81. There is a knowledge gap with regard to the extent to which the ocean can produce health benefits through proximity to it, the delivery of marine-derived pharmaceuticals and the development of novel seafood.

82. The extent of socioeconomic and gender inequalities in the human environment and health, including health risks to children²³ and other vulnerable groups, posed by poor environmental, working and living conditions also needs to be known.

83. It is essential to include the component of education in marine sciences and social appropriation of knowledge. The first, focused on generating academic, technical, and scientific capacities in the community that contribute to the traceability and repowering of technological advances, considering education in marine sciences as a basis in each of the stages of academic training (at different ages, children, youth, and adults). The second (social appropriation of knowledge), visualized as a tool that guarantee the exchange of knowledge with the communities, articulating scientific knowledge with local knowledge, which strengthen the design and implementation of mitigation and adaptation strategies in the face of climate change.²⁴

V. Further reading

Division for Ocean Affairs and the Law of the Sea

United Nations, General Assembly (2021). Report on the work of the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea at its twenty-first meeting, 16 July 2021 ([A/76/171](#)).

United Nations (2017). *The Impacts of Climate and Related Changes in the Atmosphere and the Oceans – A Technical Abstract of the First Global Integrated Marine Assessment*. Regular Process for Global Reporting and Assessment of the State of the Marine Environment, Including Socioeconomic Aspects. Available at www.un.org/regularprocess/content/technical-abstracts

United Nations (2016). *The First Global Integrated Marine Assessment: World Ocean Assessment I*. Regular Process for Global Reporting and Assessment of the State of the Marine Environment, Including Socioeconomic Aspects. Available at www.un.org/regularprocess/content/first-world-ocean-assessment.

²³ In June 2021, the Committee of the Rights of the Child (CRC) decided to draft a General Comment on children's rights and the environment with a special focus on climate change (Draft General Comment No. 26), which will make recommendations to State parties to the Convention on the Rights of the Child relating to the issue. Its main objective is to provide authoritative guidance on a child-rights approach to environmental issues. Within this context, the CRC will convene a series of online and offline consultations with State parties, experts from relevant fields, children, and youth to inform and shape the draft general comment. UNEP is supporting the CRC through the Expert Advisory Board which oversees and provides guidance to the development of the General Comment. (see <https://www.ohchr.org/en/documents/general-comments-and-recommendations/draft-general-comment-no-26-childrens-rights-and>).

²⁴The text provides additional information to the content of WOA2 suggested by the States that reflects general scientific consensus.

World Meteorological Organization and Intergovernmental Panel on Climate Change

Cooley S., D. Schoeman and others. (2022). “Chapter 3: Ocean ecosystem and services”. In *Climate Change 2022: Impacts adaptation and vulnerability—Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Hilmi, K., and Levin, L. eds. Intergovernmental Panel on Climate Change. Available at www.ipcc.ch/report/ar6/wg2

Fox-Kemper, B., H.T. Hewitt, and others, (2021). “Chapter 9: Ocean, cryosphere and sea level changes”. In *Climate Change 2021: The Physical Science Basis – Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte, V., P. Zhai and others, eds. Intergovernmental Panel on Climate Change. Available at www.ipcc.ch/report/ar6/wg1.

World Meteorological Organization (2021). State of the global climate 2021: WMO provisional report. Available at https://library.wmo.int/doc_num.php?explnum_id=10859.

World Meteorological Organization (2020). *State of the Global Climate 2020*, WMO-No. 1264. Geneva. Available at https://library.wmo.int/doc_num.php?explnum_id=10618.

IPCC (2019) *IPCC Special Report on Oceans and Cryosphere in a Changing Climate: A Intergovernmental Panel on Climate Change*. Pörtner, Hans-Otto, and others, eds. Available at www.ipcc.ch/srocc.

Considerations for the third cycle of the Regular Process

The programme of work for the third cycle of the Regular Process indicates that assessment(s) produced will build on the findings of the first and second Assessment. The focus of these assessment(s) will be developed in consultation with relevant stakeholders through a scoping exercise facilitated through regional workshops and under the guidance of the Ad Hoc Working Group of the Whole of the General Assembly on the Regular Process.

In preparing the four briefs on climate change, biodiversity, SDGs and the UN Decades on Ocean Science for Sustainable Development and Ecosystem Restoration, a number of key areas of focus for consideration during the third cycle of the Regular Process (and its associated outputs) were highlighted by member countries, United Nations agencies and intergovernmental organizations. These include the need for the Group of Experts in developing outputs of the third cycle, to consider more directly:

- (a) Emerging policy areas, including those associated with blue and aquatic foods and blue transformations;
- (b) Opportunities provided through the blue economy, including emerging and novel technologies and solutions;
- (c) Gaps in the enabling environment for the science needed to progress and deliver global initiatives, innovations and solutions, including finance, linkages with industry and support from Governments;
- (d) Progress on achieving the transformations committed to by the High-level Panel for a Sustainable Ocean Economy. These include commitments to a range of transformations associated with ocean health, ocean wealth, ocean equity, ocean

finance and ocean knowledge required for achieving a sustainable ocean economy by 2030;

- (e) Progress on achieving Sustainable Development Goal 14: Life below water, and the impacts of the COVID-19 pandemic on achieving this Goal;
- (f) The impacts of the COVID-19 pandemic on ocean industries;
- (g) Progress on achieving Sustainable Development Goal 5, on gender equality, and achieving equal opportunities for women to participate, effectively contribute to and be recognised for their roles in maritime activities, ocean science and ocean governance systems;
- (h) Gaps in understanding of the role of law and policy in addressing and mitigating threats and restoring marine ecosystems, including capacity-building for countries to advance requisite skills to formulate and review appropriate legislation, and to provide effective oversight on the negotiation and implementation of internationally agreed environmental goals; development of knowledge guidance and information material tailored to parliamentarians to address legislative challenges related to the environment; sharing of best practices on legislation and oversight and providing platforms for dialogue between legislators and key stakeholders in the context of international environmental negotiations.

Further, a number of publications that have been produced since the finalization of the second *World Ocean Assessment* were highlighted by United Nations agencies and intergovernmental organizations as being relevant to the outputs of third cycle of the Regular Process. These include:

- (a) The proceedings of the 2019 FAO International Symposium on Fisheries Sustainability. The focus of this symposium was on identifying the need for a new vision for capture fisheries, including how fisheries need to transform in response to the complex and rapidly changing challenges facing society. The proceedings provide a description of each of the sessions of the symposium, a summary of plenary discussions and key messages and recommendations identified during the symposium;
- (b) The *Global Ocean Science Report 2020*, produced by the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organisation (IOC-UNESCO) provides an assessment of ocean science being conducted globally, by whom and how, on the basis of the analyses of contributions provided from 45 countries. Key findings are that ocean science is underfunded, females are underrepresented among participants in ocean science, early career scientists are largely not recognized for their contributions, technical capacity is uneven and, as a result, countries are inadequately equipped to manage their ocean data and information. This is despite the number of ocean science publications increasing over the period of the report;
- (c) A recent publication from the Intergovernmental Oceanographic Commission Global Harmful Algae Status Reporting initiative, which details the analysis of around 9,500 harmful algal bloom events over 33 years. It found that all ocean regions of the world were affected by multiple such blooms, but in varying proportions. The analysis also found that the negative impacts caused by harmful algal blooms had risen in step with the growth of the aquaculture industry and marine exploitation;
- (d) The *Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, which updates scientific, technical and socioeconomic understanding of the climate system and climate change, including impacts on and implications to the ocean, the services it provides and human society, including the vulnerabilities and capacity to adapt to climate change.