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

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Purpose and process of preparation of the briefs

The briefs provide a synthesis of relevant facts and information from the second World Ocean Assessment[[1]](#footnote-1) related to two key global issues (climate change and marine biodiversity) and two United Nations programmes (the Sustainable Development Goals and the United Nations decades known as the United Nations Decade of Ocean Science for Sustainable Development and the United Nations Decade on Ecosystem Restoration) that have been identified as priorities by the Group of Experts of the Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects, and the secretariat of the Regular Process.

The briefs were prepared pursuant to the programme of work for the third cycle of the Regular Process, covering the period 2021–2025, which was adopted in July 2021 by the Ad Hoc Working Group of the Whole of the General Assembly on the Regular Process and endorsed by the Assembly in December 2021.

Output II of the programme of work provides for support to other ocean-related intergovernmental processes, including the preparation of a series of briefs. In the case of the brief on climate change, the intergovernmental processes include the United Nations Framework Convention on Climate Change, the Intergovernmental Panel on Climate Change and the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea, 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.

The briefs were prepared by the Group of Experts with the assistance of the secretariat of the Regular Process, reviewed by the bureau of the Ad Hoc Working Group of the Whole and then considered by the Group at its sixteenth meeting.

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Introduction: visual summary of global ocean climate change indicators

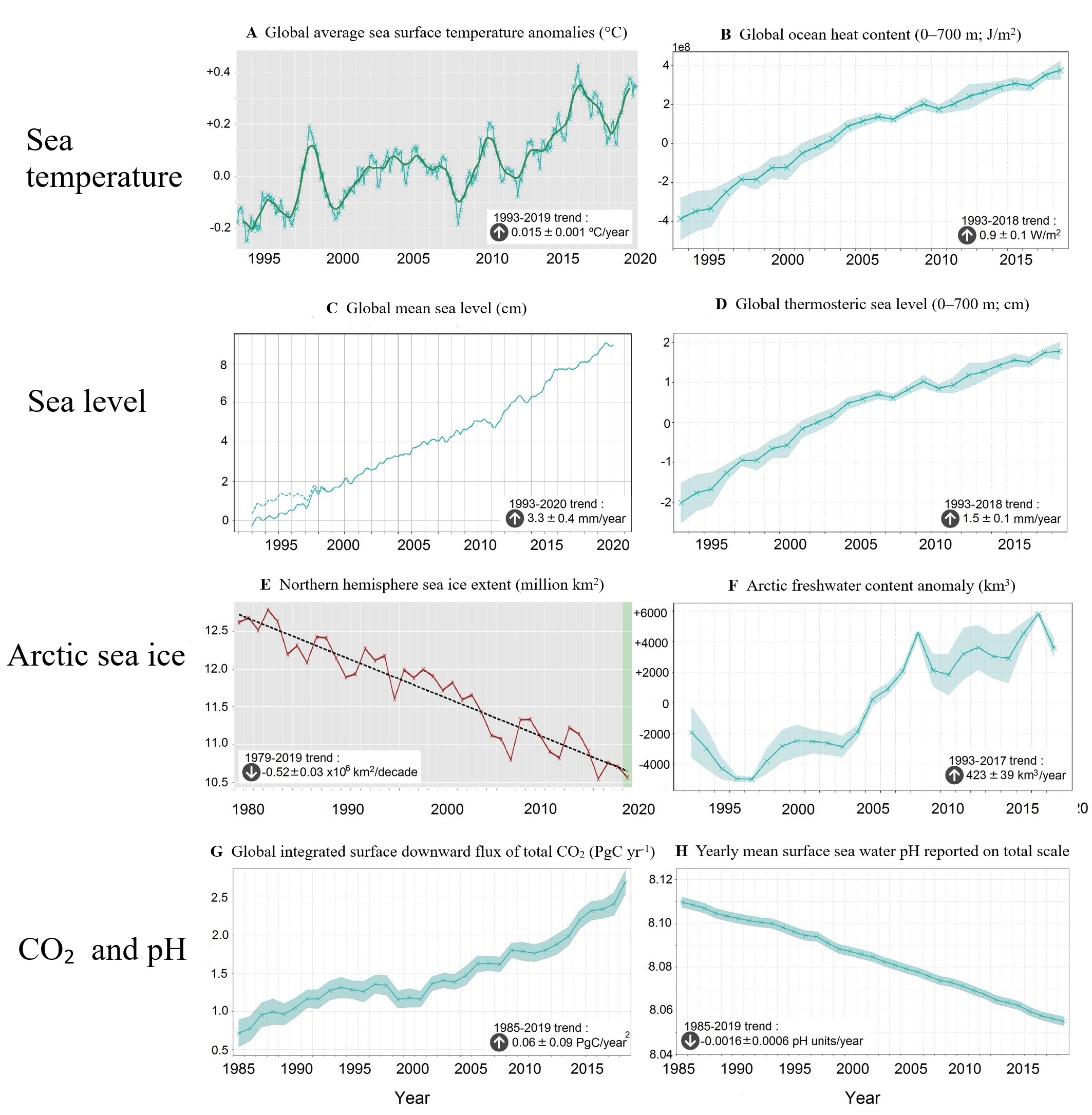
1. The ocean is currently experiencing a phase of significant climate change, and it is of the utmost importance to evaluate the rate of change. As an introduction to the brief, the figure below provides a visual summary of the trends during recent decades for some of the key ocean climate change indicators. The figure shows the global trends (from 1993 to 2019/2020) of increasing sea temperature, sea level rise and the decrease in Arctic sea ice extent and ocean pH (increasing ocean acidification). The indicators are considered essential climate variables in the Global Climate Observing System (<https://gcos.wmo.int/en/global-climate-indicators>) and are presented here as a quick first reference.

2. The sections below provide more details about the following: (a) physical and chemical impacts; (b) changes in extreme events; (c) impacts in marine ecosystems; (d) impacts and adaptation measurements in marine coastal communities; (e) knowledge gaps and capacity development needs; and (f) final remarks on potential interactions with other ocean-related intergovernmental processes. The final section provides key links for further reading.

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

Figure

Visual summary of global ocean climate change indicators



CO2 and pH

*Source*: Garcia-Soto, C., and others, 2021;[[2]](#footnote-2) individual figures credited to the Copernicus Marine Service of the European Union.

Keynote points

I. Physical and chemical impacts of climate change

Sea surface temperature and ocean heat content (chapter 5)[[3]](#footnote-3)

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. 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.

5. More than 90 per cent of the heat from global warming is stored in the world’s oceans. Increases in ocean heat content are observed throughout practically the entire ocean, down to 2,000 m. 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.

Sea level rise (chapters 5 and 9)

7. Since 1993, the global mean sea level has been rising at a mean rate of 3.1 +/- 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).

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 will continue for centuries, even if mitigation measures are put in place.

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 atmospheric water cycle.

Ocean circulation (chapter 5)

13. Different and independent proxy indicators of the evolution of the Atlantic Meridional Overturning Circulation published in recent years indicate that it is at its weakest for several hundreds of years and has been weakening during the past century. This weakening can also be seen in direct measurements over the past decade.

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.

Deoxygenation (chapters 5 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. In the upper water column, a temperature-driven solubility decrease is the dominating cause.

16. The area of oxygen minimum zones has typically been expanding in recent decades, although regional variability exists.

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.

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 the section on fish biodiversity and distribution).

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 the Industrial Revolution, 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 66 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 the sections on corals and marine invertebrates).

Arctic sea ice (chapters 5 and 7K)

22. Sea ice melt in the Arctic has been one of the most iconic indicators of climate change. The areal extent of Arctic sea ice 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 Pacific 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 over 75 per cent since 1979. This estimate is coincident with many modelling studies.

II. 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 kilometers 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 and ecosystems in all ocean basins, including on critical foundation species such as corals, seagrasses and kelps.

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 scenario[[4]](#footnote-4) 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 increases in mean ocean temperature. 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 2015–1916), 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).

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 category 4 and 5 tropical cyclones 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 near coasts and islands. However, such 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).

III. Marine ecosystems[[5]](#footnote-5)

Plankton and food webs (chapter 6A)

32. Owing to global warming, seasonal spring maximums in plankton biomass have advanced by 4.4 days per decade and the leading edges of species distributions have extended polewards by 72 km per decade.

33. In the subtropical gyres, phytoplankton net primary production 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. In the Antarctic region, krill (Euphausia superba) populations may have suffered from sea ice decline. The observed decrease in sea ice extent presages a long-term shift from a food web dominated by E. superba to one dominated by salps (benefiting from warming), with unknown cascading effects on the abundance of vertebrate predators.

Corals (chapters 6G, 7B, 7D, 7E, 7G and 7H)

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. Future projected declines in the abundance of corals (including cold-water 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 (chapter 6G)

38. The global distribution, diversity and abundance of mangroves are affected by climate change owing to alterations in temperatures and rainfall regimes. Mangroves have been decreasing annually. Increasing human population density and unplanned development in coastal zones, however, the main threats to mangrove forests today.

39. 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.

40. Seagrass meadows continue to decline, in particular where they are in conflict with human activities.

Marine mammals, seabirds and reptiles (chapters 6D, 6E and 6F)

41. Climate change and associated changes to marine ecosystem dynamics are now emerging as influencing a broader range of marine mammal species.

42. Climate change has been reported to have already caused declines in almost 100 seabird species.

43. Rising temperatures associated with climate change are hypothesized to increase the feminization of the sea turtle population and embryonic mortality.

Fish biodiversity and distribution (chapter 6C)

44. Overexploitation and habitat loss and degradation in combination with climate change have been identified as major threats to marine fish biodiversity. The impacts of climate change and thermal stress on marine fish, in particular coral reef fish communities, have become more severe.

45. 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.

Marine invertebrates (chapter 6B)

46. 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.

Polar wildlife (chapter 7K)

47. Ice-related habitats at high latitudes generally show high (albeit geographically variable) declines as a consequence of climate change, and many ice-dependent species are decreasing in abundance and reducing their distributions, in particular in the Arctic.

IV. Coastal communities

Sea level rise and cities (chapter 9)

48. 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.

49. 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.

Coastal erosion (chapter 13)

50. 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.

51. 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.

Marine infrastructure (chapter 14)

52. 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.

53. 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 ecosystem-based measures, such as marshes, mangroves, reefs or seagrass.

54. 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.

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

56. Coastal infrastructure development in the Arctic Ocean is challenged by rapidly changing weather and ice conditions due to climate change. Declining sea ice cover is leading to an increase in shipping and related infrastructure.

Human society (chapter 8)

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

58. 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.

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

60. 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.

V. Knowledge gaps and capacity development needs

Scientific observations (chapter 5)

61. 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 Oscilation 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.

62. Coastal zones are highly undersampled 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. The systematic use of new synthetic aperture radar technology in recent European Space Agency missions (e.g. CryoSat-2 and Sentinel-3) will soon make it possible to estimate sea level change very close to the coast.

63. 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.

64. 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.

65. Maintaining in situ observation networks in the polar regions is challenging owing to the harsh environment and to access 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 snow on sea ice and the thickness of sea ice are invaluable to advancing understanding of physical processes in the polar regions. These measurements are rare in the Arctic, and even more so in the Antarctic.

Coastal erosion (chapter 13)

66. 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.

67. More needs to be known about the interaction of coastal dynamic processes and sediment transport. The accuracy of models for sediment transport and coastal erosion and/or sedimentation is still limited.

68. 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.

69. 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.

70. 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)

71. 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.

72. 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.

73. 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.

Human society (chapter 8)

74. With regard to human society, and especially for communities of indigenous peoples, better information is needed on their state, the climate change threats that they face and their economic and social situation.

75. Marine citizen science approaches[[6]](#footnote-6) need to be further developed through the use of user-friendly sensors and the deployment of sensors on non-scientific ships to expand the collection of ocean observations and for early warning and prediction of marine hazards.

76. More needs to be known about the health and environmental impacts of climate change. Empirical assessments of the socioeconomic and health effects are sparse.

77. 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.

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

Final remarks: interaction with other United Nations processes

79. The briefs identify the related key knowledge presented in the second World Ocean Assessment and are aimed at interacting as appropriate with other ocean-related United Nations bodies and processes.

80. Relevant synergies between the Regular Process, the United Nations Framework Convention on Climate Change and the Intergovernmental Panel on Climate Change have been fostered in different ways.

81. They have been achieved, for example, by including authors from those specialized panels and bodies in the pool of experts and drafting teams of the second World Ocean Assessment, as was done for the chapters on climate change, or through the participation of those specialized processes in the scoping exercise that will determine the focus of the World Ocean Assessment during the third cycle of the Regular Process.

82. These United Nations processes can additionally supply direct input for the regional workshops of the Regular Process or venues for dissemination of its outputs.

83. The World Ocean Assessment is a global integrated assessment and can channel the conclusions and policy-relevant information of the diversity of United Nations ocean-related processes and assessments in a coordinated way, complementing their individual assessments and summaries.

84. Finally, the ocean and climate change dialogue of the Subsidiary Body for Scientific and Technological Advice of the United Nations Framework Convention on Climate Change and UN-Oceans ([www.unoceans.org](http://www.unoceans.org)) are also relevant forums at the current time.

85. Present and future collaboration pathways will advance the interaction of the Regular Process with other ocean-related United Nations intergovernmental processes and will make it possible to achieve the final goal of strengthening decision-making at all levels in a coordinated manner with respect to ocean climate change.

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](https://undocs.org/en/A/76/171)).

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3. In the present brief, chapters references are to chapters of the second World Ocean Assessment. [↑](#footnote-ref-3)
4. For definitions of the Representative Concentration Pathways scenarios, see [www.ipcc-data.org/ guidelines/pages/glossary/glossary\_r.html](http://www.ipcc-data.org/guidelines/pages/glossary/glossary_r.html). [↑](#footnote-ref-4)
5. See also the brief on marine biodiversity. [↑](#footnote-ref-5)
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