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Letter of transmittal

Letter dated 9 October 2025 from the Co-Chairs of the Ad Hoc Working Group of the Whole on the Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects, addressed to the President of the General Assembly

We have the honour to transmit to you, pursuant to paragraph 337 of General Assembly resolution 79/144 of 12 December 2024, the summary of the third *World Ocean Assessment* to be issued as a document of the Assembly at its eightieth session for final approval and for consideration by the Ad Hoc Working Group of the Whole on the Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects, at its twenty-third meeting, on 6 November 2025.

We kindly request that the present letter and the summary be circulated as a document of the General Assembly, under agenda item 75.

(*Signed*) Kimberly **Louis**

(*Signed*) Bahia **Tahzib-Lie**

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Summary of the third *World Ocean Assessment*

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Overall summary

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General

- The sustainable use of marine resources and services underpins environmental integrity, economic resilience, and social stability, with the ocean playing a central role in regulating climate, maintaining biodiversity, and providing food, minerals and energy vital to human well-being.
- Yet the ocean is under mounting stress from overexploitation, pollution, and the accelerating impacts of climate change, while global demand for biological, mineral, and energy resources continues to grow.

The ocean covers more than 70% of the planet and is the largest and most interconnected ecosystem. It serves as the planet's primary life support system, containing the majority of Earth's biodiversity. The ocean plays a crucial role in global nutrient cycles, particularly the carbon and nitrogen cycles, and it is a major producer of oxygen.

The ocean plays a fundamental role in the evolution of climate change as part of the planet's climatic system. The ocean has already absorbed over 90% of the excess heat and 30% of the CO_2 released into the atmosphere by anthropogenic burning of fossil fuels. Ocean currents redistribute heat at local and global scales. However, these currents are changing, and their impact on future climate change is not fully understood.

Many societies depend on the ocean directly or indirectly for their livelihood. The ocean provides a significant portion of the world’s protein supply and supports industries such as shipping, tourism, and renewable energy.

Cultural, spiritual, and recreational values are strongly connected with the ocean. Coastal communities around the world have rich traditions and cultural identities tied to the ocean, whether through art, traditions, or heritage. Recreational use of the ocean supports mental well-being and contributes to local economies.

Changes since WOA II

The WOA III builds on previous reports and updates WOA II, which was published in 2021 and covered the period from 2010 to 2018. Each chapter provides specific information on the progress and changes primarily observed between 2018 and 2023, except for newly introduced chapters. Most chapters describe all relevant information in relation to different ocean regions. The WOA now includes information on sustainability pathways and cross-cutting themes regarding gender, ITLK, and governance.

1. Stressors on the global ocean – drivers and pressures

Drivers of ocean change

- Ocean ecosystems and the services they provide continue to be reshaped by multiple interacting drivers, including climate change, economic shifts, technological advances, governance dynamics, and demographic trends.
- Understanding these drivers, and their cumulative impacts, is essential for designing adaptive, forward-looking policies that can safeguard biodiversity, sustain livelihoods, and support a resilient blue economy.

The ocean is subject to both natural (e.g. tectonic, solar) and anthropogenic (e.g. greenhouse gas emissions, population growth) drivers, which lead to a variety of stressors and pressures (e.g. atmospheric CO_2 levels, habitat destruction and plastic pollution). Progress is being made to manage drivers and mitigate pressures; however, many of them continue to negatively impact the ocean, especially its global biodiversity (see the "Social-Ecological Systems — Biodiversity and Habitats" section below). Although Ocean Hazards of Natural Origin are included in Section 5B (S5B.C4), this overall summary includes them under the subtitle "Ocean Pressures" because they are natural processes that can cause significant perturbations in ecosystems and socio-ecological systems, and because some are mediated by climate change.

Drivers of change to the ocean (S4.C1)

Drivers are widely recognised (e.g. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) or Regional Seas Conventions) as natural or anthropogenic factors that influence ecosystem structure, function or change.

The following human drivers have the greatest influence on the marine environment:

(a) Human population growth and demographic changes. Global human population increased from 7.7 billion in 2017 to 8.2 billion in late 2024. Currently, approximately 37% of the global population lives within 100 km of the coast, and 11% live on land less than 10 m above sea level. Population pressure heightens demand for food, space and resources, impacting the world ocean, including through habitat degradation.

(b) Economic activity. Global economic growth, measured as gross domestic product per capita, increased from 2.9% in 2019 to an estimated 3.3% from 2022 to 2024. Global energy consumption has accelerated from an increase of 1.5% per year around 2019, to 2.2% in 2023. Increased urbanization and industrialization have intensified the demand for energy and other resources, putting pressure on the oceans through extraction, production, consumption, and waste generation.

(c) Technological advances. Although advances in marine technology offer opportunities, they may also have negative impacts on the world's oceans.

(d) Changing governance structures and social, economic and geopolitical instability. Governance is improving rapidly due to greater global collaboration, but it is also facing major global challenges. To address these challenges, governance policies, politics, administration, and legislation need to be vertically and horizontally integrated globally and across sectors (see chapter 3).

(e) Climate change, biodiversity loss and pollution

The climate change suite of ocean pressures (e.g., warming, sea level rise, acidification, marine heat waves, storm surges, and tropical storms) exhibits significant geographical variability. However, these pressures particularly affect the coastal domain globally, where they couple with other anthropogenic stressors, such as pollution and coastal urbanization. The suite of climate change ocean pressures is increasingly disrupting ecosystem dynamics

and contributing to biodiversity loss. These pressures negatively impact the ocean economy, coastal activities, and human well-being, health, and livelihoods. Due to the geographical variability and different spatial and temporal scales at which these pressures occur, global to local responses and strategies must be implemented to effectively mitigate their impacts.

Ocean Pressures (S4.C6)

The ocean is subject to many anthropogenic pressures. As human activity is concentrated on the coast, coastal habitats suffer the greatest impact from these stressors, coupled with the effects of climate change. The combined influence of pressures generates cumulative effects that degrade ocean health, marine biodiversity, and pose risks to human well-being.

Land-based as well as marine pollution sources continue to impact the ocean (S4.C6 sub 5). Many types of legacy contaminants (metals, persistent organic pollutants (POPs) and radioisotopes) and emerging contaminants (plastics, pharmaceutical compounds and personnel care products (PPCPs) and per- and polyfluoroalkyl substances (PFASs)) have been introduced in the ocean. There is some evidence for a decline in emissions and precipitation of legacy contaminants such as mercury and some organic compounds in selected areas. However, persistent organic pollutants continue to impact many areas. Levels of pharmaceutical compounds (including antibiotics) continue to increase, particularly in coastal areas. Toxicity studies show significant adverse behavioural effects of PPCPs on marine organisms. Therefore, management action is needed to decrease the presence and potential impacts of pollution in the ocean.

Global plastic waste leaking into the ocean continues to rise, especially due to mismanaged waste, microplastic abrasion and loss, littering, and marine activities. There is limited understanding of nanoplastics. Microplastics, impact all marine ecosystems and there is evidence of their impact on over 4,000 species. Reducing production, developing material science innovation, increasing recycling and alternatives to single used plastic are needed.

The increased global demand for nuclear electricity is resulting in higher radioactive discharges.

Non-Indigenous Species

Non-indigenous species (NIS) continue to spread through various vectors, such as maritime transport. This has significant negative impacts on native species and habitats, with further economic, social, cultural, and human health consequences. Climate change exacerbates the spread and impact of NIS by facilitating their settlement and growth in novel locations due to changes in local environmental conditions.

Erosion and sedimentation

Since the mid-2010s, increased satellite data availability has enabled the detection of changing coastal erosion and sedimentation patterns and trends. Coastal erosion has significantly intensified in the Arctic, for instance, due to permafrost thawing and increased wave action, which are attributed to sea ice loss and longer ice-free seasons. Consequently, large quantities of nutrients have been released into the Arctic Ocean, which has implications for carbon sequestration and marine ecosystems.

Marine Infrastructures

The development of marine infrastructure, particularly beyond traditional coastal areas, has intensified and is exerting significant new pressures and impacts on the ocean ecosystems. This development results in the loss and disruption of natural habitats affecting biodiversity. Wind farms continue to expand further offshore putting additional human pressure on

understudied marine environments. The rate of construction of oil and gas infrastructure is also increasing, particularly in deeper waters. The placement of seafloor infrastructure, such as pipelines and cables, has a significant impact on continental slopes and submarine canyons. However, there is a growing focus on developing proactive infrastructure strategies to adapt to hazards, including nature-based solutions, buffer zones, physical barriers and systems for early warning and evacuations.

Cumulative effects

Since WOA II there has been continued recognition and research on cumulative effects and the need for coordinated management. However, there is a lack of global platforms and knowledge bases for mapping human pressures to understand their cumulative effects. Assessing cumulative effects is crucial to preventing ecosystem deterioration.

Ocean Hazards of Natural Origin (S5B.C4)

Geophysical and geological Ocean Hazards of Natural Origin (OHNOs), such as earthquakes, tsunamis, and volcanic eruptions, cause deaths and economic losses. Although tectonic subsidence operates on longer timescales, it interacts with OHNOs such as flooding, storm surges, and sea level rise. These hazards are increasing or are projected to increase due to climate change. Climate change is causing coastal erosion on all continents. By 2050, one-third of the low-elevation coastal zone is projected to experience a shoreline retreat of more than 100 meters.

Ocean weather, hydrological and climate hazards include tropical storms, meteo-tsunamis, waves, sea level rise, coastal flooding, marine heat waves, glacial melting, heavy rainfall and river flooding, droughts, saltwater intrusion, acidification and deoxygenation. These OHNOs are projected to increase or intensify with climate change but operating over very variable time scales. OHNOs lead to the loss of lives and land, damage to infrastructure and property, disruption of tourism, food systems, and livelihoods, coastal flooding and erosion, loss of habitats and biodiversity, loss of cultural and natural heritage, navigational and shipping challenges, and water quality issues, including saline intrusion.

2. Social-ecological systems (S5)

One Health (S5B)

One Health involves undertaking an integrated, unified approach to balancing the health of the physical and chemical marine environment with that of its inhabitants, including humans. The concept is based on several fundamental principles, including equity, inclusivity, equal access, parity, socio-ecological equilibrium, stewardship, and transdisciplinarity. The World Health Organization (WHO) recognizes its particular relevance to food and water safety, nutrition, controlling zoonoses, managing pollution, and combatting antimicrobial resistance.

Although One Health is a holistic concept, Section 5B groups aspects with a higher social component, such as human health, well-being, equity, gender, and ITLK, as well as aspects with a high social impact, such as the role of ecosystems in the carbon cycle, ocean hazards, and the impact of the COVID pandemic.

The role of marine ecosystems on the carbon cycle (S5B.C1)

Blue carbon

- Mangroves, seagrasses and saltmarshes, the first to be considered as Coastal Blue Carbon Ecosystems, hold higher carbon densities than terrestrial forests and host high biodiversity and associated services.
- Although their blue carbon value may be a significant financial resource as per the Paris Agreement, the understanding of their value is currently hampered by insufficient technical capacities for carbon accounting and financial mechanisms.
- Even with full restoration, CBCEs would only contribute 2% to the global climate mitigation targets.

The ocean contributes to approximately half of the Earth's annual primary production and supports 80% of global animal biomass. Marine ecosystems play a crucial role in driving the carbon cycle, which is linked to the health and well-being of billions of people due to its impact on climate change regulation and mitigation, as well as other related ecosystem services, such as food provision.

The biological pump (Fig.5B.C1.1) is the process by which plankton and nekton drive carbon from the surface of the ocean to the deep sea where it is remineralised by organisms. When carbon reaches depths below 500 to 1000 m, it becomes sequestered for hundreds to thousands of years. Although only about 2% of carbon fixed at the ocean surface reaches the deep sea, the large spatial extent of the open ocean ensures that it will continue to play a significant role in modulating climate change over decadal to centennial timescales.

However, the biological pump consists of a complex array of processes, such as sinking material versus migrating organisms, carbon dynamics within sediments and carbon export from shelf areas towards the open ocean. There is high uncertainty regarding their relative contributions and differences across geographical areas. Reducing these uncertainties is critical to understanding the role of the ocean as one of the major contributors to carbon sequestration.

Blue Carbon Ecosystems

The term Blue Carbon (BC) was first used for three vegetated coastal ecosystems, saltmarshes, seagrass meadows and mangroves, which capture and store more carbon per unit area than terrestrial forests. BC has broadened beyond these original Coastal Blue Carbon Ecosystems (CBCEs) to include other habitats.

Unvegetated seafloor sediments on the continental shelf make up around 9% of the total marine area but hold the largest carbon store in shelf systems. Over 80% of organic carbon is buried in these subtidal sediments.

The protection and restoration of CBCEs are recognized as nature-based solutions and an ecosystem-based approach to mitigating marine climate change. They may contribute to the achievement of Nationally Determined Contributions (NDCs) under the Paris Agreement. Several countries have initiated strategies to enhance the carbon sink capacity of coastal ecosystems through targeted conservation, restoration, and management. Recent estimates indicate that, with full restoration, CBCEs could contribute about 2% to the global potential for climate change mitigation.

In temperate regions, the small geographic size of these ecosystems makes it unlikely that they will play a significant role in achieving mitigation targets. However, for small island nations, with a larger geographical extent of BC habitats, the contribution may be significantly higher. Access to international financing and capacity building, including scientific cooperation, training and transfer of marine technology, are critical for the assessment and management of blue carbon~~ and to accomplish NDC's in the global south,~~

~~and therefore for achieving global targets~~ so as to ensure that efficient methodologies are applied. These actions are already included in various NDC and are necessary to achieve global targets.

Macroalgae have recently been suggested as a CBCE. While most of algal production is remineralised annually, a fraction is potentially exported to the open ocean or buried in the sediments.

While it may seem counterintuitive, calcification by marine organisms, such as corals and bivalves, provokes a net emission of CO_2, and many calcifiers additionally produce CO_2 through respiration. Recently, coralline algal beds found in sediments have been proposed as Blue Carbon habitats, because the carbon captured and stored through photosynthesis may exceed the CO_2 released by calcification.

Ocean and Human Health (S5B.C2) and Human well-being (S5B.C3)

Human Well-being and Health

- Oceans contribute to human well-being by providing a wide range of non-market benefits, including mental and physical health gains, cultural identity, spiritual fulfillment, recreation, and community cohesion. However, these contributions are under increasing pressure from climate change, pollution, habitat loss, and unsustainable exploitation, reducing the ocean's capacity to sustain people and nature.
- Human well-being and health both benefit from policies that connect conservation with equitable access, incorporate both market and non-market values, enable community-led stewardship and provide sustainable pathways for balancing human needs with ecosystem health.

The health of the ocean and human populations is deeply interconnected. There are many ways in which the ocean has a positive impact on human health. For example, there are benefits related to ocean sporting activities, the consumption of seafood, and the development of marine-derived pharmaceutical compounds. Well-being is also associated with the therapeutic and restorative qualities of marine environments, reinforcing the significance of accessible blue spaces for mental and physical health.

Ocean ecosystems contribute greatly to human well-being in ways that extend beyond health. These contributions include economic value and non-market benefits, such as spiritual, cultural, and recreational services.

Non-market valuation of marine ecosystems, despite its challenges, is crucial to understanding and quantifying the non-monetary value of the ocean, which can enable policy decisions that support both human well-being and environmental health.

Ocean ecosystems play an irreplaceable role in supporting cultural practices, traditional knowledge, intergenerational heritage and social cohesion, being particularly critical in the case of Indigenous Peoples. Communities interact with and depend on ocean resources, often employing innovative strategies to balance conservation with socio-economic needs.

The health and well-being benefits derived from ocean ecosystems are at risk due to escalating environmental challenges such as climate change, pollution, and resource depletion. Human health is increasingly challenged by harmful algal blooms (HABs), pathogenic bacteria and viruses, antimicrobial resistance, and toxic chemicals. Additionally, environmental radiation can further threaten marine ecosystems. Contaminated seafood poses

serious food safety risks and may cause endocrine disruption, neurotoxicity, renal dysfunction, osteoporosis, and various cancers.

The integration of cultural, economic, and ecological perspectives into ocean management policy ensures that the ocean continues to support human health benefits and well-being, cultural and natural heritage, and sustainable development for future generations.

Pandemics including COVID-19 Impacts (S5B.C7)

The COVID-19 pandemic resulted in a mixture of some short-term environmental benefits due to reduced human activity, alongside severe negative consequences for ocean-dependent communities, economies, and pollution levels. The COVID-19 pandemic had severe impacts on the health and safety of seafood workers and coastal communities. High infection risks, declining seafood demand, and global tourism losses disrupted business activities such as fisheries, port operations, and supply chains. Many fishing and tourism-dependent industries and communities faced significant financial losses, leading to increased unemployment and financial insecurity.

The COVID-19 pandemic reduced ocean use which reduced noise and improved reproduction for some species (e.g. whales). However, the pandemic also negatively affected marine ecosystems. Increased plastic waste, particularly from discarded face masks, threatened marine species. The pandemic also increased the use of specific medications and treatments, resulting in a higher concentration of pharmaceutical residues in marine environments.

Disruptions to scientific research and fisheries monitoring fuelled illegal fishing in certain regions. Due to the pandemic, many new policies were created to address health and safety issues related to ocean related employment (e.g. workplace safety). Many direct and indirect effects of the COVID-19 pandemic remain uncertain, underscoring the need for further research to prepare for future global health crises.

Trends in the physical and chemical state of the ocean (S4.C3)

Physical and chemical changes

- The alteration of ocean physical and chemical conditions due to climate change is accelerating.
- Approximately 16% of the total increase in ocean heat content since 1955 has occurred since 2018. The greatest relative warming has been observed in the Atlantic, and the southern parts of the Indian and the Pacific Oceans.
- Sea level continues to rise at increasing rates from less than 2.0 mm yr^{-1} prior to 2015 to 4.3 mm yr^{-1} in 2023. Tropical seas are rising more rapidly due to thermal expansion.
- The extent of Arctic sea ice continues to decrease, and the Southern Ocean has recently shown declines in sea ice extent. The Arctic Ocean could become entirely ice-free in September by mid 21st century.
- Ocean carbon dioxide uptake and ocean acidification also continue to increase, although with high spatial and interannual variability due to weather and climate conditions.
- Global ocean deoxygenation persists due to rising water temperature (reducing oxygen solubility and increasing stratification) and intensified microbial activity caused by nutrient runoff from land. Ocean hypoxic zones continue to expand (4.5 million km^2 in last 50 years).

The ocean continues to capture and store energy, warming at accelerated rates. Sixteen percent of the of ocean heat content increase from 1955 has occurred since 2018.

Salinity varies highly across the globe depending on the amount of freshwater input and evaporation and there is no significant global trend. Since 2018, salinity has decreased in the Pacific, North Atlantic, and Southern oceans but has increased notably in the mid-southern Atlantic and northern Indian oceans.

Sea level continues to rise at an increasing rate (2.0 mm yr^{-1} prior to 2015; 4.3 mm yr^{-1} 2023) due to thermal expansion (especially in tropical regions) and the melting of ice in polar regions. Additional variability is due to storm surges and tectonic/isostatic processes.

The extent of Arctic sea ice continues to decrease, and the Arctic Ocean could become entirely ice-free in September by mid 21st century. Currently, the decrease is more apparent in areas influenced by Atlantic and Pacific waters. The decrease of sea ice is resulting in changes to vertical stratification and mixing and further influencing circulation patterns. The Southern Ocean sea ice, which had seemed resilient to climate change, has recently shown declines in extent, most pronounced in regions south and west of the Antarctic Peninsula provoking changes in dense shelf water and associated Antarctic bottom water formation.

The weakening of the Atlantic Meridional Overturning Circulation (AMOC) is of particular concern due to its potential impact on the climate of the Northern Hemisphere, especially Europe. None of the recent models implemented by the World Climate Research Programme (WCRP) predict the collapse of the AMOC during this century, and the confidence level for the AMOC weakening is medium to low. This contrasts with previous WCRP results that predicted a slowdown of the AMOC, and with some models predicting an abrupt collapse during the twenty-first century. However, other studies have found that the AMOC is weakening and could reach a tipping point with an abrupt collapse by the mid-twenty-first century. AMOC circulation remains a research priority.

The ocean has decreased in pH ranging from 0.06 to 0.10 units from 1985 to 2022, with significant decrease penetrating down to 2000m depth. Ocean CO_2 uptake is responsible for the decrease in pH and is highly variable in space and time, but it has tripled in the last 60 years (1960–2019), reaching 2.7 ± 0.3 petagrams of carbon per year as of 2019. This value is expected to increase by 0.4 ± 0.1 petagrams of carbon per decade. However, this increase will be attenuated as the rise in temperature reduces CO_2 absorption. Total alkalinity, which measures the capacity to buffer acidity in the ocean, has increased in subtropical regions but varies greatly across the globe.

Global ocean deoxygenation persists due to the combination of increased nutrient pollution, rising water temperatures and intensified microbial activity. Higher water temperatures decrease oxygen solubility and increase ocean stratification. This restricts the vertical exchange of gases, heat, salt, and nutrients between surface, intermediate, and deep waters, thereby slowing deep ocean ventilation. Ocean hypoxic zones continue to expand (4.5 million km2 in the last 50 years), and the ocean continues to lose approximately one gigaton of oxygen per year.

Historical nitrogen data reveal differing trends across regions, most likely due to interactions between climate change and other anthropogenic sources and pressures. Recent phosphorous trends deviate from historical baselines, and climate change is expected to increase silica availability in the short term and a decrease in the long term (c. 150 years), but no global trends are observed yet. These results emphasize the need for updated monitoring and for understanding these complexities to accurately predict future biogeochemical cycles.

Biodiversity and habitats

- Anthropogenic, climate and other pressures are causing increasing adverse effects among all the marine taxonomic groups and habitats - from microbes to marine mammals and from the abyssal plains to the coastline.
- Climate change continues to produce impacts across the ocean, especially in high latitudes where temperature increase and sea-ice retreat are causing poleward distribution shifts across all taxa and affect the dynamics of habitats such as high-latitude ice and fjords.
- Climate-change-related extreme events (e.g. cyclones, marine heat waves or storm surges) occur across all latitudes, and are affecting many habitats, such as coral reefs which are declining rapidly.
- Coastal habitats are in general heavily impacted by accumulated effects of climate change, contamination (including plastics), coastal development, invasive species and nutrient upload.
- Land-use changes, and dam construction have drastically changed sediment fluxes, leading to coastal retreat in deltas and estuaries.
- Mangroves, seagrasses and saltmarshes are declining worldwide due to pressures such as coastal or aquaculture development, contamination, eutrophication, storm surges, cyclones and invasive species.
- The deepest parts of the ocean (e.g. trenches, abyssal areas) are difficult to access, are poorly understood, lack detailed mapping, and are increasingly under pressure for resource (e.g. mineral) extraction.
- A diverse array of marine protected areas (MPAs) are being developed and approved as part of marine spatial planning across the globe. International stakeholders are working to establish the first "blue corridors," or large-scale MPAs, to protect and ensure the long-term health of biodiversity.

Marine Biodiversity (S4.C4)

Marine biodiversity encompasses the variety of life forms within ocean ecosystems, ranging from microbes to large marine mammals. Biodiversity is critical to biological productivity, carbon cycling and climate regulation.

All marine life interacts in complex ways, providing resilience and stability to ecosystems. Since WOA II, marine biodiversity has undergone significant changes, influenced by increasing pressures that contribute to the worsening global biodiversity crisis, affecting the resources and services it provides to global society.

Plankton (S4.C4a) is the foundation of the pelagic food web, as well as shelf and deep-sea benthic habitats. It plays a fundamental role in biogeochemical cycles and for higher trophic levels, including those sustaining fisheries.

The most dramatic changes since WOA II were observed in the Arctic Ocean. The increasing phytoplankton biomass is associated with warming and sea-ice coverage, and changes are occurring in abundance, composition, phenology and distribution. Globally, phytoplankton blooms are unpredictable, disrupting carbon cycling and the accessibility of food availability for higher trophic levels. Zooplankton populations, especially krill, have demonstrated regional declines. The impacts of climate change on plankton in many regions remain unclear, largely due to the limited availability of long-term observational time series.

Cephalopods demonstrate resilience in the face of climate change due to their short life cycles and high reproductive rates, with some populations thriving as a result of increasing temperatures. Nevertheless, distribution patterns have changed, and certain exploited species consistently face pressures from fisheries.

Marine benthic invertebrates (S4. C4c), particularly corals, are experiencing increased stress due to the rising frequency of widespread bleaching events caused by elevated sea temperatures. Despite the positive effects observed from conservation efforts and MPAs since WOA II, the lack of knowledge about deep-sea species persists, as does their vulnerability to destructive activities such as trawling.

Fish (S4. C4d) populations consistently face challenges due to overfishing and habitat degradation despite improved fisheries management and bycatch reduction. While many reef fish continue to decline, some species like tuna show signs of recovery because of improved fisheries management measures.

Marine mammals (S4.C4e) persistently face risks from entanglement to vessel collisions, and plastic pollution. While some species (e.g. Mediterranean seals and dolphins) show slight recovery, others like the North Atlantic right whale remain critically endangered. Moreover, increased underwater noise pollution (e.g. armed conflict, shipping, offshore infrastructure) is disrupting marine mammal migration and communication.

Marine reptiles (S4.C4f), particularly sea turtles, struggle with habitat loss, plastic pollution, and climate change. Conservation efforts have led to improved nesting success, however general trends are alarming, especially as increasing sand temperatures are skewering hatchling sex ratios towards females.

Climate change similarly affects seabirds (S4.C4g), as changes in prey availability influence their reproductive success. Plastic ingestion and bycatch-related mortality has increased, though some bird species have experienced reduced mortality due to modified fishing techniques.

Marine vegetation (S4.C4h), including seagrass and mangrove ecosystems, is essential for coastal protection, and serves as key habitat supporting marine biodiversity. Pollution and coastal development continue to impact them and reduce their coverage area. Following WOA II, their climate-mitigating properties have become better known, spurring restoration projects. Macroalgae (S4.C4i), such as kelp forests, have diminished due to rising water temperatures and changing herbivore populations. Some regions have shown resilience due to conservation efforts; however, invasive macroalgae increasingly threaten native biodiversity.

Overall, the key findings underscore persistent challenges confronting marine biodiversity, including climate change, habitat loss, pollution, particularly from plastics, and overexploitation. Conservation efforts, strengthened regulations, and global cooperation are crucial for mitigating these impacts and preserving the resilience of marine ecosystems.

Habitats (S4.C5)

Marine habitats encompass diverse ecosystems, ranging from shallow coastal zones to deep-sea environments. These habitats are vital for maintaining biodiversity, providing ecosystem services, and supporting human livelihoods. However, they are increasingly impacted by pollution, habitat loss, climate change, and human activities. Sea-level rise, ocean acidification, increased extreme events, and habitat fragmentation have all contributed to changes in a variety of marine habitats since WOA II. Conservation efforts have grown, with a focus on nature-based solutions, ecosystem restoration, and sustainable management techniques.

The intertidal zone (S4.C5a) continues to experience significant transformations and habitat loss caused by sea level rise and coastal squeeze. Eutrophication and pollution, including micro-plastic accumulation, affects species and ecosystem services. Attempts to use intertidal ecosystems to mitigate climate change have increased. Conservation strategies increasingly use green-grey infrastructure, ecosystem co-design, and nature-based solutions.

Biogenic reefs and sandy, muddy, and rocky shores (S4.C5b) face intense pressures that threaten biodiversity and disrupt ecosystem functions. Coastal squeeze and human infrastructure already affect 33% of global beaches, with up to 26% at risk of severe sand loss by century's end. Emergent threats like plastic pollution (S4.C6 Sub 5) and artificial light at night further strain these environments requiring target research and mitigation strategies. Safeguarding coastal habitats requires robust governance that integrates diverse knowledge systems (e.g. traditional, Indigenous Peoples and local knowledges) and encourages participatory decision-making. Greater research is needed in tropical and subtropical regions, where data gaps persist, while addressing disparities in coastal management between high- and middle-income countries.

New understanding of atolls (S4.C5c), including the Antecedent Karst Theory and hydrogeology, are challenging previous models of atoll formation. Carbonate sand production and storm-driven sediment transport may help sustain atoll islands despite rising sea levels. Atolls face ocean acidification and warming seas, which weaken reefs and increase coral bleaching. Whereas some remote reefs recover within years, densely populated atolls take over a decade to regenerate. This reinforces the importance of integrated conservation approaches.

Coral reefs (S4.C5d) around the world are declining rapidly due to various stressors. Increasing disturbances, such as marine heat waves and storms, leave little time for recovery and are pushing reefs toward collapse. Since 2018, multiple global bleaching events have caused widespread coral mortality. Projections suggest that 90% of reefs could disappear if if warming exceeds 1.5°C. Even historically resilient areas, such as the South Atlantic, are experiencing severe losses. Rising hypoxia and ocean acidification add further stress. The Caribbean has lost 80% of its coral cover since the 1970s.

Although, cold-water corals and sponges (CWCS) (S4.C5e) face increasing threats, new discoveries, such as the extensive reefs on the Blake Plateau, highlight their role in carbon sequestration and ecosystem dynamics. Ocean acidification continues to weaken coral structures and further severe declines are predicted under high-emission scenarios. Advances in CWCS ecology improve our understanding of these fragile ecosystems, but long-term monitoring and policy integration remain limited. Expanding protection and global research efforts are urgent priorities.

Changes in estuarine and deltaic environments (S4.C5f) have significantly altered sediment dynamics, water quality and ecosystem structures. Since WOA II, drastic changes in land use and the construction of dams have altered sediment fluxes, resulting in accelerated coastal retreat and subsidence in many areas.

Seagrass meadows (S4.C5g) are essential for carbon sequestration, habitat biodiversity, and coastal protection. They are declining worldwide, with an overall decline of around 29% since the late 19th century. Since WOA II, marine heatwaves, storms, and sea-level rise have intensified these declines, especially in East and Southeast Asia, and certain regions of the North Atlantic. A large area (covering between 66,000 and 92,000 km²) of seagrass beds were discovered in the Bahamas. Major gaps remain, including outdated global, inadequate mapping in deep or turbid waters, insufficient comprehension of climate resilience and carbon sequestration rates, and an absence of conservation policies.

Mangroves (S4.C5h) offer important ecosystem services such as coastal protection, biodiversity and carbon sequestration, with an estimated economic value of $65 billion annually. Between 2010 and 2020, net annual mangrove loss declined to 102.4 km², primarily due to conservation efforts, compared to the previous decade. However, losses persist due to aquaculture, urbanization and sea-level rise. Notable restoration projects include China's goal to restore 18800 ha by 2025, Indonesia's goal to restore 600,000 ha by 2024 and Iran's initiative to plant 1,000 ha of mangrove forests.

Coastal development, pollution, sea level rise, and invasive species are causing saltmarshes (S4.C5i) to be in global decline. Since WOA II, losses have continued steadily, with some

areas experiencing mangrove encroachment driven by climate change. Although oil and chemical pollution has decreased, the accumulation of plastic is now a major concern.

Continental slopes and submarine canyons (S4.C5j) are increasingly affected by direct anthropogenic impacts, and by climate change. Fishing, waste dumping, litter and plastic pollution, oil and gas exploration and exploitation, placement of seafloor infrastructures, noise generation, and tourism appear as the most impacting human activities. Despite substantial advances in slope and canyon knowledge, conservation, and management, many of the gaps identified in WOA II remain. Most continental slope and submarine canyon habitats remain unexplored, and long-term data is limited, making it difficult to assess changes over the past 5-10 years.

Since WOA II, significant changes have taken place in high-latitude sea ice (S4.C5k). Arctic sea ice continues to decline, and an ice-free Arctic in September is likely within the next few decades. Meanwhile, Antarctic sea ice transitioned from gradual increase (1979–2015) to rapid decline after 2016, possibly indicating a regime shift.

Seamounts and pinnacles (S4.C5l) are submerged mountains that support distinctive deep-sea biodiversity, encompassing corals, sponges, and economically valuable fish species. Deep-sea fisheries are increasingly exploiting these ecosystems, resulting in habitat degradation. Since WOA II, conservation initiatives have intensified, resulting in enhanced protection of seamounts via MPAs and heightened recognition of their ecological significance. However, despite significant improvements, our understanding of abyssal seamounts, those found in areas beyond national jurisdictions, and the connectivity of seamount fauna remains limited.

Abyssal plains (S4.C5m), extensive deep-sea areas, are the most understudied marine habitats on Earth. These regions host unique species adapted to extreme conditions and contribute to global carbon cycling. An increasing potential threat from deep-sea mining for rare minerals raises concerns about the resulting potential for habitat destruction and biodiversity loss.

The pelagic domain (S4.C5n) is the largest habitat on Earth and plays a crucial role in global climate regulation, carbon cycling, and biodiversity. Since WOA II, advancements in observational technologies and environmental DNA (eDNA) techniques have enabled extensive data collection and supported multidisciplinary studies. The latest Earth System Models from the Coupled Model Intercomparison Project (CMIP6) have projected greater warming, acidification, deoxygenation, and nitrate reductions in the ocean, while new ecological insights, such as trophic amplification, show declining biomass in higher trophic levels.

Recent advances in deep-sea research highlight significant progress in hadal trench (S4.C5o) exploration, facilitated by new technologies, while progress on exploration of ridge systems remains limited. Since WOA II, significant findings on mid-ocean ridges have highlighted key areas of biodiversity and the impacts of human activities. The Mid-Atlantic Ridge, for example, exhibits high biodiversity supporting a wide variety of demersal fish and benthic invertebrates. The Arctic Mid-Ocean Ridge (AMOR), however, faces notable impacts from fishing, mineral extraction, and bioprospecting.

Hydrothermal vents and cold seeps (S4.C5p) host high levels of microbial and animal biomass supported by chemosynthesis and contribute to broader productivity and fisheries in the surrounding systems. Technological advances have enabled the discovery of thousands of these sites in the past, as well as the development of deep oil, gas and gas hydrate activities (seeps), and new mining exploration contracts (vents) issued in the Atlantic and Indian Oceans. Additional pressures on these ecosystems include global warming, deoxygenation, ocean acidification and altered circulation, deep-sea fishing, waste dumping and plastic debris. Conservation actions to date include scientific and industry codes of conduct, spatial protection as VMEs (Vulnerable Marine Ecosystems), MPAs, EBSAs (Ecologically or Biologically Significant Areas) and IUCN (International Union for the Conservation of Nature) red list designations.

The Sargasso Sea (S4.C5q) is an iconic high seas ecosystem that is internationally recognized as a crucial part of the global ocean. Since WOA II, significant environmental changes have been observed in the Sargasso Sea due to climate change, oceanographic shifts, and human activities. Ship traffic in the Sargasso Sea has increased over time.

The fjord systems (S4.C5r) of the world are characterized by a deep basin connecting directly or indirectly with the open sea at the mouth. They are specifically identified as carbon cycle hotspots. Fjords play a crucial role in regulating the carbon cycle over time due to their effectiveness in burying organic matter: Climate change is already affecting both northern and southern hemisphere fjords via warming, deoxygenation and acidification. The loss of glacier ice and the changing seasonality of the hydrological cycle is affecting physical and chemical factors and processes in fjords systems.

Marine food systems

- Seafood sourced from wild fisheries and marine aquaculture accounts for around 20% of the animal protein and 6.7% of the total protein consumed by humans worldwide.
- Fair, transparent, and sustainable trade frameworks will help to safeguard small-scale producers, ensure traceability and legality, and align seafood markets with climate, biodiversity, and food security goals.
- Sustainable seafood processing is a critical lever for enhancing food security, economic resilience, and social equity in ocean economies. This includes integrating circular economy approaches, such as using renewable energy, utilizing byproducts, and reducing emissions.
- Aquaculture is facing many challenges, including social acceptability, pollution and climate change, but it continues to adapt and grow and is increasingly important to ocean economies and essential to food and nutrition security.
- Marine capture fisheries production has remained relatively stable, however the proportion of global fishery stocks within biologically sustainable levels has continuously declined.
- Progress is being made across regions in fisheries governance structures and management.
- Sustainable pathways for small-scale and subsistence fisheries must address the cumulative effects of multiple drivers of vulnerability (e.g., social, economic, environmental and climate), build on the knowledge and experience of the fishers, and address their concerns about equity, human rights and security.
- Approximately 121 million people worldwide participate in marine recreational fishing. This widespread activity has substantial positive and negative economic and ecological impacts, especially on coastal ecosystems.

Food systems must ensure global food security and nutrition for a population expected to reach nearly 10 billion by 2050. Despite its large extent, the ocean provides only 4-8% of human food. Food systems are not only highly dependent on the environment but also exert significant pressure on it. Direct employment in fishing processing and related value chain activities is close to half a billion people. Sustainable wild fish and mariculture production is the foundation for sustainable seafood trade. The uneven geographical distribution of marine resources has historically driven trade from local to global scales, but the proportion of marine production that is exported has increased in recent decades.

Climate change is reshaping the global distribution of seafood. While interregional trade remains dominant for many regions, Asia has become an increasingly important destination. Although trade regulations, certifications, and traceability tools are emerging to support sustainable seafood trade, unknowns remain regarding their impact and effectiveness.

Due to the high perishability of fish and fishery products, and their importance in food, nutrition security and global trade, effective processing techniques are essential to extend shelf life, increase revenues, and enhance nutritional value (S5A.C1e). In 2022, of the 165 million tons of fish destined for human consumption, about 43 percent was live, fresh or chilled. This was followed by frozen (35 percent), prepared and preserved (12 percent) and cured (10 percent). Freezing is the main method of preserving seafood, accounting for 62 percent of the 93 million tonnes of processed aquatic animal production for human consumption. This represents about 89% for direct human consumption, with the remaining 11% for non-food purposes such as fishmeal for aquaculture and biofuel.

Since WOA II, significant progress was made in prioritizing seafood and aquatic food systems within the UN Decade of Science for Sustainable Development and the UN SDGs. Technological advances in seafood processing have great potential to promote sustainable growth and food security and to contribute to the conservation of marine ecosystems. As global demand for seafood increases, integrated policy frameworks and value chain improvements must be aligned to foster a more inclusive and resilient industry. Advanced processing techniques, particularly in the areas of traceability and rules of origin, will play a key role in ensuring compliance and meeting the diverse needs of stakeholders. By addressing some of the social and economic issues in coastal communities, the seafood processing industry can play a central role in promoting gender inclusion, fair wages, and decent working conditions for all.

Due to uncertainties and lack of global disaggregated data on small, medium and large-scale aquaculture, it is difficult to segregate the contributions and impacts of each sub-sector (S5A.C1c, S5A.C1d). In WOA III, medium and large-scale aquaculture refers to commercial orientated production for domestic or export markets, conducted by companies ranging from medium-scale enterprises through to large-scale multi-national companies. Between 2018 and 2022, marine aquaculture production increased from 55.7 million tonnes to 60.2 million tonnes, and the overall value increased from $76 billion USD to $89.2 billion USD.

Over the last two decades, aquaculture production increased at a rapid pace, and the sector has become more integrated into the global food system. There have been many improvements in farming methods in medium and large-scale aquaculture as well as major developments throughout aquaculture value chains, with aquaculture products now amongst the most globalised food items. Digitalisation and emerging technologies (e.g. block chain) are playing an increasingly important role in medium and large-scale aquaculture production. Increased attention has also been paid to the farming of low-trophic marine species, including large-scale molluscs and algae farming. However, issues of social acceptability and environmental impact must be addressed if the sector is to increase production significantly.

Over the past decade, significant efforts have been made to reduce the dependence on antibiotics in aquaculture, particularly due to the potential for antimicrobial resistance and its impact on human health. For feed aquaculture (e.g., fish and shrimp), concerns remain about the use of fishmeal and fish oil, overexploitation of wild stocks, and feed-food competition.

Climate change also poses challenges for medium and large-scale aquaculture production and the supply chain. Climate-related events affecting marine aquaculture include marine heat waves, harmful algal blooms, deoxygenation, storms, and typhoons. There is a need to focus more efforts on adapting aquaculture production to and mitigating climate change.

The assessment of small-scale aquaculture (SSA) in S5A.1d considered two different practices: (i) nearshore marine aquaculture (NSMA) and (ii) coastal marine aquaculture (CMA). The latter is typically practiced in constructed ponds onshore or in intertidal zones. SSA plays a significant role in global food security, livelihoods, nutrition, and health. On a global scale, most of the world's small-scale production of seaweed, sea cucumbers and sea molluscs are from NSMA, while crustacean production primarily takes place in onshore coastal brackish water ponds and tanks. In this case, CMA is dominated by brackish water shrimp and a few species of fish, crayfish and crabs. Some species and well-managed practices in SSA have low impacts on the ocean health (e.g. seaweeds and molluscs).

However, given the potential negative impacts of aggregation of small-scale aquaculture operations, spatial planning and consideration of carrying capacity limits should be promoted at national and regional levels. Over the past several decades, NSMA and CMA have experienced major disease outbreaks. Best management practices, including biosecurity measures, should be implemented to protect the activity and make SSA more sustainable with the least negative impact on the health of the ocean. NSMA and CMA cannot be sustainable without addressing the impacts of climate change and of stressors from land-based sources. In addition, the communities involved in NSMA and CMA are relatively poor and have limited resources, which limits their resilience to climate change.

Small-scale fisheries (SSF) (S5A.C1b) are of high social, economic, cultural and environmental importance and play a critical role in fostering food and nutrition security for millions of people. Small-scale and subsistence fisheries contribute significantly to national and global economies and are of great social and cultural importance. However, SSF are under increasing pressure from declining fish stocks and competition from industrial fisheries. The cumulative effects of a wide range of environmental stressors and climate drivers pose significant threats to the viability and resilience of SSF and subsistence fisheries in many regions of the world.

Large-scale fisheries (LSF) and medium-scale fisheries (MSF) (S5A.C1a) differ in scale and scope of operations, each with its own set of practices, impacts, and sustainability measures. While MSF plays a vital role in supporting local economies and livelihoods, LSF operations often have broader environmental and economic impacts that demand careful management and regulation. WOA III emphasizes the importance of ecosystem-based management, transparency, traceability, and stakeholder collaboration to mitigate the negative impacts of MSF and LSF.

Overfishing and illegal, unreported and unregulated (IUU) fishing are among the most pressing concerns in the sustainable use of the ocean resources. The fraction of global fishery stocks within biologically sustainable levels decreased to 62.3 percent in 2021, down from 64.6% in 2019, while many others are reaching their full exploitation or are in decline. It is estimated that between 8 and 14 million metric tonnes of unreported catches are globally traded illicitly yearly, representing gross revenues of US$9 to US$17 billion per year. In addition to the damage to fish populations and ecosystems caused by IUU, the estimated annual economic impact loss due to the diversion of fish from the legitimate trade system is estimated to be between US$26 to US$50 billion.

Marine recreational fishing (MRF) (S5A.C2) is defined as fishing of marine animals (mainly fish) that do not constitute the individual's primary resource to meet basic nutritional needs and are not generally sold or otherwise traded on export, domestic or black markets. MRF contributes billions of dollars annually, especially in developed countries, supporting local communities through job creation and encouraging marine stewardship. It is estimated that 121 million people worldwide participate in MRF. While the total estimated global marine recreational harvest is about 1% of total commercial landings, recreational removals are generally concentrated in a narrow band of coastal areas, and impacts are most intense in localized areas. The lack of formal recognition of the MRF sector is a fundamental problem in fisheries management, contributing to overfishing, conflicts with commercial and subsistence fishers, and reduced societal benefits from recreational fisheries. Addressing data gaps, stakeholder collaboration, socio-economic integration, and compliance through education and normative approaches are essential for effective management and societal benefits of MRF.

Sustainable resource use, goals and pathways

- Offshore oil and gas production is continually increasing and accounts for nearly one-third of global output, with deepwater and ultra-deepwater reserves driving recent exploration growth.
- Although incidents are trending downward, oil spills cause prolonged ecological disruption, with hydrocarbons persisting in food webs and affecting health, reproduction, and population dynamics.
- Offshore renewable energy (ORE) contributes to the global energy transition and to decarbonizing the economy, though the implementation of ORE requires careful consideration of environmental impacts.
- The long-term sequestration of CO_2 by geoengineering (or marine Carbon Dioxide Removal; mCDR) techniques, is considered as an alternative for climate change mitigation. However, their efficiency, viability and the potential adverse effects on ecosystem dynamics remain largely uncertain.
- Over 80 percent of global trade by volume is handled by maritime shipping. Decarbonizing the shipping sector is crucial because GHG emissions from ships contribute around 3% of global emissions.
- Tourism in coastal and ocean regions contributes over US$5.5 trillion annually and supports approximately 174 million jobs, making it the most significant sector of the ocean.
- Tourism can negatively affect the marine environment, but there is a growing role of nature-positive, community-based tourism models supported by targeted investments in ecosystems, cultural heritage, and inclusive governance.
- Socio-economic inequalities are reported in many coastal regions, where ocean dependent communities, particularly women and Indigenous people, often face limited access to markets, capital, and technology.
- Equity in ocean governance is essential to ensuring that the benefits, responsibilities, and opportunities of ocean use are shared fairly among all stakeholders, including women, youth, Indigenous Peoples, and marginalized communities.
- Including gender perspectives into ocean governance enhances the resilience and effectiveness of conservation and management initiatives.

Sustainable resource use refers to managing ocean resources in a manner that satisfies present needs without compromising the ability of future generations to meet their own needs. The sustainable use of natural resources is key to global environmental, economic, and social stability. The ocean plays an essential role in this process by regulating the climate, maintaining biodiversity, and providing critical resources for humanity, such as food, minerals, and energy (e.g. fisheries, oil, gas, and offshore wind). Sustainable resource use refers to managing ocean resources in a manner that satisfies present needs without compromising the ability of future generations to meet their own needs.

Observed trends in ocean renewable (S5A.C3a) and non-renewable (S5A.C3b) technology developments include offshore wind farms, tidal, and wave energy systems. While renewable energy developments focus on efficiency and cost reduction, efforts to explore non-renewable energy sources continue despite concerns about potential adverse environmental impacts. However, more sustainable approaches are emerging.

Emerging trends, such as increased global interest in offshore renewable energy, the potential use of geoengineering solutions, and growing awareness of the importance of ocean conservation, present opportunities and challenges. As the world moves toward a more

sustainable future, it is essential to balance the benefits of using ocean resources with the necessity of protecting marine ecosystems and securing social equity.

The development of offshore wind energy has become a leading solution in the renewable energy sector because offshore wind farms provide clean energy while minimizing environmental impact compared to fossil fuels. In contrast, the extraction of offshore oil and gas resources threatens marine environments, including habitat destruction and potential oil spills.

The role of ocean geoengineering (S5A.C10) solutions, i.e. the deliberate modification of the planet's environment, remains a contentious issue, with limited data and research on the impacts of this technology on the oceans and broader environment. However, it is one potential solution to the global climate crisis. Examples include but are not limited to ocean fertilization (aiming at increasing carbon absorption by stimulating phytoplankton growth) or ocean alkalinity enhancement (neutralization of ocean acidity).

While geoengineering is still an active area of research, some studies warn of its potential to disrupt marine ecosystems, harm biodiversity, and pose unknown consequences on global weather patterns). Furthermore, there are ethical and governance challenges related to the geoengineering solutions, since they may affect vulnerable communities, including coastal populations and therefore, there is a strong need for recognition of the ecological, social and economic impacts of such technologies and the development of international frameworks to govern them.

Shipping (S5A.C6) accounts for more than 80% of all world trade in goods by volume. It plays a critical role in global commerce by enabling the movement of goods and connecting businesses with customers worldwide. However, the global shipping fleet accounted for approximately 3% of total global GHG CO_2 emissions in 2023, and estimates show this figure could increase by 90-130% above 2008 levels by 2050. In times of unprecedented climate and environmental changes, sustainable shipping is of critical importance. Examples of such approaches include using cleaner fuels, employing technologies that reduce carbon emissions, and optimizing shipping routes to minimize environmental impact.

About 90% of commercial vessels use bunker fuel, a highly polluting energy source. This makes it difficult to significantly reduce emissions in the near future, since more than 70% of newly planned ships will continue to use traditional fuels. In addition to GHG emissions, shipping causes other types of environmental pressure, including chemical, biological, and energy pollution (S5A.C6). Therefore, environmental regulations, driven by concerns about pollution and climate change are becoming increasingly rigorous.

Ocean water desalination and salt production (S5A.C8) show increasing reliance on renewable energy, applied to support desalination plants. Technologies based on reverse osmosis and electrodialysis are improving efficiency. Salt production methods worldwide are rapidly evolving toward sustainable practices.

Since WOA II, the search for and use of marine genetic resources (MGRs) (S5A.C5), as well as the development of marine biotechnology, have continued to grow rapidly. Advances in marine genomics have led to many discoveries in sustainable bioproducts, pharmaceuticals, and biofuels. Although MGRs hold immense potential, they remain largely understudied. Most areas beyond national jurisdiction, including the deep sea, are still unexplored.

Mineral resources

The exploration and exploitation of marine mineral resources in maritime areas under national jurisdiction has been driven by demand. While deep-sea mineral exploration has occurred both within and beyond national jurisdiction, commercial exploitation has yet to begin. The sustainable exploration and potential exploitation of marine mineral resources

depend on scientific and technological innovation, stakeholder participation, and reliable information to effectively evaluate environmental, social and economic impacts (S5A.C7).

Despite its many positive aspects for humans, the rapid growth of coastal tourism (S5A.C4) can also lead to habitat destruction, pollution, and the overexploitation of marine resources, such as coral reefs and fish stocks. Unsustainable tourism contributes to marine pollution, including plastic waste, noise and hazard of oil spills, which harm marine life. Overcrowding at popular destinations can degrade local ecosystems and adversely affect the well-being of coastal communities. Emerging sustainable tourism practices, such as responsible waste management, eco-friendly infrastructure, and community-based conservation, are crucial to mitigating these impacts and securing sustainability.

Socio-economic inequalities are reported in many coastal regions, where ocean dependent communities, particularly women and Indigenous people, often face limited access to markets, capital, and technology (S5B.C5). Therefore, policies aimed at creating an inclusive ocean economy should emphasize social equity, access to resources, and the participation of marginalized groups in decision-making processes.

Ocean industries such as fishing, tourism, and renewable energy contribute significantly to economic growth, but they also present challenges in terms of wealth distribution and access to resources. Therefore, the concept of an inclusive economy is crucial for securing benefits of ocean resources and their fair distribution across society, including marginalized groups.

The UN Sustainable Development Goals put strong focus on the importance of gender equality in all aspects of sustainable development, including the governance of ocean resources. Integrating gender perspectives into ocean policies secures that the needs, perspectives, and rights of women are recognized, ensuring inclusive and effective management of marine resources (S5B.C6).

Gender-oriented policies and programs that provide women with equal access to resources, decision-making power, and economic opportunities are crucial for promoting both gender equality and the sustainability of ocean resources.

Ocean Governance

- The recent adoption of the BBNJ Agreement marks a milestone in extending conservation and sustainable use into areas beyond national jurisdiction, reinforcing modern environmental standards and equitable benefit sharing. The Agreement opens up a new pathway for internationally recognized Area-Based Management Tools including marine protected areas for the high seas
- Yet, the challenge remains to overcome institutional and thematic fragmentation, ensuring that global, regional, and national efforts align under shared principles such as the ecosystem approach, precautionary action, and best available science.
- WOA III is the first ocean integrated assessment to include an ocean governance section.
- The fragmentation of ocean governance at global and regional levels has continued to draw significant attention over the past five years, thereby promoting the development of different mechanisms including cross-sectoral interplay, systemic responses such as judicial proceedings, and others that strengthen and foster multilevel cooperation such as in the BBNJ Agreement;
- The application of ocean governance concepts across global and regional institutions strengthens legal connectivity, enhancing coherence and synergies in governance.

Ocean governance (Section 3) is underpinned by a highly complex and dynamic interplay of states, multilevel intergovernmental institutions and regimes where concepts, principles, and means of implementation are developed and used.

The 1982 United Nations Convention on the Law of the Sea (UNCLOS) sets out one of the key legal framework within which all activities in the ocean and seas must be carried out. Other global treaties have been progressively agreed in the last 70 years, including two agreements that entered into force in 2025 (BBNJ Agreement, 2023; Fisheries Subsidies Agreement, 2022). These treaties address various aspects of the marine environment, including biodiversity protection, harmful fisheries subsidies, pollution from sectoral activities and other threats to the marine environment.

In addition, many non-binding instruments, customary laws, and associated intergovernmental policy processes focus on the marine environment. These processes can facilitate cooperation, action, and coordination between states (e.g. UN mechanisms such as UN-OCEANS) or the development of a common scientific understanding (e.g. IPCC, IPBES, WOA and UN Decade of Ocean Science for Sustainable Development).

However, the fragmentation of ocean governance at the global and regional levels has continued to draw significant attention since WOA II. In recent years, new binding and non-binding instruments have been developed to strengthen the existing governance framework and address gaps in ocean governance, including mechanisms for cross-sectoral interplay (e.g. Convention on Biological Diversity, Kunming-Montreal Global Biodiversity Framework (CBD GBF), 2022; Fisheries Subsidies Agreement, 20252; BBNJ Agreement, 20235; International Maritime Organisation (IMO) Greenhouse Gas (GHG) Emissions Strategy, 2023)

The application of ocean governance concepts across global and regional institutions strengthens legal connectivity, enhancing coherence and synergies in governance.

Over the last five years, the areas of concern of relevant intergovernmental institutions have expanded beyond traditional marine environmental issues (e.g. pollution and fisheries), to include more recent priorities like climate change mitigation, plastic pollution, ocean monitoring and observation, food security, maritime security, migration by sea, and human rights.

Overarching objectives such as sustainable and inclusive ocean economies, blue health, and blue justice are playing a significant role in ocean governance, and the social sciences are becoming increasingly relevant.

4. Marine observations and ocean knowledge

Marine observations, technological developments advancing our scientific understanding of the ocean

Effective ocean management, decision-making, and policies must be based on observations, information, and scientific knowledge acquired through an extensive and diverse array of methodologies and technologies used by multiple disciplines, including the social sciences, which are integral to the ocean system. Technologies and methodologies for ocean observation are developing rapidly, and together with advances in modeling, they are greatly increasing our scientific understanding of the ocean and the development of management tools. These advances are partially responsible for the progress made since WOA II. However, significant gaps remain in our knowledge of vast areas and important components of the ocean. There are also inequalities in access to data and technologies, as well as in scientific capacity across regions.

The use and development of automated or semi-automated ocean observation platforms, such as Argo floats (which are now expanding to include deep Argo floats that observe depths beyond 2,000 meters), gliders, submarine cables, unmanned autonomous vehicles (UAVs), remote observing vehicles (ROVs), and drones, continues to expand. These platforms provide

valuable data and information at an increasing range of spatial and temporal scales and resolutions beyond the ocean's surface. The observation of the ocean's surface was revolutionized decades ago by the use of satellites. However, the deeper domains of the ocean remain one of the major knowledge gaps due to the challenges of observing deep waters, especially those far from the coast. This will be a major challenge during the implementation of the BBNJ treaty. Nevertheless, significant progress has been made in identifying hotspots of biodiversity in deep-sea habitats, such as seamounts, submarine canyons, trenches, and hydrothermal vents.

Newer observation platforms are equipped with higher-resolution and more precise sensors, as well as sensors that can measure new variables. Examples include the use of higher-resolution satellite sensors, the incorporation of biogeochemical variables into Argo floats, advances in image acquisition systems, and the use of passive and active acoustic sensors in biological studies, including fisheries. The COVID-19 pandemic revealed the critical importance of automated data acquisition systems when non-automated monitoring systems were interrupted.

However, the acquisition of real-time or near-real-time data is skewed towards physical variables rather than biological variables, with biochemical variables falling somewhere in between. This imbalance is due to the complexity of the biological components of marine ecosystems, the different nature of their variables (e.g. taxonomic, ecological, and physiological), the lower number of sensors developed for biological variables, and the energy consumption of image acquisition systems and active acoustic sensors. Nevertheless, image acquisition systems and advances in acoustic technologies have significantly improved our understanding of biodiversity and species distribution patterns, as well as fisheries management.

Nevertheless, research vessels are still essential platforms for studying the biogeochemical and biological components of the ocean, as well as for managing biological resources, such as fisheries, and for the conservation of biodiversity, habitats and ecosystems. In most cases, samples must still be processed in a laboratory.

The advancement and expansion of biomolecular technologies, such as genetic sequencing, *in situ* sequencing platforms, synthetic biology, metagenomics, and eDNA/metabarcoding, have led to significant progress in biodiversity and ecology studies across all taxonomic groups, habitats, and fisheries, aquaculture, and Marine Protected Areas implementation and management. Nevertheless, the application of these techniques is limited. For example, the study of biodiversity still requires on-the-ground verification by expert taxonomists. Unfortunately, the number of taxonomists is decreasing globally, which has become a serious concern.

Furthermore, long-term monitoring and observation systems are needed to understand long-term ecosystem dynamics, including the effects of climate change, as well as for management and decision-making purposes. International initiatives such as Argo and GOA-ON, which are coordinated under the Global Ocean Observing System (GOOS), as well as more recent programs under the Ocean Decade, continue to reinforce international cooperation and assist with implementation and standardization of methodologies and ocean indicators. However, long-term monitoring programs are often hindered by a lack of adequate long-term funding.

Modeling is now widely used across all disciplines, including climate change, ocean circulation, species distribution, erosion and sedimentation, food web dynamics, and fisheries and aquaculture. It contributes to progress in scientific understanding and serves as a management tool. The implementation of Digital Twins of the Ocean (DTOs) and the application of artificial intelligence (AI) are particularly promising for management

decisions. However, both DTOs and AI require extensive data sets that adhere to the FAIR principles (Findable, Accessible, Interoperable, and Reusable). Although many data remain inaccessible, initiatives such as the European Marine Observation and Data Network (EMODnet), the Bureau of Ocean Energy Management, the Mid-Atlantic Ocean Data Portal, and the International Oceanographic Data and Information Exchange (IODE) are contributing to this demand.

As discussed in the governance section (and further in S4.C1), effective decisions for the sustainable management of the ocean require the incorporation of social sciences. Therefore, ocean observation systems must integrate social variables, and social science is increasingly incorporated into knowledge systems.

Indigenous, traditional and local knowledges

- ITLK is increasingly being acknowledged as a valuable component of knowledge systems and ocean governance models. Effective knowledge systems are challenged by a persistent failure to recognize or engage with diverse world views, including indigenous ways of knowing. Ocean governance models that incorporate ITLK are more likely to achieve comprehensive marine ecosystem and well-being outcomes.

Indigenous Peoples, traditional and local community knowledges (ITLK) collectively refers to knowledge systems developed by Indigenous Peoples, traditional communities and local communities through extended close interaction with their surrounding environment or long-standing continuous culture (See Section 5B Chapter 8 for in-depth description). ITLK are increasingly being acknowledged as a source of information complimentary to classical scientific information.

There is growing recognition that ITLK can provide valuable insights for sustainable resource management and biodiversity conservation. The loss of biodiversity and habitat is not only a significant ecological loss but also leads to the loss of cultural identity. The cultural assets of most Indigenous, traditional and local communities are linked to the natural environment and significant changes in these environments can undermine the cultural security of these communities. The impacts of change (e.g. climate) are different across societal and cultural groups and may vary greatly between Indigenous and non-Indigenous Peoples. Certain social classes and groups will be impacted differently than others. The WOA III has recognized the need to meaningfully weave ITLK throughout the assessment in order to capture a more holistic understanding of the state of the marine environment and inform sustainable ocean.

The ocean is an essential part of the planet's life support system. Improving its health is crucial to the sustainability of marine ecosystems and the well-being of all life on Earth. Scientific understanding of the ocean must be advanced from an interdisciplinary perspective and across spatial and temporal scales if human activities and climate-related impacts are to be managed effectively.