Draft 3 of the third World Ocean Assessment [text is unedited]

Section 1: Overall summary

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~~1. Introduction~~

General

- The sustainable use of marine resources and services underpins environmental integrity, economic resilience, and social stability, with the ocean ~~plays~~playing a ~~crucial~~central role ~~for life on Earth,~~in regulating climate ~~and ecosystems, and it supports world economies. Covering~~, 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 ~~Earth's surface, the ocean constitutes~~planet and is the largest and most interconnected ecosystem ~~on Earth. It sustains a diverse range of marine life and contributes to numerous, complex environmental processes.~~ . 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.

~~Part of the climatic system of the planet, the~~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 ~~more than~~over 90% of the excess heat and 30% of the ~~C02~~CO_2 released ~~to~~into the atmosphere by ~~the~~ anthropogenic burning of fossil fuels.

Ocean currents~~, due to the high absorption capacity of the water and the enormous mass of the ocean, with an average depth of approximately 3600 m, contribute to~~ redistribute heat ~~and buffer temperatures~~ at ~~global to~~ local and global scales. ~~Modifications of global ocean current patterns~~However, these currents are ~~already conspicuous~~changing, and ~~although the consequences for the evolution of~~their impact on future climate change ~~itself, no matter how, will be critical, are yet to be~~is not fully understood.

~~The majority of Earth's biodiversity is contained within the ocean. Coral reefs, for example, are among the most biologically diverse ecosystems on the planet, providing habitat for countless marine species. The ocean is also home to not only fish, mammals, and numerous plants and algae but microorganisms that are crucial in the global biogeochemical cycles. The ocean ecosystems provide essential services, such as oxygen production, nutrient recycling, and support to food webs that sustain life on our planet.~~

Many societies depend on the ocean directly or indirectly ~~depend on the ocean~~ for their livelihood. ~~Fisheries and aquaculture provide~~The ocean provides a significant portion of the world's protein supply~~, especially for coastal~~ and ~~island communities. The ocean also~~ supports ~~numerous~~ industries ~~like~~such as shipping, tourism, and renewable energy~~, offering substantial contributions to the global economy~~.

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~~, underscoring the ocean's role in prosperity and human resilience~~.

~~The ocean is a key part of the planet's life support system. Improving the health of the ocean is essential not only for the sustainability of marine ecosystems but also for the well-being of all life on our planet. Advancing scientific understanding of the ocean across spatial and temporal scales is key for effective management of human activities and climate-related impacts.~~

Changes since WOA II

The WOA III ~~derives directly from the~~ builds on previous reports~~, especially to the findings of the~~ and updates WOA II, which was published in 2021 ~~with information up~~and covered the period from 2010 to 2018. Each chapter provides specific information on the progress~~/~~ and changes ~~which have been~~primarily observed between 2018 and 2023, except for ~~those chapters that are~~ newly introduced~~. A key new feature of WOA III is that~~ chapters. Most chapters describe all relevant information in ~~each chapter is described in~~ relation to different ocean regions. The ~~novelty aspects of~~ WOA ~~III~~now includes~~, the inclusion of a section~~ information on sustainability pathways~~,~~ and cross-cutting themes ~~on~~regarding gender, ITLK, and governance~~, in every chapter where relevant~~.

~~2~~

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). ~~Although progress~~Progress is being made to manage drivers and mitigate pressures; however, many of ~~these~~them continue to negatively impact the ~~world~~ ocean, especially its global biodiversity (see the "Social-~~ecological systems –~~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 (~~See also Section 4, Chapter 1~~S4.C1)

Drivers are widely recognised~~—across platforms such as~~ (e.g. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES~~), Intergovernmental Panel on Climate Change (IPCC), the European Economic Area (EEA), and the~~) or Regional Seas Conventions~~—~~) as natural or anthropogenic factors that influence ecosystem structure, function~~,~~ or change.

The ~~WOA III acknowledges the~~following human drivers ~~having~~have the greatest influence on the marine environment~~ and its sustainability are~~:

(a) ~~Population~~ Human population growth and demographic changes~~,~~

. Global human population increased from 7.7 billion in 2017 to 8.2 billion ~~between 2017 and~~ in late 2024~~, though the growth rate is slowly decreasing. Approximately~~. Currently, approximately 37% of the global population lives within 100 km of the coast, and 11% live on land ~~that is~~ less than 10 m above sea level. ~~The increasing population~~ Population pressure ~~on river catchments~~ heightens demand for food, space and resources, impacting the world ocean~~. Increasing populations also result in increased resource removal, such as fishing, which can be a major driver of~~ , including through habitat degradation.

(b) Economic activity

~~Economic~~ . Global economic growth, measured as gross domestic product per capita, ~~is variable but has overall~~ increased ~~globally~~ from 2.9% in 2019 to an estimated 3.3% ~~in~~from 2022~~-~~ to 2024. Global energy consumption ~~growth~~ has accelerated from an increase of 1.5% per year around 2019, to 2.2% in 2023. ~~The increased~~Increased urbanization and industrialization~~, particularly in coastal regions,~~ have intensified the demand for ~~societal goods and benefits such as~~ energy and other resources, ~~increasing ocean~~putting pressure on the oceans through extraction, production, consumption, and waste generation.

(c) Technological advances

~~The growth of sustainable inclusive ocean economies, increasing urbanization and the industrialization on land and at sea has been accompanied by~~ . Although advances in marine ~~technological advances, offers both~~technology offer opportunities ~~and potential increased~~, they may also have negative impacts ~~to the world ocean. For example, some fisheries technologies have both increased catches causing overfishing and helped to reduce by-catch.~~on the world's oceans.

(d) Changing governance structures and social, economic and geopolitical instability

~~Governance~~ . 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 ~~across the globe~~ globally and across sectors~~. Each of the states' governance instruments requires an administrative body which results in overlapping statutory bodies.~~ (see chapter 3). ~~Governance structures are both improving rapidly with greater global collaboration, but also fracturing with global inconsistencies.~~

(e) Climate change, biodiversity loss and pollution

~~Climate change is progressing rapidly, with widespread and cascading impacts across the global ocean. Climate both influences, and is influenced by oceanic conditions, which creates dynamic feedbacks within the Earth system. Although climate change represents a global exogenic pressure, its local manifestations require targeted responses at regional or national levels.~~

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 ~~stressors~~

~~Although progress is being made to reduce greenhouse gas emissions, their levels in the earth's atmosphere continues to rise, affecting the world ocean physically and chemically. Since the WOA II, the world ocean continues to change quite rapidly, in many ways faster than was previously understood. The tracking and understanding of the changes in physical and chemical properties of the ocean is critical to understanding the current state of the ocean and a key methodology for understanding the likely future. In the period covered by WOA III, technologies and collaboration for marine observation have continued to improve and these technologies are revealing continued physical and chemical changes to the ocean globally.~~

~~Rapid, substantial climatic changes are taking place across the globe. Significant changes have occurred on coastal ocean dynamics which will impact regional communities into the future.~~

~~The ocean continues to capture and store energy, leading to a sustained increase in ocean heat content. Notably, 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 Ocean.~~

~~Salinity varies across the globe depending on freshwater input and evaporation. Since 2018 salinity has decreased in the Pacific, North Atlantic and Southern oceans, but notably increased in mid-southern Atlantic and northern Indian 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) through thermal expansion, melting ice with additional changes due to storm surges and tectonic/isostatic processes. Tropical seas are rising more rapidly than other areas as a result of thermal expansion.~~

~~Arctic sea ice extent continues to decrease, and the Southern Ocean is recently showing declines in sea ice extent, though it is variable across the region. The Arctic Ocean could become entirely ice-free in September by mid 21st century.~~

~~Sea ice changes are resulting in changes to ocean vertical stratification (e.g. temperature, salinity), mixing and circulation. These changes are most notable in the North Atlantic (i.e. Atlantic Meridional Overturning Circulation (AMOC)), related to changes in the Southern Atlantic and Indian oceans, and in the Arctic and Southern oceans (e.g. global overturning circulation).The AMOC is still projected to weaken, but the probability of collapse has decreased since WOA II.~~

~~Enhanced ocean chemistry monitoring reveals a likely decrease in pH ranging from 0.06 to 0.10 units from 1985 to 2022 , with ongoing fluctuations and deeper penetration into the ocean (beyond 2000m).~~

~~Ocean carbon dioxide uptake is highly variable spatio-temporally but has tripled in the last 60 years (1960 – 2019) changing to 2.7 ± 0.3 petagrams of carbon per year as of 2019. Ocean uptake is expected to increase by 0.4 ± 0.1 petagrams of carbon per decade, though this will be attenuated as temperatures increase, which reduces CO_2 absorption. Total alkalinity (i.e. bicarbonate, carbonate), which buffers acidity in the ocean, has continued increasing in sub-tropical regions, but is highly variable across the globe.~~

~~Global ocean deoxygenation persists due to rising water temperature (reducing oxygen solubility) 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) and the ocean continues to loose around 1 Gigaton of oxygen per year decreasing by more than two per cent (4.8 ± 2.1 petamoles) since 1960.~~

~~Nitrogen availability and fixation are highly variable, with understanding of the processes still developing. Climate change, through temperature, stratification and circulation, has also affected phosphorus dynamics, which itself interacts with nitrogen dynamics and fixation, with implications for marine productivity and ecosystems. Rising ocean acidification lowers the dissolution rate of biogenic silica and therefore increases the burial rate in sediments. This is expected to trigger diatoms decline, which require silicic acid to grow and currently account for near 40 percent of marine primary production.~~

Pressures (S4.C6)

The ocean ~~has been~~is subject to many anthropogenic pressures. As human activity is concentrated on the coast, coastal habitats suffer the greatest impact from these stressors ~~generated by humans – such as pollution, invasions of non-indigenous species, erosion and sedimentation and marine infrastructure, as well as their cumulative~~ , coupled with the effects~~.~~ of climate change. The combined influence of ~~multiple stressors~~pressures generates cumulative effects that ~~can intensify and~~ degrade ocean health, marine biodiversity, and pose risks to human well-being. ~~As a result, progress toward achieving Sustainable Development Goal 14, Target 14.1, remains significantly off track.~~

Land-based as well as marine pollution sources continue to impact the ocean ~~with chemicals and other materials~~ (S4.C6 sub 5). ~~There are many~~Many types of legacy contaminants (metals, persistent organic pollutants (POPs) and radioisotopes) and emerging contaminants (plastics, pharmaceutical compounds and personnel care products (~~PCPs~~PPCPs) and per- and polyfluoroalkyl substances (PFASs)) ~~that were~~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 ~~polar regions and the deep sea as well as coastal marine ecosystems.~~ many areas. Levels of pharmaceutical compounds ~~in the ocean~~(including antibiotics) continue to increase, ~~with new pharmaceutical compounds and personnel care products being detected~~ particularly in coastal areas. ~~The levels of antibiotics have increased and spread to other areas of the ocean.~~ Toxicity studies show significant adverse behavioural effects of PPCPs on marine organisms ~~including behavioural changes in various species such as fish, invertebrates, and algae.~~. Therefore, management action ~~plans and priorities are~~is needed to decrease the presence and potential impacts of ~~PPCPs~~pollution in the ocean.

Global plastic waste leaking into the ocean continues to rise, ~~with significant leakage from~~especially due to mismanaged waste, microplastic abrasion and loss, littering, and marine activities ~~and with only~~. There is limited ~~knowledge about~~ understanding of nanoplastics. ~~These plastics, especially microplastics~~Microplastics, impact all marine ecosystems and there is evidence of their impact on over 4,000 species. ~~Plastic pollution costs billions annually, so addressing this issue requires reducing~~Reducing production, ~~advancing~~developing material science innovation, ~~promoting~~increasing recycling~~,~~ and ~~finding~~ alternatives to single~~-use plastics to lessen the scale of the problem.~~

~~Improvements in wastewater treatment technologies~~ used plastic are ~~necessary to reduce levels of POPs, PPCPs, micro and nanoplastics in effluents, thereby alleviating the pressure on coastal marine environments~~needed.

The ~~need for non-carbon electricity is increasing the~~increased global demand for nuclear electricity~~, and consequently the related~~ is resulting in higher radioactive discharges.

Non-Indigenous Species

Non-indigenous species (NIS) continue to spread ~~with~~through various vectors, such as maritime transport. This has significant negative impacts on native species and habitats, with ~~global ecological, socio-~~further economic, social, cultural, and human health ~~impacts~~consequences. Climate change exacerbates ~~these effects by facilitating~~ the spread and impact of NIS by facilitating their settlement and ~~undermines progress towards up~~growth in novel locations due to ~~11 of the 17 United Nations Sustainable Development Goals (SDGs), as well as other global biodiversity and conservation commitments.~~

~~Therefore, it is essential to prevent the introduction of NIS species either intentionally or unintentionally, although few mandatory global or regional regulations or policies are in place to do this. Systematic monitoring programs and data sharing at multiple and spatial scales are needed to allow the possibility of putting~~changes in ~~place management effects and solutions.~~ local environmental conditions.

Erosion and sedimentation

~~Anthropogenic pressures are increasing and highly concentrated in coastal zones, which are inherently vulnerable to the impacts of climate change.~~ Since the mid-2010s, ~~the~~ increased ~~availability of~~ satellite data availability has enabled the detection of changing ~~patterns and trends in~~ coastal erosion and sedimentation~~. Although there are still uncertainties and limitations of using of this technology, evidence exists that coastal~~ patterns and trends. Coastal erosion has significantly intensified in the Arctic, for instance, due to permafrost ~~thaw~~thawing and ~~increase in~~increased wave action, which are attributed to sea~~-~~ ice loss and longer ice-free seasons. Consequently, ~~considerable amounts~~large quantities of nutrients have been released into the Arctic Ocean~~ with emerging~~, which has implications for carbon sequestration and marine ecosystems. ~~Increasing the exposure of people, property and economic activities to coastal flooding and erosion across all latitudes was observed because of climate change.~~

~~Nature-based approaches, including the re-naturalisation of flood plains and intertidal areas, are being increasingly implemented on catchments and coasts in the Northern Hemisphere. These approaches aim to enhance resilience in the longer term.~~

Marine Infrastructures

~~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's~~ocean ecosystems. This development ~~puts increased pressure on~~results in the loss and disruption of natural habitats affecting biodiversity~~, generating noise and vibrations that affect marine life behaviour. Offshore wind~~. Wind farms continue to expand further offshore putting additional human pressure on understudied marine environments. ~~There~~ The rate of construction of oil and gas infrastructure is also ~~an~~ increasing~~ rate in creation of oil and gas infrastructures~~, particularly in deeper waters~~, while at the same time some decommission of these infrastructures is taking place. In addition, changes and developments in submarine cables and~~ . The placement of seafloor infrastructure, such as pipelines ~~continue~~and cables, has a significant impact on continental slopes and submarine canyons. However, there is a growing focus on developing proactive infrastructure strategies to ~~be developed forming a critical part of global communications infrastructures~~adapt to hazards, including nature-based solutions, buffer zones, physical barriers and systems for early warning and evacuations.

Cumulative effects ~~(S4.C6 Cumulative effects)~~

Since WOA II there has been continued recognition and research ~~of~~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. ~~Chemical contaminants can interact in multiple ways, and 7% of pesticides have been estimated to act in synergy. There is a need to jointly develop global platform(s) that map human pressures and natural assets, alongside a knowledge base to predict the potential~~Assessing cumulative effects ~~of different combinations of human pressures on these assets. Therefore, cumulative effects assessment can guide further development of assessment approaches for decision makers including scenario analyses of anthropogenic activities and the associated stressors to prevent unnecessary ecosystems damage.~~is crucial to preventing ecosystem deterioration.

Ocean Hazards of Natural Origin (S5B.C4)

~~Several ocean-related processes are sources of hazards for coastal societies and cause perturbations on marine and coastal ecosystems.~~ Geophysical and geological Ocean Hazards of Natural Origin (~~OHNO) can be classified in three categories: a) Geophysical/Geological; b) Ocean Weather, Hydrology and Climate, c) Ecological and Biological. Chapter S5B.C4 focuses on the first two, since they affect ecological and biological hazards, which are in turn covered in other chapters of WOA III. S5B.4C stablishes a framework that connects climate and weather pressures,~~ OHNOs~~, the types of impacts and disasters they cause and the mitigation, management and adaptation measures that can be implemented.~~

~~Among geophysical hazards,~~), such as earthquakes, tsunamis, and volcanic eruptions, ~~are the most impactful OHNO in~~ cause deaths and economic losses. ~~Tectonic~~Although tectonic subsidence ~~in coastal regions causes the lowering of the land~~operates on longer timescales, it interacts with ~~respect to~~ OHNOs such as flooding, storm surges, and sea level~~. This geological process operates at scales larger than decadal, although it makes areas more sensible to other OHNO, such as fooding, storm surges or Sea Level Rise that~~ rise. These hazards are increasing or are projected to increase ~~with~~due to climate change~~, acting at different time scales. In the case of~~. Climate change is causing coastal erosion~~, climate change will cause the retreat of sandy coastlines in~~ on all continents. ~~One~~By 2050, one-third of the ~~global densely populated Low Elevation Coastal Zone (LECZ)~~low-elevation coastal zone is projected to experience a shoreline retreat of more than ~~100m by 2050, and to rise between 52 percent to 63 percent by the end of the century, with a potential for a wide range of impacts, including important economic loss.~~ 100 meters.

Ocean ~~Weather, Hydrology~~weather, hydrological and ~~Climate~~climate hazards include ~~cyclones, meteotsunamis~~tropical storms, meteo-tsunamis, waves, ~~Sea Level Rise~~sea level rise, coastal flooding, marine heat waves, glacial melting, heavy rainfall and river flooding, ~~draughts~~droughts, saltwater intrusion, acidification and deoxygenation. These ~~OHNO~~OHNOs are projected to increase or intensify with climate change~~. Those being, or being related with, meteorological processes, such as cyclones, meteotsunamis or coastal flooding, act the time scales of events. Climate-related OHNOs act mainly at the scale of decades or over, whereas others such as droughts and saline intrusions act across all scales, as they are both related with meteorological and climatic processes.~~

~~The complex interactions between the nature of these OHNOs, the time scales at which they operate, and the modulation that weather conditions and climate change exert on many of them, cause different impacts and disasters including:~~ but operating over very variable time scales. OHNOs lead to the loss of lives and land~~; infrastructures~~, damage to infrastructure and property ~~damage;~~, disruption of tourism, ~~-~~food ~~system~~systems, and ~~livelihood disruption;~~livelihoods, coastal flooding and erosion, ~~habitat~~loss of habitats and biodiversity, loss~~;~~ of cultural and natural heritage ~~loss; navigating~~, navigational and shipping challenges~~;~~, and water quality issues, including saline intrusion. ~~Accordingly, different actions can be implemented to mitigate the impacts, manage the consequences and stablish measures for adaptation. The approach identifies a first level of risk reduction actions that include: monitoring, forecasting and early-warning systems; warning, dissemination and communication; preparedness and response; sectoral medium to long term planning (zoning, infrastructure); Nature-Based Solutions; Digital Twins; Managed Retreat; infrastructure upgrading, climate proofing and building codes. However, these risk-reduction measures need to be implemented together with and imbibed in, high overarching governance, institutional or social transformations, including Marine and Maritime Spatial Planning; governance frameworks; Disaster Recovery Planning; Equitable Coastal Resilience; government investments, financing and insurance; capacity-building or Corporate Social Responsibility (CSR).~~

~~Furthermore, these overarching transformations have to be aligned with evolving international climate policy frameworks on ocean resilience, National Adaptation Plans (NAPs), Nationally Determined Contributions (NDCs) and international coordination of early warning systems (e.g. Tsunamis).~~

~~**3**~~

2. Social-ecological systems (S5)

One Health (S5B)

~~The concept of~~ One Health involves undertaking an integrated, unified approach to balancing the health of the physical and chemical marine environment~~, the inhabiting organisms and people interacting~~ with ~~both. It is recognized by the World Health Organization (WHO) as being particularly relevant for food and water safety, nutrition, the control~~that of ~~zoonoses, pollution management, and combatting antimicrobial resistance.~~its inhabitants, including humans. The concept is based on several fundamental principles, including equity, inclusivity, equal access, parity, socio-ecological equilibrium, stewardship, and ~~trans disciplinarity.~~transdisciplinarity. The World Health Organization (WHO) recognizes its particular relevance to food and water safety, nutrition, controlling zoonoses, managing pollution, and combatting antimicrobial resistance.

~~Under this definition of "~~Although One Health~~", all the chapters of Sections 4 and 5 in this WOA could have been included, as any taxonomical group, marine habitat, or ocean economy sector are interacting with each other and with societies, and must be balanced under an integrated, unified approach. However, under~~ is a holistic concept, Section 5B ~~(One Health),~~groups aspects with a higher social component~~(e.g.~~, such as human health, ~~wellbeing~~well-being, equity, gender, and ~~Indigenous peoples knowledge) or~~ITLK, as well as aspects with a high social ~~high~~ impact~~(e.g.~~, such as the role of ecosystems in the carbon cycle, ocean hazards, and the impact of the COVID ~~19) have been grouped~~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 ~~around~~approximately half of the Earth's annual primary production~~,~~ ~~supporting~~ and supports 80% of global animal biomass. ~~Understanding and protecting the role of marine~~Marine ecosystems play a crucial role in driving the carbon cycle, which is ~~intrinsically~~

linked to the health ~~[S5B.C2]~~ and well-being of billions of people ~~[S5B.C3],~~ due to ~~the role of marine ecosystems in the regulation and potential mitigation of~~its impact on climate change ~~and~~ 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 ~~in~~ from the surface of the ocean ~~towards~~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 ~~with high uncertainties on their relative contribution and differences across geographical areas. Examples of these include: the role of~~, such as sinking material ~~vs.~~versus migrating organisms~~; the composition of plankton communities; the~~ , carbon dynamics ~~of carbon~~ within sediments~~; the amount of~~ and carbon ~~exported~~export from shelf areas towards the open ocean~~, and; factors related with climate change (e.g. ocean stratification deoxygenation or ocean acidification).~~ . There is high uncertainty regarding their relative contributions and differences across geographical areas. Reducing these uncertainties is critical to ~~understand~~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 ~~biggest~~largest carbon store in shelf systems~~, and over~~. Over 80% of organic carbon is buried in these subtidal sediments.

The protection and restoration of CBCEs are ~~increasingly recognised~~recognized as ~~a Nature~~nature-based ~~Solution (NbS) for~~solutions and an ecosystem-based approach to mitigating marine climate change ~~mitigation and~~. 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 ~~interventions.~~. Recent estimates indicate that, with full restoration, CBCEs ~~would~~could contribute ~~approximately~~about 2% to the global potential for climate change mitigation ~~potential~~.

In temperate regions, the small ~~geographical area~~geographic size of these ecosystems ~~means~~makes it ~~is~~ unlikely ~~to~~that they will play a significant role in ~~meeting~~achieving mitigation targets. ~~For~~However, for small island nations, ~~which have~~with a larger geographical extent of BC habitats, the contribution may be significantly higher. ~~Further, the huge global variability of carbon stocks in the same habitat makes it difficult to accurately assess carbon sequestration, and studies are often under-represented in the global south.~~ Access to international financing and capacity building, including scientific cooperation, training and transfer of marine technology, are ~~particularly~~ critical for the assessment and management of blue carbon so as to ensure that efficient methodologies are applied. These actions are already included in various NDC and are necessary to achieve global targets~~and to acomplish~~~~accomplish~~ ~~NDC's in the global south, and therefore for achieving global targets~~.

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

~~Whilst~~While it may seem counterintuitive, calcification by marine organisms, such as ~~corals~~ 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 ~~also~~ been ~~suggested to be~~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 ~~wellbeing~~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~~ within a complex global network, making a healthy~~. There are many ways in which the ocean ~~essential for supporting human health and well-being. These interactions provide numerous health benefits, derived from a higher sport activity in coastal areas~~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.

~~In addition, biotechnology, economic benefits, and opportunities~~Well-being is also associated with the therapeutic and restorative qualities of marine environments, reinforcing the significance of accessible blue spaces for ~~cultural, spiritual, and artistic expression contribute to the well-being of coastal communities.~~ mental and physical health.

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

Non-market valuation of marine ecosystems, despite its challenges, ~~remains~~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. ~~Subjective well-being is further linked to the therapeutic and restorative qualities of marine environments, reinforcing the significance of accessible blue spaces for mental and physical health.~~

~~Furthermore, ocean~~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. ~~Several case studies in S5B.C3 illustrate how different communities~~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 ~~(AMR),~~, and toxic chemicals~~, including persistent organic pollutants (POPs), heavy metals (mercury, cadmium, and lead), hydrocarbons, pesticides, and emerging contaminants such as pharmaceutical residues, personal care products, nano-/microparticles (especially plastics increasingly detected in marine species), and per- and polyfluoroalkyl substances (PFAS), also known as "forever chemicals."~~. Additionally, environmental radiation can further threaten marine ecosystems ~~(S4.C6).~~. Contaminated seafood ~~presents~~poses serious food safety ~~concerns~~risks and may ~~lead to~~cause endocrine disruption, neurotoxicity, renal dysfunction, osteoporosis, and various ~~types of cancer in humans~~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~~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. However, the~~ COVID-19 pandemic had severe impacts on the health and safety of seafood workers and coastal communities. ~~Seafood workers faced high risks of contracting the virus due to their working conditions.~~ High infection risks, declining seafood demand, and global tourism losses disrupted ~~several~~ 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 ~~several marine species (S4.C6. Poll). Reduced shipping, recreation, and fishing led to behavioural changes and increased biodiversity, though marine mammals and birds were also affected. Lower underwater noise altered species communication, while disruption of scientific research and fisheries monitoring fuelled illegal fishing in certain regions. As a result of COVID-~~

~~19 pandemic, many new policies were created to deal with health and safety issues related to ocean related employment (e.g.~~ marine species. The pandemic also increased the use of specific medications and treatments, resulting in a higher concentration of pharmaceutical residues in marine environments.~~workplace safety).~~

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. ~~It underpins ocean health by supporting primary~~Biodiversity is critical to biological productivity, ~~facilitating~~ carbon cycling~~,~~ and ~~contributing to~~ climate regulation.

~~The vast network of~~ All marine life interacts in complex ways~~ to guarantee~~, providing resilience and stability ~~of~~to ecosystems. ~~Marine~~Since WOA II, marine biodiversity has undergone significant changes~~ since WOA II~~, influenced by ~~several elements~~increasing pressures that contribute to the worsening global biodiversity crisis, affecting ~~species composition, population dynamics,~~the resources and ~~ecosystem stability.~~ services it provides to global society.

Plankton (S4.C4a) is the ~~base fueling~~ foundation of the pelagic food web~~ and for most of the~~, as well as shelf and deep-sea benthic habitats. It plays a fundamental role in biogeochemical cycles ~~(S5B.C1)~~ and for higher trophic levels, including those sustaining fisheries.

The most dramatic changes since WOA II were observed in the Arctic Ocean~~, with~~. The increasing phytoplankton biomass is associated ~~to~~with warming and sea-ice coverage, and changes are occurring in abundance, composition, phenology and distribution. Globally, phytoplankton blooms ~~have increasingly exhibited unpredictability~~are unpredictable, disrupting carbon cycling and the accessibility of food availability for higher trophic levels. Zooplankton populations, especially krill, have demonstrated regional declines~~ (S4. C4a).~~. The impacts of climate change on plankton in many regions remain unclear, largely due to the limited availability of long-term observational time series~~—particularly across the Southern Hemisphere~~.

~~Some studies show conspicuous responses in abundance and composition associated to climate related extreme events.~~ 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 ~~(S4. C4b).~~.

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. ~~The~~Despite the positive effects observed from conservation efforts and MPAs since WOA II, the lack of knowledge about deep-sea species~~, together with~~ persists, as does their vulnerability to ~~some~~ destructive activities such as trawling~~, persists despite the positive effects observed from conservation efforts and marine protected areas since WOA II (S4. C4c).~~ .

Fish (S4. C4d) populations consistently face challenges due to overfishing and habitat degradation~~,~~ despite ~~a heightened emphasis on sustainable~~improved fisheries management and bycatch reduction ~~compared to WOA II~~. While many reef fish continue to decline, some species like tuna show signs of recovery because of improved ~~fishing rules (S4. C4d).~~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 ~~since WOA II.~~. Moreover, increased underwater noise pollution (e.g. armed conflict, shipping, offshore infrastructure) is disrupting marine mammal migration and communication ~~(S4.C4e).~~.

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

~~Seabirds are~~Climate change similarly ~~affected by climate change,~~affects seabirds (S4.C4g), as changes in prey availability influence their reproductive success. ~~Following WOA II, the frequency of plastic~~Plastic ingestion and bycatch-related mortality has ~~risen, although mortality of~~increased, though some bird species ~~is being~~have experienced reduced ~~as a result of~~ mortality due to modified fishing techniques ~~(S4. C4g).~~.

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

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~~, and~~. These habitats are~~ all~~ 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.~~ Below is a summary of key habitats and the changes they have undergone since WOA II.~~

The intertidal zone ~~has historically and~~(S4.C5a) continues to experience significant transformations and habitat loss caused by sea level rise and coastal squeeze. Eutrophication~~,~~ and pollution~~ included~~, including micro-plastic accumulation~~ increased, affecting~~, affects species and ecosystem services. Attempts to ~~incorporate~~use intertidal ecosystems ~~into programs aimed at mitigating~~to mitigate climate change have increased~~ despite some challenges since WOA II. To increase resilience, conservation~~. Conservation strategies ~~now incorporate~~increasingly use green-grey infrastructure, ecosystem co-design, and nature-based solutions~~ (S4.C5A, S5A.C9).~~.

Biogenic reefs and sandy, muddy, and rocky shores (S4.C5b) face intense pressures~~ impacting~~ 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. ~~including~~ 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~~ (S4.C5B).~~.

New ~~findings, include~~understanding of atolls (S4.C5c), including the Antecedent Karst Theory and ~~insights into atoll~~ 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 ~~different threats, with~~ ocean acidification and warming seas ~~weakening~~, which weaken reefs and ~~increasing~~increase coral bleaching. ~~While~~Whereas some remote reefs recover within years, densely populated atolls~~, like the Maldives,~~ take over a decade to regenerate~~ (S4.C5C).~~. This reinforces the importance of integrated conservation approaches.

Coral reefs (S4.C5d) around the world are declining rapidly due to ~~a range of~~various stressors. Increasing disturbances, such as marine ~~heatwaves~~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~~, with projections suggesting~~. Projections suggest that 90% of reefs could disappear if warming exceeds 1.5°C. Even historically resilient areas~~ like~~, such as the South Atlantic, are experiencing severe losses~~, while rising~~. Rising hypoxia and ocean acidification add further stress. ~~The Northeast Atlantic and Mediterranean are warming at triple the global rate, and the~~The Caribbean has lost 80% of its coral cover since the 1970s.~~ The Indian Ocean, Red Sea, and Persian Gulfare now experiencing rapid declines. On remote protected atoll reefs of the Chagos Archipelago recovery to net accretion, albeit with reduced biodiversity, has been achieved within 2–6 years following past El Niño Southern Oscillation (ENSO) episodes. This compares with a period of 14 to 16 years on some densely populated atolls in the Indian Ocean, underlining the need for a wholistic approach to supporting coral reef recovery (S4.C5D).~~

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~~, while habitat suitability models predict~~ and further severe declines are predicted under high-emission scenarios. Advances in CWCS ecology~~,~~ improve our understanding of these fragile ~~ecosystem~~ecosystems, but long-term monitoring and policy integration remain limited. Expanding protection and global research efforts are urgent priorities ~~(S4.C5E).~~.

~~Estuaries~~Changes in estuarine and ~~deltas face increasing pressure, changing the~~ deltaic environments (S4.C5f) have significantly altered sediment dynamics ~~of sediments~~, water quality and ~~the stability of ecosystems.~~ecosystem structures. Since WOA II, drastic changes in land-use ~~changes,~~ and ~~dam~~the construction of dams have ~~drastically changed~~altered sediment fluxes, ~~leading to~~resulting in accelerated coastal retreat and subsidence in many areas ~~(S4.C5F).~~.

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 km^2) 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 ~~(S4.C5G).~~.

Mangroves (S4.C5h) offer important ecosystem services such as coastal protection, biodiversity and carbon sequestration, with an estimated economic value of $65 billion annually. ~~A~~ ~~A~~Between 2010 and 2020, net annual mangrove loss ~~has~~ declined to 102.4 ~~km2 between 2010-2020 compared to previous decade,~~km^2, 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. ~~(S4.C5H).~~

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. ~~While~~Although oil and chemical ~~pollutants have dropped, plastic~~ pollution has decreased, the accumulation of plastic is now ~~causes great worry (S4.C5I, S4.C6 Sub 5).~~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 ~~(S4.C5J).~~.

~~Significant~~Since WOA II, significant changes have taken place in high-latitude sea ice ~~since WOA II.~~(S4.C5k). Arctic ~~Sea~~sea ice ~~is still declining, with~~ continues to decline, and an ice-free Arctic in September ~~probable~~is likely within the ~~forthcoming~~next few decades. ~~The~~Meanwhile, Antarctic ~~Sea~~sea ice ~~has~~ transitioned from ~~a~~ gradual increase (1979–2015) to ~~a~~ rapid decline after 2016, possibly indicating a regime shift. ~~Loss of continental ice has accelerated from Greenland since the early 1990's and from Antarctic ice sheets since the late 1990s,~~

~~contributing 21.0 mm to global sea-level rise for 1992-2020. Important gaps remain in several areas including the recent sharp declines in Antarctic Sea ice, ice thickness, snow cover quantification, and future ice loss and sea-level rise projections enhancement (S4.C5K).~~

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 ~~marine protected areas~~ MPAs and heightened recognition of their ecological significance. ~~Nonetheless, enforcement and sustainable fisheries management continue to pose~~However, despite significant ~~challenges (S4.C5L).~~ 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 ~~among~~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 ~~raise~~raises concerns about the resulting potential for habitat destruction and biodiversity loss. ~~Following WOA II, research on these ecosystems has increased as has development of a deep-sea mining code (S4.C5M).~~

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 ~~technologiesand~~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) ~~Earth System Models~~ 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. ~~Fisheries data indicate mixed trends, with growing interest in mesopelagic fisheries and persistent threats from overfishing and pollution. Key knowledge gaps include the role of species movements and ecological interactions among organisms across trophic levels, the impacts of extreme events, quantitative estimates of fish and plankton biomass, and digitizing and mobilizing existing data (S4.C5N).~~

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. ~~In the~~The Arctic Mid-Ocean Ridge (AMOR~~)~~), however, faces notable impacts from fishing, mineral extraction, and bioprospecting ~~Habitat suitability modelling (HSM) is increasingly used to predict the distribution of faunal communities for management of data-poor areas. Despite ongoing progress, several gaps persist including deep-sea sampling, the management of ridges, plateaus and trenches located beyond national jurisdiction (S4.C5O).~~.

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~~ 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~~ (Marine Protected Areas)),~~, EBSAs (Ecologically or Biologically Significant Areas) and IUCN (International Union for the Conservation of Nature) red list designations.~~ Key gaps include understanding symbioses and other mutualistic interactions among species, genetic resource potential at vents and cold seeps, vent-seep-organic fall connectivity and the role of inactive and ecotone/transition vent and cold seep (S4.C5P).~~

The Sargasso Sea ~~supports a unique surface ecosystem based upon floating aggregations of two species of Sargassum (*S. natans* and *S. fluitans*). The Sargasso Sea~~(S4.C5q) is an iconic high seas ecosystem that is internationally recognized as a ~~fundamentally important~~crucial part of the global ocean. Since WOA II, significant environmental changes have been observed in the Sargasso Sea~~, driven by~~ due to climate change, oceanographic shifts, and human activities. ~~Fishing effort remains low~~ Ship traffic in the Sargasso Sea~~, but research shows most fishing activity requires heavy subsidies to reach the area. Ship traffic~~ has increased ~~on the Sargasso Sea~~ over time~~ and *de facto* shipping routes have been established by shipping companies. However, significant knowledge gaps remain, concerning bycatch, illegal, unreported, and unregulated (IUU) fishing, the movements of highly migratory species, plastic pollution, and the impacts of~~ .

The fjord systems (S4.C5r) of the world are characterized by a deep~~-~~ basin connecting directly or indirectly with the open sea ~~mining (S4.C5Q).~~

~~Fjords are ecologically~~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~~-rich regions. Global warming~~ matter: Climate change is already affecting ~~the~~both northern and southern hemisphere fjords~~, and freshwater fluxes are likely to increase/decrease~~ via warming, deoxygenation and acidification. The loss of glacier ice and the changing seasonality of the hydrological cycle is affecting physical and chemical factors~~/processes in fjords habitats. A critical knowledge gap exists for fjords habitats, as only a small percentage of the world's fjords have been studied. In addition, little is known about the resilience of fjord systems to changes in hydrologic and oceanography conditions (S4.C5R).~~ 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. ~~The~~ Despite its large extent, the ocean ~~covers more than 70% of the earth but~~ provides only 4-8% of human food. ~~In addition, food systems provide livelihoods for those along the food supply chain.~~ Food systems are not only highly dependent on the environment but also exert significant pressure on it. ~~Sustainable wild fish and mariculture production is the foundation for sustainable seafood trade.~~

~~Marine resources are unevenly distributed around the world, and human population centers are often geographically distant from areas of high abundance. The uneven distribution of marine resources has driven trade from local to global scales for millennia, but the proportion of marine production that is exported has increased in recent decades.~~

~~Seafood trade (S5A.C1f) can have positive or negative impacts on local environments, economies, and communities, and the impacts depend on the institutional and governance context.~~ Direct employment in fishing processing and related value chain activities is close to half a billion people. ~~Climate change is also reshaping the global distribution of seafood. Although landings of wild marine fish levelled off in the mid-1990s, total aquatic food exports nearly doubled between 1996 and 2020, with aquaculture accounting for most of the increase. During this period, interregional trade remained dominant for many regions, but Asia became an increasingly important destination. Accordingly, there have been shifts in the top importers and exporters of marine products. Trade regulations, certifications and traceability tools are emerging to support sustainable seafood trade, but unknowns remain regarding aspects of their impact and effectiveness.~~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). ~~Moreover, freezing~~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. ~~However, there are still bottlenecks and challenges that need to be addressed if the sector is to significantly increase production and further contribute to sustainability goals.~~ 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 ~~remain, highlighting~~and environmental impact must be addressed if the ~~need for more meaningful engagement with local communities in the planning and management of aquaculture in the future~~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 ~~(AMR)~~ 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, ~~hypoxia/~~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 ~~WOA III (S5A1.d) focused on SSA practiced in~~S5A.1d considered two ~~environments~~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 ~~little or no negative~~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~~ in many countries. There appears to be a serious lack of specific national legislation to regulate the sustainability of small-scale inshore and coastal aquaculture.~~.

~~Fisheries are categorized based on the scale and scope of their operations, which significantly influence their environmental impact, economic contribution, and social dynamics. Small-scale fisheries (SSF~~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 ~~worldwide. The viability of SSF is increasingly threatened in many regions. Creating sustainable pathways for small-scale and subsistence fisheries must involve a commitment to principles of equity and justice, human rights and security, and emphasize the knowledge and capacity of small-scale fishers~~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. ~~LSF and MSF differ in their operational approaches, with each playing a unique role in the global fishing industry (S5A.C1a).~~ 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 report recognizes certain limitations, such as the complexities of defining these two fisheries sectors across diverse contexts and the~~

~~challenges of balancing economic growth with environmental and social sustainability. In their own ways, LSF and MSF contribute to complex challenges in the marine environment, underscoring the need for tailored, sustainable management approaches.~~ WOA III emphasizes the importance of ecosystem-based management, transparency, traceability, and stakeholder collaboration to mitigate the negative impacts of MSF and LSF.

Overfishing ~~is~~and illegal, unreported and unregulated (IUU) fishing are among the most pressing concerns in the sustainable use of the ocean resources~~ and according to the Food and Agriculture Organization (FAO).~~. 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~~ associated with these catches~~. 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. ~~Effective governance structures are essential to ensure that the LSF and MSF sectors contribute positively to sustainable development.~~

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~~ (S5A.C2). It plays an important role in many coastal ecosystems worldwide, particularly in developed countries.~~. 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. ~~Despite its importance, only about two-thirds of countries mention recreational fisheries in primary fisheries legislation. Recreational fisheries could put pressure on stocks already being depleted by commercial 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 ~~a~~ key to global environmental, economic, and social stability~~ and the~~. The ocean plays an essential role in ~~the~~this process ~~through~~by regulating the climate, maintaining biodiversity, and providing critical resources ~~vital~~ for ~~humans~~humanity, such as food, minerals, and energy (e.g. fisheries, oil, gas, and offshore wind). ~~The ocean is under stress due to overexploitation, pollution, and the effects of climate change.~~ 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.

~~However, we still live in the world of increasing competition for all resources. In the case of biological resources for example, the shift is clearly from capture fisheries to coastal and offshore aquaculture (see relevant chapters and marine food systems). The demand for minerals, energy, and space-based resources has several dimensions as described in more detail below.~~

~~The observed~~Observed trends in ocean renewable (S5A.C3a) and non-renewable (S5A.C3b) technology developments include offshore wind farms, tidal, and wave energy systems ~~(S5A.C3a, S5A.C3b).~~. While renewable energy developments ~~center~~focus on efficiency and cost reduction, efforts to explore non-renewable energy ~~exploration efforts keep enhancing,~~sources continue despite concerns ~~over~~ about potential adverse environmental ~~adverse impact, however,~~ impacts. However, more sustainable approaches are ~~visible~~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 ~~both~~ opportunities and challenges. As the world ~~trends should aim at shifting towards~~moves toward a more sustainable future, it is essential to balance the benefits of using ocean ~~resource use~~resources with the necessity ~~to protect~~of protecting marine ecosystems and ~~secure~~securing social equity.

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

~~Sustainable ocean resource management also involves other types of pollution, particularly plastic waste, which has become a significant issue for marine ecosystems. The challenge lies in minimizing pollution while balancing economic growth, which usually causes environmental degradation.~~

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~~ (S5A.C10).~~. However, it is ~~among proposed solutions~~one potential solution to the global climate crisis.~~ Marine geoengineering techniques involve the altering or utilization of ocean systems as a proposed tool for climate change mitigation.~~ 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.

~~Accounting~~Shipping (S5A.C6) accounts for ~~88~~more than 80% of all world trade~~, shipping~~ in goods by volume. It plays a ~~vital~~critical role in global ~~trade, and it is a basis of today's~~ commerce~~,~~ by enabling the movement of goods and connecting businesses with customers worldwide~~ (S5A.C6).~~. However, the global shipping ~~produced 2.~~fleet accounted for approximately 3% of total global ~~TTW~~GHG CO_2 emissions in ~~2024~~2023, and ~~the~~ estimates show ~~that~~ this ~~number can rise by a half~~figure could increase by 90-130% above 2008 levels by 2050. In times of unprecedented climate and environmental ~~unprecedented~~ changes~~ green and~~, sustainable shipping ~~are becoming~~is of critical importance. Examples of such approaches include using cleaner fuels, employing technologies ~~to~~that reduce carbon emissions, and optimizing shipping routes to ~~reduce~~minimize environmental impact.

~~Roughly~~About 90% of commercial vessels use bunker fuel, a highly polluting energy source. This ~~situation limits efforts~~makes it difficult to significantly ~~cut~~reduce emissions in the near future ~~and a significant number~~, since more than 70% of newly planned ships~~, more than 70%,~~ will continue to ~~be fuelled by~~ 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. ~~Globally, salt~~Salt production methods worldwide are ~~fast~~rapidly evolving toward sustainable practices.

~~Like in many other ocean development activities, ocean~~ Since WOA II, the search for and use of marine genetic resources ~~and~~(MGRs) (S5A.C5), as well as the development of marine biotechnology~~ continuous~~, have continued to ~~show rapid growth since WOA II, with advances~~grow rapidly. Advances in marine genomics~~, which lead~~ have led to many discoveries in sustainable bioproducts, pharmaceuticals, and biofuels~~ (S5A.C5). Developments in novel search for compounds and enzymes~~. Although MGRs hold immense potential, they remain largely understudied. Most areas beyond national jurisdiction, including the deep sea, are ~~observed globally, however, on the positive side, innovations in marine biotechnology tend to conform to sustainability practices, hence help to reduce ecological impact of ocean~~ 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).

~~Global sea level rise and increasing strong storm frequency pose a significant threat to coasts across the world, requiring dedicated mitigation plans and actions. Progressing flooding and erosion have adverse impact on planned developments, making it difficult to foster sustainable communities. Additionally, the pressure on ecosystems, such as e.g. mangroves, coral reefs, and wetlands, is very strong and leads to disruption of these habitats, and biodiversity loss. Regulatory solutions, along with conflicts between economic development and environmental conservation, lead to tensions between stakeholders. The high cost of ongoing and upgrading maintenance of coastal infrastructures, combined with unpredictable climate change consequences, makes coastal areas most vulnerable areas on Earth.~~

~~The observed rapid growth of coastal tourism, despite~~Despite its many positive aspects for humans, ~~can be connected with the threat of~~ 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~~ (S5A.C4).~~. Unsustainable tourism~~, including cruise ships and recreational boating, contribute~~ contributes to marine pollution, including plastic waste, noise and hazard of oil spills, which harm marine life. Overcrowding ~~of~~at popular destinations ~~leads to the degradation of~~can degrade local ecosystems and adversely ~~affects~~affect the well-being of coastal communities. ~~The emerging~~Emerging sustainable tourism practices, such as responsible waste management, eco-friendly ~~infrastructures~~infrastructure, and community-based conservation, are crucial to ~~mitigate~~mitigating these impacts and ~~secure~~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 ~~planned for~~aimed at creating an inclusive ocean economy ~~must~~should emphasize social equity, access to resources, and the participation of ~~marginalized group~~persons in marginalized situations in decision-making processes.

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

The UN Sustainable Development Goals put strong focus on the importance of gender equality in ~~every aspect~~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.

~~There is progress towards ocean related SDGs, but the targets that were set to be achieved 2025 have not been achieved and those with a target in 2030 are unlikely to be achieved. Some of the major reasons for this involves: increasing economic pressures; lack of governance, unwillingness to use nature-based solutions, and the changing geopolitical landscape.~~

~~Mangrove forests, saltmarshes and seagrass beds are increasingly recognized for their role as blue carbon ecosystems, with initiatives aiming to (re-)establish and protect these habitats for their ecological and economic value. Seagrasses contribute to several SDGs, including carbon sequestration and disaster resilience (SDG 13), protection of coastal communities (SDG 11), and food and economic security (SDG 10), while promoting sustainable use (SDG 12), marine conservation (SDG 14), and partnerships (SDG 17) (United Nations, 2015). Their value was~~

~~highlighted in UNEP's 2020 report Out of the Blue: The Value of Seagrasses to the Environment and People (UNEP, 2020). Seagrass conservation efforts, including the 2030 Seagrass Breakthrough, align with global climate commitments and all ten targets listed within SDG 14. However, unintended consequences of development initiatives remain a concern.~~

~~There are ongoing Blue Carbon projects in different regions of the world. Mangroves are of particular concern with regard to carbon sequestration and for achieving SDG targets. Some examples include: restoration and conservation action such as planting 1,000 hectares of mangrove forest habitat in the Persian Gulf; China's plan to improve coastal ecosystem carbon sink capacity and restore 18,800 ha of mangrove by 2025; while the National Mangrove Rehabilitation Program of Indonesia aimed to restore 600,000 ha of degraded mangroves by 2024.~~

~~Ocean governance~~

~~Introduction~~

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~~, marine spatial planning, and other management processes are crucial for the conservation and sustainable use of the global ocean. These processes aim to balance ecological, economic, and social interests while addressing the growing pressures on marine ecosystems.~~

~~This is the first time that a dedicated ocean governance section is included in a WOA report, as previous WOA reports addressed ocean governance within specific chapters.~~

~~Ocean Governance~~

~~Ocean governance~~ (Section 3) is underpinned by a highly complex and dynamic interplay of ~~States~~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 ~~in the last five years~~agreements that ~~are yet to come~~entered into force in 2025 (BBNJ Agreement~~, 2023~~; Fisheries Subsidies Agreement~~, 2022~~). ~~They are devoted to different~~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, ~~a large number of~~many non-binding instruments, customary ~~law~~laws, and associated intergovernmental policy processes focus on the marine environment. These processes can facilitate cooperation, action, and coordination between ~~States~~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~~). International courts and tribunals within specific proceedings provide interpretation on these legal instruments. Many of the governance instruments that are developed globally further develop UNCLOS concepts (e.g. ecosystem approach, precautionary principle/approach, best available science).~~ for Sustainable Development).

~~Yet~~However, the fragmentation of ocean governance at the global and regional levels has continued to draw significant attention ~~over the past five~~since WOA II. In recent years~~. Most of the~~, new binding and non-binding instruments ~~in recent years were~~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, ~~2022~~2025; BBNJ Agreement, ~~2023~~2025; International Maritime Organisation (IMO) Greenhouse Gas (GHG) Emissions Strategy, 2023)

~~Other significant elements within the global ocean governance are the concepts, principles and means of implementation that have developed over time in different institutions of the ocean governance regime and have progressively penetrated such regime. For example, governance concepts emerging from national experiences and non-state actors' proposals and practices, such as the sustainable blue economy and marine spatial planning, have gained increased significance in State-led governance developments.~~

~~The ocean governance overview provided in section 3 of the present WOA report highlights the central role of both natural and social sciences, including the knowledge systems of Indigenous Peoples and local communities, and the importance of their integration in all stages of the policy cycle at all geographic scales.~~

~~Recent developments in governance~~

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, ~~substantive~~the areas of concern ~~in the work~~ of relevant intergovernmental institutions have ~~extended~~expanded beyond traditional marine environmental ~~pressures~~issues (e.g. pollution and fisheries), to include more recent priorities ~~(e.g.~~like climate change mitigation~~ and adaptation, marine plastics, ~~, plastic pollution, ocean monitoring and ~~ocean ~~observation~~) and non-traditional areas such as~~, food security, maritime security, migration by sea, and human~~-~~ rights~~ based approach and food security.~~.

Overarching objectives such as ~~a ~~sustainable and inclusive ocean economies~~ (e.g. blue economy),~~, blue health, and blue justice are playing ~~central roles~~a significant role in ocean governance~~ developments. Remote monitoring technologies are assisting with more rapid governance~~, and ~~management.~~

~~The past five years have seen increasing references to human dimensions, including human rights and use of ~~the social sciences~~. New international agreements and frameworks have been developed or are in negotiation (e.g. the Kunming-Montreal Global Biodiversity Framework, WTO Agreement on Fisheries Subsidies, the international legally binding instrument on plastic pollution, including in the marine environment). There have been calls for better data collection and monitoring of marine ecosystems, including improved integration of Indigenous knowledge and local perspectives~~ are becoming increasingly relevant.

4. Marine observations and ocean knowledge

~~The collection of new information and retention/application of global ocean knowledge are important parts of managing our ocean. Diverse scientific technologies and methodologies are developing rapidly in marine observation, data collection and modelling, which is greatly improving our knowledge and scientific understanding of our ocean. Knowledge systems are the practices, values, methodology and culture surrounding the collection of information and how it is used. The majority of WOA III focusses on classical scientific knowledge, but there is increased acknowledgment of the relevance to global ocean understanding via alternative or complementary **Indigenous, traditional and local knowledges**. WOA III has begun the process of better acknowledging and including these complementary knowledges (S.5b Ch8).~~

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

~~Technology is developing rapidly in ocean observation and data collection in diverse areas. Drones, autonomous vessels, remote sensing, aerial surveillance, airborne LiDAR (Light Detection and Ranging technology), and satellites are all enhancing real-time data collection on physical/chemical conditions, sea level, ocean circulation, pollution (including noise), biochemistry and biology, as well as improving high resolution sea-floor mapping. Research vessels are increasingly serving as motherships for unmanned, remotely operated or autonomous vessels, including aerial or underwater drones which enables the collection of large amounts of video, image, physical and chemical data. Deep ocean areas are more readily accessible. Independently operating vehicles, through for example the Argo program, are now operational throughout the world ocean collecting biogeochemical information throughout the water column. Through such programs, scientists are better understanding conditions - including difficult to capture extreme events - across the globe simultaneously. New things are being discovered completely, such as deep-sea biological communities (Western Antarctic Peninsula), and new physicochemical processes, for instance geo-chemically generated oxygen.~~

~~Through technological development in remotely operated technologies, coupled with advanced data gathering (e.g. video monitoring), deep-sea submersible technology (e.g. Chinese submersible “Striver”), seabed scanning and analysis (Artificial Intelligence (AI) modelling) techniques, coupled with machine learning and AI, scientists have increased knowledge about remote locations, including those historically more inaccessible areas (e.g. deep ocean, seamounts, fjords). Globally, all major hadal trenches have been surveyed with new technologies revealing a rich diversity of habitats. The understanding of Abyssal taxa have extended into hadal depths and new trench-endemic species and ecological relationships revealed with a rich hadal microbial flora, including viruses, bacteria and fungi that contribute to biochemical processes. We are now aware of over 10,000 submarine canyons and thousands of new seamounts, with more yet to be mapped in underexplored oceanic regions. Recent discoveries of new deep-sea species (e.g., sponges, gastropods, octocorals and corals) include, for example, 111 unique taxa off the Western Antarctic Peninsula.~~

~~These remote technologies also enable better monitoring of our environments. They are enabling the development of key metrics (e.g. habitat condition, population trends) for monitoring and decision to support biodiversity treaties (e.g. BBNJ). Satellite imagery, video systems, drones applying aerial photogrammetry and Geographic Information Systems (GIS)~~

~~are increasingly used for monitoring coastal changes, erosion, sedimentation and coastal health (e.g. Red tide algal bloom monitoring) and marine plant distribution (e.g. mangrove forests), as well as the restoration of these areas (e.g. Mangrove regeneration projects around the globe). Population assessments are improving as a result of remote technologies (e.g. marine mammals, seabirds). These technologies are also assisting with ship monitoring and weather observations.~~

~~Data collection, analysis and modelling~~

~~New developments in data processing, machine learning and artificial intelligence are being applied in many areas, greatly enhancing data analysis, model production and predictive capacity, as well enhanced integration of data networks. These are greatly improving the availability of spatiotemporal data to be fed into biological, physical and chemical models which are then combined into more cumulative large oceanographic and ecosystem models. These large-scale environmental models are improving our understanding of biological (productivity, communities, food webs) and physical (e.g. integrated coastal and hydrodynamic modelling of estuaries and deltas with catchments) (e.g. Delft3D, MIKE21 and SWAN models) aspects of our ocean. New models are being developed and/or updated for ocean behaviour and ecosystems. (e.g. work by Fisheries & Marine Ecosystem Marine Intercomparison Project (FishMIP)). Ecosystem service models are improving for coastal mangrove areas, including carbon storage potential~~

~~Habitat suitability modelling (HSM) is increasingly used to predict the distribution of faunal communities for the management of data-poor areas (e.g. deep-sea corals near New Zealand). Modelling and spatial planning software also aid the design of offshore protected or managed areas (e.g. South Pacific Regional Fisheries Management Organisation (SPRFMO)) vulnerable marine ecosystems). Work is being carried out to develop "digital ocean twins" to assist in modelling of ocean habitats.~~

~~Global treaties and non-binding instruments help facilitate new collaborations, shared databases and information sources among regions, which provide information and maps for marine observations and offshore structures (e.g. European Marine Observation and Data Network (EMODnet); Bureau of Ocean Energy Management (BOEM); Mid-Atlantic Ocean Data Portal (MARCO); Open Infrastructure Map, and; European Maritime Affairs). Efforts continue to achieve FAIR (Findable, Accessible, interoperable, reusable) data standards.~~

~~Climate change~~

~~Scientific knowledge is rapidly expanding on natural and anthropogenic contributions to climate change and the impacts to the world ocean. There is rapid development of monitoring, reporting and verification of~~ $\cancel{CO_2}$ ~~emissions, including associated modelling which support resource managers and policymakers across the globe. Scientists have also increased understanding of marine plant role in carbon sequestration. Significant advances are being made via remote techniques to understand ice related processes in polar areas and their influence on global circulation and climate change.~~

~~Genetic/molecular technologies~~

~~There has been rapid development of genetic technologies (e.g. sequencing methods, eDNA (environmental DNA), isotope analysis) leading to a relatively rapid increase in understanding of biological communities, trophic systems and ecosystems (e.g. range, numbers of species, population size) and of the food web (e.g. seabird and plankton diet) for all marine taxonomic groups. Libraries and taxonomic reference collections of genetic information are developing quickly, now with more information about microbiomes, plants and animals from remote areas (e.g. cold water corals). Functional trait analysis, along with eDNA, is offering new perspectives for ecosystem modelling.~~

~~**Socio-economic knowledge**~~

~~Globally, there is an increase in socio-economic and socio-ecological research and improved methodologies to support better outcomes for marine planning and resource use aimed at improving human well-being and equity. Indigenous, traditional and local knowledges are increasingly used to complement scientific understanding. Research continues in non-market goods and services, such as clean air, biodiversity, and recreational spaces, which contribute non-trivially to human well-being. The ability to value the environment in terms of economic (e.g. value of environment goods and services such as contingent valuation and travel cost methodologies) as well as developing non-economic valuation methodologies for restoration and preservation of marine environment is increasing.~~

~~The understanding of equity is improving steadily and efforts are being made globally to support participatory ocean governance requires that all rights holders and stakeholders are recognized, that all affected actors are included, and that diverse knowledge systems and perspectives are represented in decision-making are an important part of good policy making.~~

~~**Engineering and marine structures**~~

~~Marine related engineering technology is rapidly developing in a wide variety of fields – from deep-sea mining/drilling to coastal infrastructure and renewable energy platforms and aquaculture. Drilling, wind turbines, mining and trawling are all being developed further from the coast and in/at greater depths. Recent technological developments are also occurring for controlling sea level rise, with increasing estuarine barriers and hard defences, alongside the nature-based solutions and habitat creation (S5A. C9. New offshore renewable energy technologies are developing rapidly – floating wind turbines, tidal and wave energy generation, as well as more novel approaches such as salinity gradients and ocean thermal energy conversion. Grid integration (and offshore micro-grids) and energy storage is also improving rapidly. AI is being used to optimise predictive modelling for energy production. There is growing understanding of noise, electromagnetic fields and their effects on the environment. Ocean carbon capture and storage technologies are also being developed and trialled, as are hydrogen storage technologies for energy created by renewable sources.~~

~~**Fish and fisheries**~~

~~Improvements are being made in tagging, video monitoring, and fish genetics. Advanced technologies, such as remote cameras, satellites, computer vision, and aerial and underwater drones, enable in-situ monitoring of fishing activities, species populations, and habitats. These innovations allow for the assessment of fishing pressure and fish behaviour patterns, which can be integrated into monitoring programs. Genetic sequencing, in-situ sequencing platform,~~

~~synthetic biology, metagenomics and eDNA/metabarcoding have increased for fishing/fisheries information since the last WOA, with substantial reductions in cost. Ecosystem-based fisheries management is being developed, along with improved modelling and understanding of spatial and temporal trends in fish biomass. Fish data are increasing in shared global databases. There is better understanding of fish communication and the potential impacts of noise on fish communities. Fisheries extraction technological improvements are also improving, reducing bycatch.~~

~~Gaps~~

~~Although developing rapidly, there are still large gaps in our understanding of the ocean. Large tracts of the ocean remain unknown. Currently only 28% of the ocean seabed is mapped in high resolution, while other areas have very little information at all (e.g. Arctic and Southern oceans). Monitoring of deepwater areas (e.g. continental slopes, submarine canyons, abyssal plains, hydrothermal vents, seeps) is still weak in many areas and limited to exclusive economic zones for countries. Many regions lack capacity (e.g. skills, experts, vessels) for deepwater research and this prevents setting baselines and ongoing monitoring. High resolution coverage is still lacking for remote monitoring coastal vegetation (e.g. mangroves, seagrasses) and there is a lack of funding for monitoring programs of coastal areas (e.g. mangroves) in many parts of the world ocean. Fjord systems remain largely unknown.~~

~~Scientists still have a weak understanding of species movements and interactions at different trophic level in pelagic environment, which prevents effective management and conservation. Remote, deep-sea and inaccessible microbial and invertebrate communities (e.g. hydrothermal vents) and marine plants lack documentation, monitoring and genetic information. Major gaps still exist in less developed countries in a variety of research areas (e.g. coral reefs) for restoration and monitoring technologies (e.g. eDNA, 3D photogrammetry).~~

~~We still have limited understanding of climate driven changes to the ocean and what will change in the future. Scientists still struggle to understand cumulative impacts of extreme or global events at various spatiotemporal scales, including how they interact with global climate systems (e.g. Pacific Decadal Oscillation, ENSO, Atlantic Multidecadal Oscillation) and anthropogenic effects. There is still very little understanding of the impacts of rapidly changing areas, like the polar areas, and their role as a heat sink and for freshwater input for driving global circulation.~~

~~There is a lack of observations and understanding of coastal carbon cycles and sequestration, which make it difficult to understand past, current and predict future carbon sequestration (e.g. in marine plants). There is a gap in the understanding coastal shelf sediments, carbon accumulation/release rates and how anthropogenic activities affect the storage or release of~~ CO_2~~. The carbon cycle in coastal wetlands and their~~ CO_2 ~~storage is not fully understood with regard to greenhouse gas emissions. There is a lack of information about bacterio-plankton and heterotrophic eukaryotes and their roles in decomposition and carbon cycling.~~

~~In general, approaches to ocean governance, from local to international, continue to under-represent certain groups (e.g., Indigenous Peoples and small-scale fisheries).~~

~~Scientific understanding is still developing regarding the effects of noise, wind farms, offshore farming, seabed mining and nano-plastics on biological communities.~~

~~Scientists still struggle to engage with policymakers and to have scientific knowledge/data used for policy development. Continually increasing competition for limited funding is occurring generally across ocean research areas. The availability and exchange of scientific information/data is still hampered by issues related to language, gender, socio-economics and education.~~

~~**Data gaps**~~

~~There is still a need to generate long-term historical datasets of the open ocean, but especially deep sea and coastal areas for plankton to understand variability and extreme events. There was substantial loss of data during the COVID 19 pandemic, including the generation of gaps in what were long term historical datasets.~~

~~Existing models and databases are still lacking for coastal zone understanding and prediction. There is insufficient data for modelling erosion and sedimentation along many regional coastlines, especially in Small Island Developing States, Caribbean and South Atlantic areas. Although the trajectory of sea ice in the Arctic region is towards considerably reduced cover, polar ice models (especially in the Antarctic) still unable to predict annual changes to ice and the resulting impact to the globe. There remains a disconnect between anthropogenic stressors and spatiotemporal ecosystem responses and a clear need to develop global platforms to map human pressures and natural assets and modelling to predict anthropogenic pressures.~~

~~Data sharing is improving, but information tends to remain in silos (e.g. pelagic systems, seagrasses) (e.g. 81% of zooplankton monitoring data are at most only partially accessible). It is difficult to standardise global approaches to data management and data accessibility.~~

~~**Indigenous, traditional and local knowledges**~~

~~Indigenous~~

- 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). ~~Indigenous, traditional and local knowledges~~ITLK are increasingly being acknowledged as a source of information complimentary to classical scientific information.

~~The uptake of ITLK is experiencing both successes and challenges.~~ There is growing recognition that ITLK can provide valuable insights for sustainable resource management and biodiversity conservation. ~~This has led to the incorporation of ITLK into global processes and assessments such as the Global Assessment Report on Biodiversity and Ecosystem Services, Intergovernmental Panel on Climate Change and contributions to the Convention on Biological Diversity. One of the challenges to non-Indigenous knowledge, classical scientific method and governance systems is that they often treat the ocean as being separate from the land-based communities. There is also an assumption that ITLK need to be integrated with or validated by non-Indigenous knowledge or classical scientific methodologies.~~

~~ITLK and the World Ocean Assessment~~

~~The World Ocean Assessment/ Regular process has also 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 governance. The Regular Process is looking to increase ITLK content throughout the WOA. Regional workshops were carried out by the United Nations Division of Ocean Affairs and Law of the Sea (UNDOALOS) and included consideration of regional global ITLK issues.~~

~~Workshops identified that ITLK plays a vital role in supporting ocean governance, maintaining cultural heritage and fostering community resilience. It provides valuable, culturally authoritative, and context-specific insights for managing coastal and marine resources. ITLK groups can provide relevant information to the management of coastal resources and resource use pattern and that the impact on these communities can't be understood without Indigenous, traditional or local perspectives.~~ The loss of ~~a biological species~~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. ~~Future projections and outlooks~~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. ~~Future WOAs will build on these findings~~The WOA III has recognized the need to ~~further~~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 ~~content~~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.