2021 2030 United Nations Decade of Ocean Science for Sustainable Development

The Ocean Decade

Vision 2030 White Paper

Challenge 5

Unlock ocean-based solutions to climate change

Zero Draft - January 2024

unesco
Intergovernmental Oceanographic Commission

The Decade Coordination Unit of IOC/UNESCO extends its sincere appreciation to the co-chairs and members of the Working Group for their leadership and commitment in the process of drafting and authoring the draft White Paper. The draft White Paper is a foundation for diverse stakeholders to provide comments and suggestions, and its contents will be refined and complemented following the public review process. A revised version of the White Paper will be presented and discussed at the 2024 Ocean Decade Conference in Barcelona, before being finalized and published as part of UNESCO's Ocean Decade Series of publications.

Published in 2024 by the United Nations Educational, Scientific and Cultural Organization (UNESCO), 7 place de Fontenoy, 75352 Paris 07 SP, France

Cover design: UNESCO

VISION 2030 WHITE PAPER

ZERO DRAFT – JANUARY 2024

CHALLENGE 5: PROVIDING SOLUTIONS TO MITIGATE, ADAPT AND BUILD RESILIENCE TO THE EFFECTS OF CLIMATE CHANGE

Enhance understanding of the ocean-climate nexus and generate knowledge and solutions to mitigate, adapt and build resilience to the effects of climate change across all geographies and at all scales, and to improve services including predictions for the ocean, climate and weather.

Table of Contents

Acknowledgment

To be included after the review process

Acronyms

BBNJ	Biodiversity Beyond National Jurisdiction
CDR	Carbon Dioxide Removal
DCO	Decade Coordination Office
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
MRV	Monitoring, Reporting and Verification
UN	United Nations
UNESCO	UN Educational, Scientific and Cultural Organization
UNFCCC	UN Framework Convention on Climate Change

1. Executive summary

To be included after the review process

1.1. Overview of the Ocean Decade Challenge

This white paper sets out the strategic framework required to assess the key action areas that need to be addressed to meet the goals of the UN Decade of Ocean Science for Sustainable Development (2021-2030). As we approach the midpoint of the decade, it is appropriate to consider what has been accomplished so far and what remains to be done. Together with the other critical issues of food security, sustainable management of biodiversity, sustainable ocean economy, pollution, and natural hazards, the challenge of addressing climate change must necessarily involve proactive ocean solutions.

The goal of Challenge 5 is to enhance understanding of the ocean-climate nexus and generate knowledge and solutions to mitigate, adapt and build resilience to the effects of climate change across all geographies and at all scales, and to improve services including predictions for the ocean, climate, and weather. This is a monumental task that must be broken down into manageable components that can be addressed at national and international scales with a collective effort of making a global impact. Thus, measures of success for this challenge include the provision of information to enable such users to understand how they can fit into an integrated global network of actionable items that can be undertaken over the latter half of this decade.

1.2. Key Findings and Recommendations

This document takes a two-pronged approach to near-term actionable items: mitigation and adaptation. Mitigation is the action of reducing the severity, seriousness, or painfulness of something, while adaptation is the process of change by which an organism or species becomes better suited to its environment. Both approaches need to be addressed in parallel. Key mitigation approaches include the development of marine renewable energies, reduction in marine pollution, the development of blue carbon, and marine carbon dioxide removal., Adaptation approaches include increased ocean literacy/awareness; Co-designed governance and co-operation; Improved risk reduction policies; and Improved predictive capability of ocean, climate and weather forecasts.

2. Introduction

2.1. Background and context of the Challenge

The challenge to "Unlock Ocean-Based Solutions to Climate Change" is a pivotal component of the United Nations Decade of Ocean Science for Sustainable Development (2021-2030)[1]. It aims to deepen our understanding of the intricate interplay between the

[1] www.oceandecade.org/

ocean and climate, driven by the imperative to tackle climate change, a defining crisis of our era.

This challenge is founded on several key factors: firstly, climate change impacts have been observed in marine environments including rising temperatures, sea-level rise, ocean acidification, deoxygenation and extreme weather events imperiling ecosystems, economies, and societies worldwide (IPCC, 2021). Given the ocean's pivotal role in the Earth's climate system, addressing its capacity to regulate climate and provide ecosystem services that are relied upon by people worldwide, becomes paramount.

The ocean acts as a vast carbon sink (25%±2% of the total anthropogenic CO2 emissions from the early 1960s to the late 2010s (Gruber et al., 2023)), absorbing heat and carbon dioxide, thereby slowing climate change on land to some extent. However, these processes trigger unintended consequences, including ocean acidification and deoxygenation, posing severe risks to marine life, ecosystems and communities reliant on the ocean for their livelihoods (Doney et al., 2009, 2020). Understanding the ocean's intricate relationship with climate is crucial for harnessing its potential as a solution to climate change.

Finally, conventional climate mitigation strategies alone are insufficient to meet the targets of the Paris Agreement (IPCC, 2021, UNFCCC, 2015). Ocean-based carbon dioxide removal approaches such as carbon sequestration through blue carbon ecosystems, human derived manipulations of nutrients or alkalinity could offer innovative avenues to mediate climate change, resulting in so called negative emissions. These solutions can complement terrestrial actions and expand our toolkit for mitigating climate change (Duarte et al., 2021).

2.2. Overview of Current Work in the Ocean Decade

The Ocean Decade is currently overseeing (November 2023), a total of 152 actions related to Challenge 5. Twenty programmes and 90 projects are contributing in some way to Challenge 5. The Ocean Decade Progress Report 2022-2023, in an analysis of the distribution of endorsed Decade Programmes and Projects, lists that 8 programmes and 42 projects contribute to Challenge 5 (UNESCO-IOC, 2023). The geographical scope of the Programmes is mostly global, with the majority of programmes under this challenge focused on observations and co-design of observations, reducing stressors (sustainable fisheries, sound, pH, oxygen and others), emissions management, blue carbon ecosystems and forecasting/prediction. These specific actions are coordinated by the Decade Coordination Unit (IOC-UNESCO), with a number of Decade Collaborative Centers (DCC) and Coordination Offices (DCO) providing support to the DCU. These include the DCO for Ocean Observing, the DCC for Ocean Prediction, the DCC for Ocean-Climate Solutions (Ocean Visions, 2023), and the DCC for Ocean-Climate Nexus and Coordination Amongst Decade Implementing Partners in P. R. China all addressing different aspects of Challenge 5..

Challenge 5 was reported as one of the most commonly cited Challenges for knowledge uptake in the Decade (UNESCO-IOC, 2023). However, important gaps still remain in terms of the geographical scope of the actions under this and other challenges.

2.3. Importance and Relevance of the Challenge for Sustainable Development

Harnessing ocean-based solutions to tackle climate change holds immense significance for sustainable development on multiple fronts. Firstly, it is crucial for enhancing climate resilience, particularly in the context of vulnerable coastal communities and ecosystems. Developing management strategies that account for the interconnectedness of oceans and climate and that address mitigation and adaptation is vital to strengthening the resilience of these regions (IPCC, 2019). Second, marine biodiversity is of paramount importance to the functioning as known for the past centuries of marine ecosystems and the services they provide to society. A thriving ocean ecosystem not only sustains marine life but also plays a key role in climate regulation, ensuring food security, livelihoods, and overall ecological stability. Consequently, safeguarding and effectively managing these ecosystems through ocean-based solutions such as restoration of disturbed and destroyed ecosystems is essential for sustainable development (UN, 2023).

Third, attaining this challenge offers substantial economic potential, especially through the growth of the blue economy sectors encompassing renewable energy, sustainable fisheries, and marine tourism. These sectors can serve as engines of economic growth while simultaneously mitigating the effects of climate change (World Bank & United Nations Department of Economic and Social Affairs, 2017).

Lastly, fostering global partnerships and interdisciplinary collaboration, which are fundamental principles of the Ocean Decade, promotes international cooperation, contributing to global peace, security, and the advancement of the Sustainable Development Goals (SDGs) (UN, 2023).

2.4. Methodology for strategic ambition setting

Challenge 5 presents an important opportunity to harness the potential of ocean-based solutions to reduce the impacts of climate change. To succeed, we must prioritize scientific rigor, invest in research and innovation, and promote international collaboration to mitigate, adapt to, and build resilience against climate change while benefiting both humanity and the planet.

Effectively addressing Challenge 5 in the Ocean Decade involves setting a strategic ambition that guides research, innovation, and action. However, it is crucial to acknowledge the uncertainties and potential side effects of ocean-based climate solutions. Carbon dioxide removal (CDR) is now considered a necessity to limit global warming to 1.5 ℃, and it is estimated that a carbon removal of 100–1,000 Gt CO_2 is needed to achieve this target (IPCC, 2018). There has been a growing focus in ocean-based CDR approaches in recent years, however, there are high uncertainty about the potential impacts of these approaches and no regulations about the safety and effectiveness of this research (Boyd et al., 2023, Loomis et al., 2022). Some of the potential consequences of CDR include nutrient depletion to natural plankton and algae from cultivated phytoplankton, and alteration in plankton diversity and abundance with unknown ecosystem impacts (Oschlies et al., 2010). Therefore, a cautious, scientifically rigorous approach is necessary, focusing on inter- and transdisciplinary research (Smith et al., 2020), pilot projects (Johnson and Brown, 2019), risk assessments (Jones et al., 2021), adaptive management (Garcia et al., 2018) and fostering strong connections between the scientific community and policymakers (UNESCO-IOC, 2021).

The monitoring, reporting and verification (MRV) of marine CDR is also imperative, and the efficacy of these technologies must be tested through pilot studies before scaling up to larger testing and application (Loomis et al., 2022). Similarly, these technologies can only be upscaled if the pilot studies indicate that they do not have negative ecosystem impacts (NASEM, 2022, Boyd et al., 2023). Codes of conduct and monitoring frameworks for the detection, attribution and determination of side effects of marine CDR have been recently published (Boyd et al., 2023, Loomis et al., 2022, Cooley et al., 2022) and must guide the development of these technologies.

3. Strategic ambition setting

3.1. Analysis of user needs and priorities

Identifying and classifying the needs of users within the ocean-climate nexus can be a complex task, as it involves understanding the diverse range of stakeholders, their goals, and how they intersect with both ocean and climate-related issues. The science required to provide solutions to reduce the impacts of climate change on land and in the ocean must include mitigation and adaptation approaches tailored to local and regional capabilities (Figure 1).

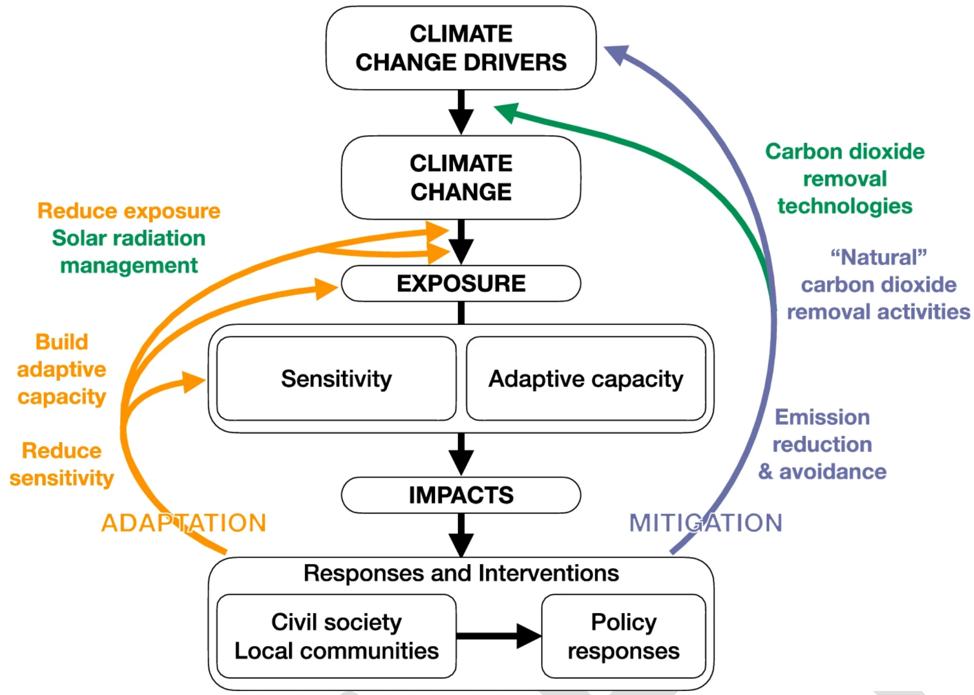

Figure 1: Mitigation (blue) and adaptation (gold) and interventions to address the impacts of climate change. Interventions with a technological focus (often collectively termed "geoengineering") are shown in green (Adapted from Trebilco et al., 2021 (https://link.springer.com/article/10.1007/s11160-021-09678-4/figures/2)

High level agreements that have already, or will likely soon commit nations to several obligations related to the ocean and climate nexus and ocean solutions include:

- UNFCCC and Paris Agreement
- The Kunming-Montreal Global Biodiversity Framework (GBF)
- The Agreement on Marine Biodiversity of Areas beyond National Jurisdiction (BBNJ Agreement) or High Seas Treaty.
- The resolution at the UN Environment Assembly (UNEA-5) to End Plastic Pollution and forge an international legally binding agreement by 2024.
- 2030 Agenda for Sustainable Development

These regulations and frameworks may introduce conflicts between the various rights and stakeholders and those undertaking the regulation.

The primary beneficiaries of ocean-based solutions to mitigate, adapt and build resilience to the effects of climate change are populations threatened by the effects of climate change. These solutions will be likely provided by a set of commercial enterprises or government actors and regulated by an agent appointed by the relevant statutory authority. These groups have a shared mutual interest in satisfying themselves that these solutions are a) certified, b) effective, c) verifiable, d) economically viable and e) do not harm other components of the ocean system.

As an example, a wide range of legislation is in place that governs the legality of carbon dioxide removal interventions designed to address climate change. Arcusa and Sprenkle-Hyppolite (2022) provide an overview which suggests that the regulatory system is incredibly complex (‘at least 30 standard developing organizations proposing at least 125 standard methodologies for carbon removal from 23 different CDR activities and selling 27 different versions of certification instruments in voluntary and compliance markets’). Further they suggest that some activities have multiple regulators and that some activities have no regulators. They suggest that marine solutions are subject to a less comprehensive regulatory regime than are land-based methods.

Multilateral Commissions and other regional management bodies can help setting legally binding instruments for nations to implement the previously mentioned agreements, but they need science-based solutions to provide direction. International/intergovernmental science organizations have a role to play in developing best practices (including data management and sharing, and capacity development) for measurement of variables that show the status and impacts of mitigation and regulation.

Partnerships between the various actors in each region will be required, for example, Morgera et al., (2023) make ambitious recommendations on implementing Strategic Ecosystem Assessments at the regional level through fair research partnerships, mutual capacity-building and technology co-development between least and well-developed states (termed the Global North and South), to fill key knowledge gaps and ensure ecologically meaningful management of BBNJ, including for the purposes of climate change mitigation.

Taking one example of an ocean-based solution, that of offshore renewable energy, which is a rapidly expanding area. It has the potential to allow nations to meet their reduced emissions targets but may also negatively impact marine biodiversity and fishing activities co-located near installations. The International Council for Exploration for the Seas (ICES) has a working group focused on these issues in the North Atlantic, “Working Group on Offshore Renewable Energy”. The working group aims to provide information on the state of development of marine renewable energy and identifies future issues that will require environmental assessment. Defining best practices and improving understanding across a range of human activities such as fishing is also a goal., Similar science-based focused expert groups should be implemented by other Intergovernmental/international organizations. However, even just the potential conflict between offshore renewables and fishing comprises a range of impacts to consider such as damage to fishing gear or property, restricted access to high value fisheries, crowding around installations or alternative fishing grounds, and loss of fishing revenue and income that affects livelihoods (Chaji and Werner, 2023). Balancing priorities and user needs is likely to vary regionally and will involve many sectors.

3.1.1. Mitigation approaches

3.1.1.1. Marine Renewable Energy

Fossil fuel dependence contributes significantly to environmental degradation and severe climate change impacts to the climate system. In this context, renewable energy emerges as a key mitigation strategy to not only mitigate climate change impact on the marine ecosystem but also foster economic growth and energy security on a global scale. The shift towards renewable energy sources is in progress across numerous regions worldwide, with renewables emerging as the second-largest contributor to global electricity production, after coal (Bosch et al., 2017).

Renewable energy sources encompass a diverse array of technologies, each one harnessing a different natural process to generate sustainable power. Solar photovoltaic and wind power are two of the most competitive and low-cost options with their combined global potential comprising an amount beyond that required to sustain ambitious mitigation strategies and limit warming below 2°C (Bosch et al., 2017, Clarke et al., 2022). Hydropower is a long-standing and widely adopted renewable energy source, with the best conversion efficiencies among all known energy sources, although its future mitigation potential depends greatly on the minimization of the environmental and social impacts.

The exploration and implementation of ocean renewables represent a vast potential and a grand challenge in the renewable-energy sector. Ranging from offshore wind farms to wave energy technologies and tidal energy systems, these sources present a vast and largely untapped potential. Beyond offering a clean and consistent power source, these technologies emphasize the importance of diversifying our energy portfolio. As the ocean renewables sector progresses, it not only holds promise for mitigating the impacts of climate change but also for catalyzing economic growth and fostering resilience in the ever-changing energy landscape.

3.1.1.2. Reducing Marine Pollution

Marine Pollution is strongly interconnected with the other planetary crises of climate change and biodiversity loss. Combatting marine pollution is a global challenge that needs a global approach if it’s to be mitigated. Increasing population and changes in consumption patterns are driving larger waste generation. Limited waste management capabilities in some countries result in significant percentages of this waste finding its way to the ocean. This waste creates additional stress on marine organisms that are also feeling the stress of climate change. Reducing marine pollution can help give organisms more time to adapt to their changing environment creating a more resilient ecosystem structure.

The production of products that ultimately lead to marine pollution is also a source of greenhouse gas that contribute to climate change. Reducing waste and better managing the waste, we already have can have multiple benefits, including providing another pathway to reduced emissions.

3.1.1.3. Blue Carbon

Vegetated coastal ecosystems (mangrove forests, seagrass meadows and tidal marshes) are characterized by disproportionately high levels of carbon sequestration (Macreadie et al., 2019; 2021) The term "blue carbon" has been applied to these ecosystems, which have drawn global attention for their role in climate change mitigation efforts (Lovelock & Duarte, 2019). Fundamental aspects of blue carbon sequestration, however, remain unresolved. These include questions about the extent to which disturbance, or restoration of these ecosystems results in release or uptake of greenhouse gases, how a changing climate is affecting carbon stores within mature blue carbon ecosystems, and the role of macro algae in blue carbon cycling (Macreadie et al., 2019). Low-cost diagnostic tools are lacking to set baselines and precisely track rates of sequestration in blue carbon restoration and conservation projects (Wedding et al., 2021). Finally, the impact of sea level rise on the resilience of coastal vegetative ecosystems is unclear. However, the crucial role of blue carbon ecosystems not only for climate change mitigation, but also in achieving biodiversity conservation goals, renders the valuation of blue carbon ecosystems important even though it is challenging and disputed (Wedding et al., 2021; McHarg et al., 2022).

3.1.1.4. Marine Carbon Dioxide Removal (mCDR)

To achieve the climate targets set by the Paris Agreement, negative emissions technologies (NETs) that remove existing atmospheric carbon dioxide will be needed at the gigaton scale by 2050 (IPCC 2022). Removals are needed alongside the prioritization of massive efforts to mitigate emissions, including the implementation of ocean-based solutions since the oceans cover 71% of the earth's surface. Some marine solutions are currently ready for large-scale deployment such as ocean-based renewable energy and decarbonization of ocean transport, but purposeful sequestration of atmospheric CO_2 into the ocean is more of a challenge (Ho, 2023, Hoegh-Guldberg et al., 2023).

To date, the ocean has naturally removed an amount of carbon from the atmosphere that is equivalent to 37% of all fossil fuel emissions, 179 PgC (Friedlingstein et al., 2023). Without this "ocean carbon sink", atmospheric CO_2 level would be almost 100 ppm higher than it is today. This results from the increased partial pressure of CO2 in the atmosphere driving a net air to sea flux n Carbonate chemistry in seawater allows the ocean to absorb vast amounts of carbon. Thus, if human intervention could practically increase this capacity by removing and durably storing ocean carbon, excess carbon may be drawn down from the atmosphere to mitigate climate change. Ocean CDR pathways including ocean alkalinity enhancement, forms of direct atmospheric removal with ocean storage, and nutrient fertilization, among others, are currently low in technological readiness and need significant further development (Hoegh-Guldberg et al., 2023). Controlled field testing must be co-designed and implemented with invested communities, modeled, and monitored for the long-term (NASEM 2022, Hoeugh-Guldberg et al., 2023, Ocean Visions 2023) before we can determine whether additional carbon sequestration can practically be engineered at the necessary scales.

A common challenge across marine CDR pathways is that the natural cycling of carbon creates large fluxes to and from the ocean surface and atmosphere, as well as high rates of transformation between inorganic and organic carbon pools in the water column. Though theoretical arguments suggest more carbon uptake could be forced by human interventions, determining if and how much additional ocean carbon uptake has occurred due to specific human activities is exceedingly difficult. There is a great need for development of observational technologies and modeling capacity to support robust and standardized monitoring and carbon accounting (NASEM 2022, Ocean Visions 2023). High priority development is needed to improve understanding of how user communities use monitoring instrumentation and data, and what these communities might need in the future; improve ocean chemistry baseline measurements; innovate more robust sensor designs; and develop more robust model designs to improve carbon life cycle accounting (NASEM 2022, Hoegh-Guldberg et al., 2023, Ocean Visions 2023). Improved capacity for making measurements in under-sampled areas is also needed.

Ocean-based CDR pathways have potential to benefit ocean ecosystems by mitigating ocean acidification, but each also carries potential negative ecosystem impacts that must be investigated and considered in a risk analysis framework that compares them to the status quo (Hoegh-Guldberg et al., 2023, Ocean Visions 2023, Smith et al., 2023). Science delivered to meet Challenge 5 could include the impacts of pH and saturation state changes on marine ecosystems, nutrient redistribution, and changes to net primary productivity, and changes throughout the water column, including deep ocean impacts (NASEM 2022, Smith et al., 2023). Unintended consequences are also anticipated (NASEM 2022), and the knowledge base on both intended and unintended impacts needs strengthening.

Alongside an improved understanding of carbon accounting and ecosystem impacts, a critical understanding of human dimensions of marine CDR is necessary for generating durable and just ocean-based solutions to the climate crisis. Human dimensions include governance, policy, regulation, economic, livelihood, supply chain, and social and relational components such as perception and acceptability, for which the harms and co-benefits of marine CDR, intended and unintended, must be identified and deliberated (Hoegh-Guldberg et al., 2023, Ocean Visions 2023). Key scientific outputs addressing human dimensions of marine CDR could include: spatial analyses to understand where technical, economic, social, infrastructure, and political conditions make mCDR likely feasible and where there may be used conflicts; implications of scaling for supply chains, work force and livelihoods, and sustainability; development of model international and domestic (where applicable) legal and regulatory frameworks that accelerate mCDR field testing and account for procedural and distributional justice; and co-creation of knowledge around community and practitioner perception of the co-benefits and risks of marine CDR and their acceptability (NASEM 2022, Ocean Visions 2023, Smith et al., 2023).

Finally, NETs can only meaningfully contribute to remedying climate warming if they are combined with massive efforts to mitigate emissions. Ocean CDR or other NETs are not the first-line solution to climate change; mitigation of at least 80% of emissions must be the first priority. In fact, it is only after massive mitigation do NETs make practical sense (Ho, 2023).

3.1.2. Adaptation and Building Resilience

Adaptation is a critical component in unlocking ocean-based solutions to climate change (Figure 2). The global ocean and inland waters collectively contribute to the diets of over 3.3 billion people, supplying them with at least 20% of their protein intake, and supporting the livelihoods of 60 million people. Coastal communities, where 40% of the global population resides within 100 kilometers off the coast (UNR Seas), heavily depend on the improved predictive capability of ocean, climate, and weather models for sustainable planning and resilience.

Human adaptation comprises an array of measures that reduces harm or exploits opportunities from climate change (Cooley et al., 2022). Indeed many adaptation approaches can deliver benefits both for mitigation and for reducing climate change impacts (Bindoff et al., 2019), at a variety of scales. Adaptation in oceans and coastal ecosystems continues to be based primarily on theory because of limited evidence about implemented solutions and their success across regions, particularly in low-income nations (Cooley et al., 2022).

There is a continued need for improved modelling capabilities at different timescales ranging from days for short-term extreme events and disaster prevention, seasonal prediction for agricultural planning, water resource management, decadal variability prediction for resilient strategies across different sectors such as agriculture, infrastructure and ecosystems and long-term climate for urban planning, resource management and policy development.

Nonetheless, the advancement of ocean, climate, and weather forecast capabilities faces several challenges such as the advancement in the modeling of atmosphere and complex interactions and feedback mechanisms, uncertainty reduction leading to reliable long-term predictions, reducing the gaps in observation networks both in spatial coverage and depth, which hinder the monitoring and model validation, computing infrastructural challenges for computationally demanding ocean and near-shore coastal models, increased global collaboration in data sharing and model development.

One priority is the need for shorter-term forecasts of extreme events such as heatwaves or harmful algal blooms. For areas with operational forecasting systems, it is important these forecasts are co-developed, easily accessible and understood by users to inform their behavior and decision-making. This is because despite significant improvement and efforts in weather forecasting and climate prediction, the general public are not well aware of how to access forecasts and apply it to daily life and decisions. The challenge should therefore aim to bridge the gap between the general public and access to weather and climate forecasting.

To navigate this challenge effectively, researchers and policymakers must employ adaptive and resilient strategies that acknowledge the inherent uncertainties in climate models and projections. This involves continually refining models based on new data, advancements in scientific understanding, and improved computational capabilities. Additionally, fostering collaboration among scientists, policymakers, and stakeholders is crucial to developing holistic and informed strategies that can withstand the uncertainties associated with long-term climate modeling.

Ocean literacy – that is, enhanced understanding of the ocean, sustainable ocean use, and the climate-ocean nexus – will be an important element in achieving climate mitigation and sustainable development goals but requires the development and implementation of dedicated strategies to improve societal connections to the ocean (Kelly et al., 2022). Ocean stewardship, and ocean-based solutions to climate change, will also be enhanced by a movement towards co-designed governance and co-operation between users including local and indigenous communities (e.g. Karrasch et al., 2017; Lyons et al., 2023). Adaptive governance and management can be supported by decision support tools for the assessment of vulnerability and risk to coastal communities and marine industries, and for developing climate change adaptation pathways (e.g. Fulton et al., 2022).

The ability to adapt to sea-level rise, cope with future coastal risks and associated social conflict depends on immediate mitigation and adaptation actions. Until 2050, adaptation planning needs to increase significantly in most coastal regions (Cooley et al., 2022). Effective responses to rising sea-level require locally applicable combinations of decision analysis, public participation, and conflict resolution approaches; together these can anticipate change and help adapt and address the challenges due to rising sea level (Cooley et al., 2022). Updating sea-level projections for local and regional scale and reducing uncertainties are also key for adaptation measures to sea-level rise. Providing scientific support to have local-scale sea-level projection for low-lying low-income countries with less research capability will be crucial. For example, global scale projection or IPCC projection is not enough for low-income countries in Southeast Asia such as Philippines, Indonesia, Vietnam.

Furthermore, immediate adaptations to challenges such as harmful algal blooms, fishing-area closures, can be informed by public communications and education along with early-warning forecasts. These types of adaptations are more effective in building trusted relationships and effective coordination among involved parties and are inclusive of diversity in a coastal community.

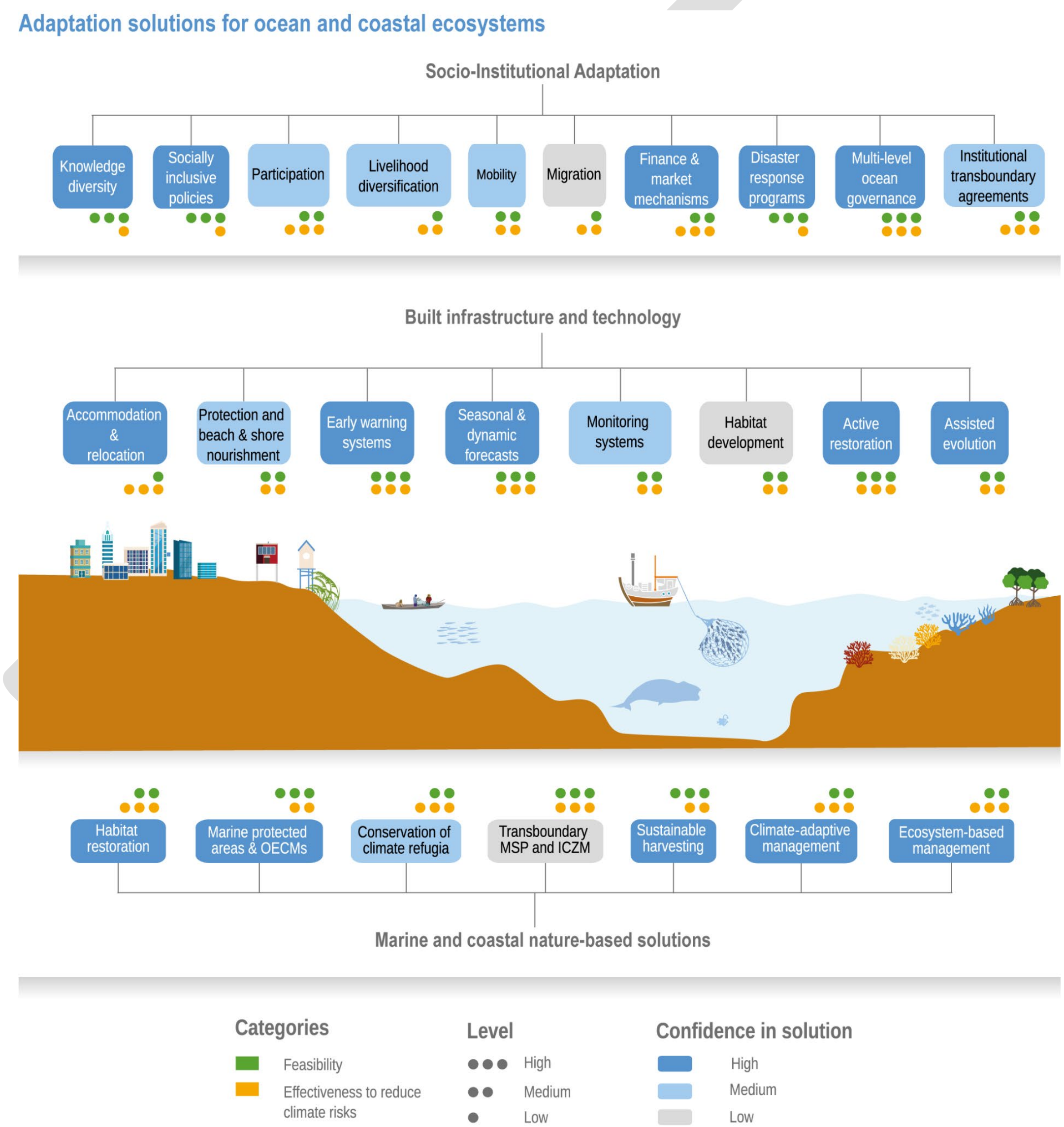

Figure 2: Adaptation solutions for ocean and coastal ecosystems to address climate change risk in ocean ecosystems and communities. Box color indicates confidence in the solution's potential to reduce risk. The figure is adopted from IPCC AR6 WGII chapter 3. https://www.ipcc.ch/report/ar6/wg2/figures/chapter-3/figure-3-023

3.2. Definition of the strategic ambition for the Challenge

We can ask the question, what does success look like for mitigating, adapting, and building resilience to the effects of climate change in the ocean?

mitigation - provision of data, knowledge, infrastructure, personnel capacity, governance frameworks and societal engagement to enable mitigation of climate change - maintaining global temperatures below 1.5˚C warming by 2100.

adaptation and resilience - provision of required data, knowledge, infrastructure, personnel capacity, governance frameworks and societal engagement to enable society to adapt to / be resilient to anticipated levels of climate change.

Table 1: summary table linking 'science needed' with 'what success looks like'

	Priority datasets	Knowledge generation	Infrastructure	Partnerships	Capacity	Technology
Challenge 5 in general	link with GOOS, Argo etc.					
Mitigation: Develop marine renewable energy		-improved knowledge of energy potential -understanding of potential unintended consequences -cost/benefit ratio	-cabled arrays to get power to shore -robust energy generation systems	-strengthened partnerships between social and ecological science researchers and the private sector developing and deploying field trials -improved communication and partnerships between legislators and policy makers and the private sector to enable better cross-	-finance - marine engineers -energy sector people	-innovation of more robust designs -innovation of more robust models

				sectoral understanding of parties’ needs and concerns and accelerate implementation of controlled field trials		
Mitigation: Reduce marine pollution		-better understanding of environmental sensitivities	-marine debris collection systems	-industries that generate marine debris -fishing industry	-finance	-efficient clean-up approaches
Mitigation: Restore and increase vegetation		-coastal ecosystem dynamics	-coastal development and regulations	-blue carbon community -biodiversity community	-finance	-seed farms
Mitigation: Marine Carbon Dioxyde Removal	high quality, comprehensive and accessible carbonate system measurements	-improved knowledge of intended and unintended ecosystem impacts -spatial	-robust MRV program -designated areas for marine CDR testing	-CDR companies	-monitoring community development	-innovation of more robust sensor designs -innovation of more

		analyses of feasibility and use conflicts -improved understanding of implications of scaling of each marine CDR approach for supply chains, livelihoods, and economies -improved understanding of perceptions of risks, benefits, and acceptability governance frameworks				robust model designs
<u>Adaptation: Increased ocean literacy / awareness</u>		-improved understanding of the impacts may alter behavior	-information coordination center	-science media -science writers	-mass media	-improved storytelling tools

		-ability to crowdsource solutions for adaptation				
Adaptation: Co-designed governance and co-operation		-build on all available sources of information	-ocean conservation lobbyists	-NGOs, governments at all levels	-connections to government bodies	-?
Adaptation: Improved risk reduction policies		-environmental information to inform policies	-knowledgeable policy writing centers	-policy makers -social science	-improved assessment capacity	-computing capacity
Adaptation: Improved predictive capability of ocean, climate and weather forecasts		-robust integrated models and underlying knowledge of drivers	-computing facilities	-operational weather forecasting community	-higher resolution integrated models	-computing capacity

3.3. Integration, synergies, and interdependencies with other Challenges

Achieving success in addressing ocean challenges, particularly Challenge 5, the climate-ocean nexus, entails seamless collaboration and integration across challenges, including marine pollution, biodiversity conservation, sustainable development, and equitable resource access. Such success creates a resilient and climate-resilient ocean that aligns with the United Nations' sustainable development goals. Crucially, the success of Challenge 5 is intricately linked to the outcomes of Challenges 1 to 4, which focus on understanding climate-ocean interactions, controlling marine pollution, conserving biodiversity, and ensuring sustainable food production. For instance, a deeper comprehension of climate-ocean interactions (Challenge 1) is vital for informing climate-resilient solutions, while effective marine pollution control (Challenge 2) is imperative for maintaining the health and integrity of the ocean ecosystem. Enhancing community resilience (Challenge 6) is essential for fostering adaptive capacities in the face of climate change impacts, reinforcing the overarching resilience objectives. Expanding ocean observations (Challenge 7) provides critical data for understanding and responding to climate-related challenges, directly supporting the scientific foundation of Challenge 5. The creation of digital ocean representations (Challenge 8) facilitates advanced modeling and simulation, aiding in the development of innovative solutions for climate resilience. Promoting knowledge and skills (Challenge 9) ensures a well-equipped workforce capable of addressing the complexities of Challenge 5, while the transformation of humanity's relationship with the ocean (Challenge 10) establishes a sustainable and harmonious coexistence with this vital ecosystem.

4. Milestones and indicators

4.1. Key milestones to measure progress and success

The key milestones for challenge 5 connect with the common milestones found in the Vision 2030 process as illustrated below.

<u>Milestone 1: Enhanced Ocean Data Accessibility and Availability</u>

Improved understanding of the mitigation potential, development, and safe scaling and deployment of effective marine CDR technologies

Improved climate prediction and modelling capabilities to support public needs at different scales

<u>Milestone 2: Advancement in Ocean Knowledge Sharing</u>

Increased number of ocean and climate forecasts and projections available to users

Milestone 3: Building Capacity for Ocean Decade Challenges

Improved observational, experimental, modelling, and technological capacity to ensure the Ocean-Climate Nexus is maintained

Milestone 4: Sustainable Policy and Governance Implementation

Development of a standardized and accepted framework for the monitoring of marine CDR activities

Development and implementation of a policy and governance framework to guide CDR research and technologies, assess potential side effects and minimize negative impacts

Increased implementation and effectiveness monitoring of policies aimed to reduce overfishing, pollution, and biodiversity loss

Milestone 5: Inclusive Stakeholder Engagement

Increased number of co-developed ocean-based solutions, including CDR technologies and activities like forecasts

Milestone 6: Societal and Environmental Impact

Milestone 7: Increased Funding for Decade Actions

Milestone 8: Diverse and Inclusive Decade Actions

Milestone 9: Advancement in Ocean Technology and Innovation

Increased modeling capacity and technologies to support robust and standardized monitoring and carbon accounting

Milestone 10: Enhanced Utilization of Ocean Science and Knowledge

4.2. Indicators to track the achievement of the strategic ambition

The indicators used to track the progress achieved by Challenge 5 are 1) the number of knowledge products produced disaggregated by (i) type of product and (ii) inclusion of indigenous and local knowledge (generation of knowledge) and 2) Number of references of knowledge products by users disaggregated by type of use (IOC-UNESCO, 2023). In addition, we propose the following indicators to measure progress in achieving the strategic ambition:

Priority datasets to unlock or to generate

- Registry/Number of mCDR activities and other ocean-based solutions
- Number (% of total) of impact studies associated with the mCDR activities, including feasibility and effectiveness assessments

- Oceanographic and atmospheric datasets at appropriate resolution to quantify the impact of climate change on the ocean's ability to absorb atmospheric carbon dioxide and to determine the effectiveness of marine CDR activities
- Integrated assessments of vulnerability and risks for different regions and sectors
- Valuation of Ocean Climate services
- Seasonal and decadal-scale forecasts/predictions at appropriate scales

Knowledge to generate or to share

- Number of operational forecasts per continent/basin
- Knowledge and understanding to underpin the implementation of ocean management that is dynamic and adaptive to a changing environment and changing uses of the ocean (implementation plan, p.28-31)
- Knowledge of the ocean's role in climate regulation

Infrastructure required to generate or share data or knowledge or to build capacity and skills

- Cloud infrastructure e.g. https://gallery.pangeo.io/repos/pangeo-gallery/cmip6/ with sustained support available to endorsed actions
- Number of platforms measuring ocean carbon and essential ocean variables related to mCDR

Partnerships and financial or in-kind resources to generate and ensure uptake of knowledge

- Number of climate- and ocean-smart investments supporting ocean and nature-based solutions

Capacity development and exchange needs

- Number of capacity building /development activities by type (i.e. mentoring programmes, exchange programmes, number/amount of travel support for ECRs
- Number of webinars/seminars/communication activities raising societal awareness of climate change, impacts and the role of the ocean in climate regulation

Technology and innovation solutions including those required for uptake of knowledge.

References

Arcusa, S. & Sprenkle-Hyppolite, S., 2022. Snapshot of the Carbon Dioxide Removal certification and standards ecosystem (2021–2022), Climate Policy, 22:9-10, 1319-1332, https://doi.org/10.1080/14693062.2022.2094308

Boyd et al., 2023. Operational Monitoring of Open-Ocean Carbon Dioxide Removal Deployments: Detection, Attribution, and Determination of Side Effects. https://doi.org/10.5670/oceanog.2023.s1.2

Bosch, J., Staffell, I. and Hawkes, A.D., 2017. Temporally-explicit and spatially-resolved global onshore wind energy potentials. Energy, 131, pp.207-217.

Chaji, M. and Werner, S., 2023. Economic Impacts of Offshore Wind Farms on Fishing Industries: Perspectives, Methods, and Knowledge Gaps. Mar Coast Fish, 15: e10237. https://doi.org/10.1002/mcf2.10237

Clarke, L., Y.-M. Wei, A. De La Vega Navarro, A. Garg, A.N. Hahmann, S. Khennas, I.M.L. Azevedo, A. Löschel, A.K. Singh, L. Steg, G. Strbac, K. Wada, 2022. Energy Systems. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change[P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. https://doi.org/10.1017/9781009157926.008

Cooley, S., D. Schoeman, L. Bopp, P. Boyd, S. Donner, D.Y. Ghebrehiwet, S.-I. Ito, W. Kiessling, P. Martinetto, E. Ojea, M.-F. Racault, B. Rost, and M. Skern-Mauritzen, 2022. Oceans and Coastal Ecosystems and Their Services. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 379–550, https://doi.org/10.1017/9781009325844.005

Doney, S.C., V.J. Fabry, R.A. Feely, J.A. Kleypas, 2009. Ocean Acidification: The Other CO2 Problem. Annual Review of Marine Science, vol. 1, pp. 169-192. https://doi.org/10.1146/annurev.marine.010908.163834

Doney, S.C., Busch, D.S., Cooley, S.R., & Kroeker, K.J., 2020. The Impacts of Ocean Acidification on Marine Ecosystems and Reliant Human Communities. Annual Review of Environment and Resources. https://doi.org/10.1146/annurev-environ-012320-083019

Duarte, C.M., S. Agusti, E. Barbier, G.L. Britten, J.C. Castilla, J.-P. Gattuso, R.W. Fulweiler, T.P. Hughes, N. Knowlton, C.E. Lovelock, H.K. Lotze, M. Predragovic, E. Poloczanska, C. Roberts & B. Worm, 2021. Rebuilding Marine Life. Nature, vol. 580, no. 7801, 2021, pp. 39-51. https://doi.org/10.1038/s41586-020-2146-7

Fulton EA, van Putten EI, Dutra LXC, Melbourne-Thomas J, Ogier E, Thomas L, Murphy RP, Butler I, Ghebrezgabhier D, Hobday AJ, Rayns N, 2020. Adaptation of fisheries management to climate change Handbook, CSIRO, Australia.

Garcia, Peter, et al., 2018. Adaptive Management in Ocean-Based Climate Solutions." Journal of Environmental Management, vol. 32, no. 4, pp. 575-589.

Ho, D. T., 2023. Carbon dioxide removal is not a current climate solution — we need to change the narrative. Nature, 616(7955), 9–9. https://doi.org/10.1038/d41586-023-00953-x

Hoegh-Guldberg, O., Northrop, E. et al., 2023. "The ocean as a solution to climate change: Updated opportunities for action." Special Report. Washington, DC: World Resources Institute. Available online at https://oceanpanel.org/publication/ocean-solutions-to-climate-change

IPCC, 2021. IPCC Sixth Assessment Report. https://www.ipcc.ch/assessment-report/ar6/

IPCC, 2019. Special Report on the Ocean and Cryosphere in a Changing Climate. Intergovernmental. https://www.ipcc.ch/srocc/

Johnson, Robert, and Susan Brown, 2019. Pilot Projects for Ocean-Based Climate Solutions. Climate Research, vol. 42, no. 3, pp. 235-252.

Jones, Michael, et al., 2021. Risk Assessment of Ocean-Based Climate Solutions. Nature Climate Change, vol. 15, no. 7, pp. 891-903.

Karrasch L, Maier M, Kleyer M, Klenke T, 2017. Collaborative Landscape Planning: Co-Design of Ecosystem-Based Land Management Scenarios. Sustainability. 9(9):1668. https://doi.org/10.3390/su9091668

Kelly, R., K. Evans, K. Alexander, S. Bettiol, S. Corney, C. Cullen-Knox, C. Cvitanovic, K. De Salas, G. R. Emad, L. Fullbrook, C. Garcia, S. Ison, S. Ling, C. Macleod, A. Meyer, L. Murray, M. Murunga, K. L. Nash, K. Norris, M. Oellermann, J. Scott, J. S. Stark, G. Wood, and G. T. Pecl, 2022. Connecting to the oceans: supporting ocean literacy and public engagement. Reviews in Fish Biology and Fisheries 32:123–143.

Loomis R, Cooley SR, Collins JR, Engler S and Suatoni L, 2022. A Code of Conduct Is Imperative for Ocean Carbon Dioxide Removal Research. Front. Mar. Sci. 9:872800. https://doi.org/10.3389/fmars.2022.872800

Lovelock, C. E. & Duarte, C., 2019, Dimensions of Blue Carbon and emerging perspectives. Biol. Lett. 15.

Lyons, P., S. Mynott, and J. Melbourne-Thomas, 2023. Enabling Indigenous innovations to re-centre social licence to operate in the Blue Economy. Marine Policy https://doi.org/147:105384

Macreadie, P.I., Costa, M.D.P., Atwood, T.B., Friess, D.A., Kelleway, J.J., Kennedy, H., Lovelock, C.E., Serrano, O. & Duarte, C.M., 2021. Blue carbon as a natural climate solution. Nat Rev Earth Environ 2, 826–839. https://doi.org/10.1038/s43017-021-00224-1

Macreadie, P.I., Anton, A., Raven, J.A., Beaumont, N., Connolly, R.M., Friess, D.A., Kelleway, J.J., Kennedy, H., Kuwae, T., Lavery, P.S., Lovelock, C.E., Smale, D.A., Apostolaki, E.T., Atwood, T.B., Baldock, J., Bianchi, T.S., Chmura, G.L, Eyre, B.D., Fourqurean, J.W., Hall-Spencer, J.M., Huxham, M., Hendriks, I.E., Krause-Jensen, D., Laffoley, D., Luisetti, T., Marbà, N., Masque, P., McGlathery, K., Megonigal, J.P., Murdiyarso, D., Russell, B.D., Santos, R., Serrano, O., Silliman, B.R., Watanabe, K. & Duarte, C.M., 2019. The future of Blue Carbon science. Nat Commun 10, 3998. https://doi.org/10.1038/s41467-019-11693-w

McHarg, E., E. Mengo, L. Benson, J. Daniel, A. Joseph-Witzig, P. Posen, T. Luisetti, 2022 Valuing the contribution of blue carbon to small island developing states' climate change commitments and Covid-19 recovery. Environ. Sci. Policy 132, 13–23. https://doi.org/10.1016/j.envsci.2022.02.009

Morgera, E., McQuaid, K., La Bianca, G., Niner, H., Shannon, L., Strand, M., Rees, S., Howell, K., Snow, B., Lancaster, A. M. S., & Sauer, W., 2023. Addressing the Ocean-Climate Nexus in the BBNJ Agreement: Strategic Environmental Assessments, Human Rights and Equity in Ocean Science. The International Journal of Marine and Coastal Law, 38(3), 447-479. https://doi.org/10.1163/15718085-bja10139

Ocean Visions, 2023. A comprehensive program to prove or disprove marine carbon dioxide removal technologies by 2030. Report. Available online at https://oceanvisions.org/wp-content/uploads/2023/10/A-Comprehensive-Program-to-Prove-or-Disprove-Marine-Carbon-Dioxide-Removal-Technologies-by-2030_FINAL.,pdf

SDGs, Sustainable Development Goal 14: Conserve and sustainably use the oceans, seas, and marine resources for sustainable development. United Nations, http://www.un.org/sustainabledevelopment/oceans/. Accessed [20/10/2023].

Smith, John, et al., 2020. Interdisciplinary Approaches to Ocean-Based Climate Solutions. Environmental Science and Policy, vol. 25, no. 5, pp. 121-138.

UNESCO-IOC, 2021. Ocean Decade Science-Policy Interface Guidelines. Paris: United Nations Educational, Scientific and Cultural Organization. https://unesdoc.unesco.org/ark:/48223/pf0000377082

UNESCO-IOC, 2023. Ocean Decade Progress Report 2022–2023. UNESCO, Paris. (The Ocean Decade Series, 46).

UNFCCC, 2015. Paris Agreement. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

UNR Seas. year. PERCENTAGE OF TOTAL POPULATION LIVING IN COASTAL AREAS https://www.un.org/esa/sustdev/natlinfo/indicators/methodology_sheets/oceans_seas_coasts/pop_coastal_areas.pdf

Wedding, L. M., M. Moritsch, G. Verutes, K. Arkema, E. Hartge, J. Reiblich, J. Douglass, S. Taylor, A.L. Strong, 2021. Incorporating blue carbon sequestration benefits into sub-national climate policies. Glob. Environ. Change 69, 102206. https://doi.org/10.1016/j.gloenvcha.2020.102206

World Bank & United Nations Department of Economic and Social Affairs, 2017. The Potential of the Blue Economy: Increasing Long-term Benefits of the Sustainable Use of Marine Resources for Small Island Developing States and Coastal Least Developed Countries. The Potential of the Blue Economy. https://doi.org/10.1596/26843

List of Working Group members

<u>Working Group 5 Co-chairs:</u>

Christopher Sabine (University of Hawaiʻi at Mānoa, USA)

Carol Robinson (University of East Anglia, UK)

<u>Working Group 5 Members:</u>

Courtney McGeachy (Ocean Visions, USA)

Fangli Qiao (First Institute of Oceanography (FIO), Ministry of Natural Resources (MNR), P. R. China)

Dhrubajyoti Samanta (NTU, Singapore)

Richard Bellerby (NIVAR, China)

Sonia Batten (PICES, Canada)

Richard Sanders (NORCE, Norway)

Galen McKinley (LDEO, USA)

VVSS Sarma (NIO, India)

Kelly Ortega Cisneros (University Cape Town, South Africa)

Robert Blasiak (Stocholm University, Sweden)

Andrea Lira Loarca (University of Genoa, Italy)

Suchana Chavanich (Chulalongkor, Thailand)

Sophia Laarissa (Cadi Ayyad, Morocco)

Jess Melbourne Thomas (CSIRO, Australia)

<u>Supporting Staff</u>

Kirsten Isensee (UNESCO-IOC, France)

United Nations Decade of Ocean Science for Sustainable Development (2021-2030)

Proclaimed in 2017 by the United Nations General Assembly, the UN Decade of Ocean Science for Sustainable Development (2021-2030), provides a convening framework to develop the scientific knowledge and partnerships needed to catalyse transformative ocean science solutions for sustainable development, connecting people and our ocean. The Ocean Decade is coordinated by UNESCO's Intergovernmental Oceanographic Commission (IOC).

Established during the Preparatory Phase and to continue throughout implementation until 2030, the IOC's Ocean Decade Series will provide key documentation about this global initiative and aims to serve as a primary resource for stakeholders seeking to consult, monitor and assess progress towards the vision and mission of the Ocean Decade.

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

https://oceandecade.org/