Deliverable D8.3

RoadMap of gaps, synergies & opportunities for OceanICU to deliver impact

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1.Abbreviations

ABNJ - Areas Beyond National Jurisdiction
BBNJ - Biodiversity Beyond National Jurisdiction (UN Agreement)
BCP - Biological Carbon Pump
CBD - Convention on Biological Diversity
CAOFA - Central Arctic Ocean Fisheries Agreement
CO_2 - Carbon Dioxide
COP - Conference of the Parties (to UNFCCC or BBNJ)
DST - Decision Support Tool
EBM - Ecosystem-Based Management
EEZ - Exclusive Economic Zone
EIA - Environmental Impact Assessment
EMODnet - European Marine Observation and Data Network
EU - European Union
EU4Ocean - European Union Ocean Literacy Coalition
GDP - Gross Domestic Product
GtC - Gigatonnes of Carbon
HELCOM - Helsinki Commission (Baltic Marine Environment Protection Commission)
ICES – International Council for the Exploration of the Seas
IMO - International Maritime Organization
IOC-UNESCO - Intergovernmental Oceanographic Commission of UNESCO
IPBES - Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC - Intergovernmental Panel on Climate Change
KPI - Key Performance Indicator
MARPOL - International Convention for the Prevention of Pollution from Ships
MPA -Marine Protected Area
NGO - Non-Governmental Organization
O – Outreach objetives
OSP - Ocean System Pathway
OSPAR - Oslo-Paris Convention for the Protection of the Marine Environment of the North-East Atlantic
RIA - Research and Innovation Action
SDG - Sustainable Development Goal
SSP - Shared Socioeconomic Pathway
ST – Scientific and Technical objectives
UN - United Nations
UNCLOS - United Nations Convention on the Law of the Sea
UNDOALOS - United Nations Division for Ocean Affairs and the Law of the Sea
UNFCCC - United Nations Framework Convention on Climate Change
WP - Work Package
WWF - World Wide Fund for Nature

WMO - World Meteorological Organization
WMU - World Maritime University

2. Glossary

Blue Carbon: Carbon that is captured and stored by marine ecosystems, usually associated with coastal ecosystems such as mangroves, saltmarshes, and seagrass beds.

Carbon export: refers to the carbon that is transported from the atmosphere to the ocean through biological, physical, or chemical processes.

Carbon residence/sequestration time: Is the amount of time that carbon molecules remain stored before returning to the atmosphere in a CO_2 molecule.

Decision Support Tool (DST): A modelling and visualization platform designed under the OceanICU project, to explore and visualize the impacts of natural processes and human activities on ocean carbon dynamics and ecosystem health. Developed collaboratively with scientists, policymakers, and industry stakeholders, it helps explore trade-offs between conservation, resource use, and climate goals. The DST supports evidence-based decision-making under the EU Green Deal, ensuring that management strategies for ocean resources are both sustainable and socially equitable.

Ecosystem-Based Management (EBM): An integrated approach that incorporates the entire ecosystem, including humans, into resource management decisions, and is guided by an adaptive management approach.

Exclusive Economic Zone (EEZ): An area of the ocean, generally extending 200 nautical miles (230 miles) beyond a nation’s territorial sea, within which a coastal nation has jurisdiction over both living and non-living resources.

Marine Protected Area (MPA): A defined region designated and managed for the long-term conservation of marine resources, ecosystems services, or cultural heritage.

Ocean Governance: The integrated conduct of the policy, actions and affairs regarding the world's oceans to protect ocean environment, sustainable use of coastal and marine resources as well as to conserve of its biodiversity.

Ocean Literacy: Understanding the ocean's influence on people and people's influence on the ocean. OceanICU works with IOC-UNESCO and the EU4Ocean Coalition, on ocean literacy initiatives which aim to empower citizens and decision-makers to act sustainably.

Ocean System Pathways (OSPs): Climate change scenarios that developed a new set of socio-economic scenarios derived from the Shared Socioeconomic Pathways (SSPs). The OSPs extend the SSPs to the economic, governance, management and socio-cultural contexts relating to fisheries and mariculture.

Shares SocioEconomic Pathways (SSPs): Climate scenarios used by the Intergovernmental Panel on Climate Change (IPCC) that account not only for changes in climate but also in socio economic conditions.

Valuation of Ecosystem Services: The assigning of economic value to the assets, goods and services, humans derive from ecosystems, such as carbon sequestration, biodiversity, and fisheries productivity. Valuation is based on either market prices (price of fish per tonne, CO_2 offset, etc.) or shadow prices (social cost of carbon, willingness-to-pay, etc.).

3. Key Messages for OceanICU Stakeholders

- There is a disconnect between global climate and ocean policies. This links to the division between, on the one hand, the cooperation under the UNFCCC (United Nations Framework Convention on Climate Change), where targets relating to the Biological Carbon Pump (BCP) may be set, and the law of the sea on the other, which provides the global rules for ocean governance but does not consider climate change. As a result of this divide, there is a real risk that scientific knowledge on the BCP is not considered in policy development and that appropriate measures fail to materialise.
- The new UN Agreement on Biological Diversity in Areas Beyond National Jurisdictions (BBNJ) marks a strategic window of opportunity to integrate considerations of the BCP in ocean governance. Among its guiding principles, the agreement includes the first reference to the BCP, in its large sense, ever made in a binding treaty, and generally calls for integrating climate considerations in the development of measures. The BBNJ also builds on holistic approaches, integrating contributions from different ocean governance institutions. As the BBNJ is likely to enter into force in 2026 its implementation is in a formative phase. Ocean-ICU should strive to capitalize on this opportunity to advocate for prioritizing the BCP as a key interest.
- Until these pieces fall into place, we advocate a precautionary approach: expanding area-based management to safeguard the biological carbon pump, investing in ecosystem restoration to bolster its efficiency, and aligning climate and marine biodiversity policies to ensure that this critical service continues to benefit both people and the planet.
- The magnitude BCP sequestration service within national and international waters are of comparable in terms of climate benefit. As a result, efforts will have to be made both by individual countries and through international treaties to manage this important resource. Negotiating governance frameworks under the Biodiversity Beyond National Jurisdiction treaty is particularly critical.
- Large Ocean States (AKA Small Island Developing States) could play an important role in preserving the BCP and its carbon sequestration service by reducing current human activities or foregoing new ones that could damage the BCP. However, they lack financial resources to do so, also because climate finance does not consider the importance of open ocean ecosystems, and “Life under water” Sustainable Development Goal is one of the most underfunded.
- As climate change becomes more significant, fishing in the Arctic is expected to increase. This will have repercussions on carbon stocks in the seabed, but will also increase emissions linked to fuel burning.
- Fisheries have halved the contribution of commercial marine macrofauna to carbon export, compared to the 1950s. This impact will be amplified by climate change by the end of the century. Although rebuilding macrofauna

stocks may offer a pathway to sequester more carbon in the ocean, several knowledge gaps must be filled before incorporating fish-carbon into future ocean management plans.

4. Abstract

This report provides an overview of activities that have been undertaken primarily within Task 8.1 of WP8 with contributions from Task 8.2 and 8.3. We explored the interface between science and policy and the limitations, gaps, and opportunities in integrating science in management, decision-making, and policy-making. In particular, we investigated: 1) Policy gaps in relation to the regulation, management and protection of the BCP; 2) Opportunities for integrating oceanic carbon into decision-making; 3) Valuation and distribution of the BCP carbon sequestration service; 4) The combined impact of fisheries and climate change on carbon sequestration by oceanic macrofauna and arctic fisheries expansion under climate change 5); The importance of ocean literacy; and 6) Ocean System Pathways to develop ocean-specific scenarios built to explore the future of the ocean under different climate and socio-economic conditions. We used a range of methods that included desk-based analysis, interviews and workshops with stakeholders, economic theory, mathematical modelling and spatial analysis. We found:

- several gaps in regulation and policy
- a lack of awareness and understanding of the climate and socio-economic benefits provided by the BCP
- a growing interest and demand from policymakers and stakeholders for a better understanding of the BCP's role
- an interest (from stakeholders) in developing joint strategies for a more sustainable use of ocean resources.

The valuation of carbon sequestration and analysis of Arctic fisheries expansion were explicitly developed to address some of the gaps highlighted during our stakeholder engagement activities (Task 8.2). We also engaged in Ocean Literacy-related activities (Task 8.3). Lastly, we identified and developed synergies that can fill the above-mentioned gaps within and across sectors and create opportunities for the OceanICU project to have clear and measurable impacts as detailed by the Key Performance Indicators. In doing so, we identified ways for OceanICU to have an impact on society through uptake of data, knowledge, and tools produced by the Project.

5. Work carried out

Throughout the project, we engaged extensively with a wide range of stakeholders, including policymakers, industry representatives, NGOs, educators, and youth groups. This ensured that real-world perspectives informed our findings and could directly support policy dialogues and decision-making processes. These interactions took place through workshops, interviews, and participation in international events such as the UNFCCC COP meetings, the 2024 UN Ocean Decade Conference, the One Ocean Science Conference, the 2025 UN Ocean Conference, and initiatives under the EU4Ocean umbrella.

Key activities included mapping international legal frameworks such as UNCLOS, the BBNJ Agreement, the UNFCCC, the CBD, and IMO conventions to identify governance gaps affecting the BCP. This analysis revealed the fragmented nature of existing laws. It underscored the need to link climate cooperation with the law of the sea, particularly through ambitious implementation of the new BBNJ Agreement. We also examined how instruments such as the London Protocol, UNCLOS provisions on pollution and fisheries, and the CBD biodiversity targets could be used to strengthen protection for the BCP and integrate it more effectively into international governance. The project contributed directly to policy forums, supported discussions on BBNJ implementation. It raised awareness of how future marine regulations, such as those on deep-sea mining, MPAs, and carbon cycling services, could incorporate BCP considerations.

Building on this, we conducted a focused study with high-level negotiators and policy experts to explore how the BCP might gain stronger recognition in international governance. Interviews identified key barriers, including limited awareness, fragmented frameworks, and weak compliance mechanisms, while also highlighting opportunities such as improved science communication, economic valuation, transdisciplinary collaboration, and engagement in forums like the BBNJ implementation and regional seas initiatives. The study emphasised the need to link biodiversity, climate, and ocean governance within a more coherent framework to raise the BCP's profile in policy discussions.

On the scientific side, we produced a comprehensive economic valuation of the BCP, estimating its carbon sequestration at 2.81 gigatonnes of carbon per year; this is not a net flux but helps maintain CO_2 concentrations low. This translates to an annual monetary value of around US$1 trillion, underscoring the BCP's significant climate and economic importance. Another study focused on the contribution of commercial marine macrofauna to carbon sequestration, and estimated the impact of fishing and climate change on it. This analysis enabled us to assess the gains in terms of carbon sequestration that can be achieved by restoring the commercial macrofauna population. However, it also acknowledges that several research gaps need to be addressed before considering any management or restoration measures as solutions to mitigate climate change. We are also exploring modelling techniques to predict the expansion of Arctic fisheries under different climate scenarios. By applying machine learning algorithms, this work forecasts future fishing activity. It assesses potential impacts on CO^2 emissions and seabed carbon disturbance, providing key insights into the links between industrial fishing and disruption of the ocean's carbon cycle.

Ocean literacy formed another core strand of work. The OceanICU project joined the EU4Ocean Platform as a member, with an online member page and opportunities for the team to participate in EU4Ocean meetings, activities, and events. This has increased the project's visibility among ocean literacy experts, education professionals, and young people. For instance, in March 2025, the OceanICU team participated in the Ocean Literacy Island networking exhibition, organized by the EU4Ocean Coalition, during the European Ocean Days. This provided a platform to exchange ideas with ocean literacy experts and to demonstrate the pilot Decision Support Tool (DST).

This work provided the foundation for the project's main results, summarised in the next section and organised into six interlinked areas:

1. Policy gaps in managing and protecting the BCP.
2. Opportunities to Enhance the Protection of the Ocean's Biological Carbon Pump
3. Economic valuation and spatial distribution of the BCP's sequestration service.
4. Estimate the combined impact of fisheries and climate change on carbon sequestration by oceanic macrofauna
5. Case study on Arctic fisheries expansion and associated CO_2 emissions
6. Ocean Literacy

5.1. Stakeholder engagement and Ocean System Pathways

The project actively engaged stakeholders to understand their views and needs around ocean carbon, ensuring that outputs were co-designed for real-world use. In April 2025, two online workshops were held with representatives from the Shelf Seas and High Seas fishing industries to gather feedback on the OceanICU Decision Support Tool (DST), which was being developed collaboratively to support decision-making on ocean carbon. These sessions focused on refining the tool's configuration based on stakeholder preferences. They marked the beginning of an iterative co-development process, with additional workshops planned to further tailor the DST.

Alongside tool development, the workshops featured presentations from WP8 and WP5, which gathered input on future scenarios for ecosystem modeling. This ongoing engagement aimed to raise awareness of ocean carbon issues and incorporate stakeholder feedback into scientific work to make it more socially relevant. Discussions also addressed ocean equity, considering the societal impacts—both positive and negative—of ocean carbon policies, particularly on the fishing industry. The project continued to involve stakeholders and the broader consortium to ensure models and outputs reflected diverse perspectives and evolving needs.

Additionally, during these workshops, we shared the project's vision for developing Ocean System Pathways (OSPs) with stakeholders and sought their feedback on the approach and its relevance to them. The identification in WP8 of the existing disconnect between ocean, biodiversity, and climate governance regimes highlighted the need to create a communication tool that could make the BCP relevant for policymakers across these different governance regimes. The Shared Socioeconomic Pathways (SSPs) have become an essential tool for incorporating considerations of the various trajectories of human societal development on global emissions pathways and climate mitigation and adaptation options. As a result, they have been used extensively by the IPCC and are relatively familiar to policy makers in that they represent different possible trajectories of human development and associated climate risks. Ocean System Pathways (OSPs) expand the SSPs to consider marine industries and how these may develop under the five socioeconomic pathways outlined by the SSPs. The first effort to do this focused on small pelagic fisheries and has now been extended to benthic-demersal, artisanal, large pelagic, and emerging fisheries as well as mariculture with the primary goal of incorporating different climate trajectories into future scenarios for fishing and mariculture production.

However, we see that the OSPs can also offer another important opportunity – that of examining feedback between the development of marine industries and the biological carbon pump, and hence on climate trajectories. The OSPs provide a path to connect the basic scientific outcomes of OceanICU (e.g., biological processes, climate, and industry effects on the BCP) and make them policy-relevant for policymakers across ocean, climate, and biodiversity governance regimes. OSPs also offer an exploratory tool to examine how socioeconomic trajectories can shape the evolution of marine industries, and how these in turn can perturb the climate mitigation service of the ocean. The development of OSPs is still in progress in OceanICU, led under WP8, and has progressed through a series of five targeted meetings, a workshop with the OceanICU consortium at the Annual Science Meeting, and presentations to stakeholders at the stakeholder workshops. From feedback during the stakeholder workshops, it was clear that the industry stakeholders targeted for those workshops are unlikely to be the key users of the OSPs, as generally, the feedback was that the scenarios were too theoretical to be of practical use for their concrete and regional needs. Some of this feedback may also reflect that the scenarios are in a state of development. When operationalized as part of the decision support tool, they may become more relevant to the project's industry stakeholders as well. Development of the OSPs also has an academic relevance as the workflow undertaken in WP8 to expand the OSPs to marine industries such as deep-sea mining can be further extended to look at emerging industries such as marine carbon dioxide removal.

6. Main results achieved

6.1. Gaps across the legal and institutional landscapes

The Biological Carbon Pump (BCP) is a central mechanism in regulating the global climate, yet it remains insufficiently addressed within international legal and institutional frameworks. Although several treaties and conventions indirectly influence its operation, none explicitly focus on its preservation or enhancement. This creates a patchwork of fragmented responsibilities that risks leaving the largest carbon sink on Earth—the high seas ocean—without effective protection. Interviews and dialogue conducted in the project with representatives of multilateral marine governance institutions and national desk officers responsible for marine cooperation indicate that, as a result of this regulatory fragmentation, there is a lack of ownership for the BCP in the global climate and oceans institutional landscape. A clearer and more structured inclusion of the BCP in global ocean cooperation could act as a driver for integrating the BCP into domestic policy.

6.1.1. Legal Gaps

International climate cooperation, under the Paris Agreement and UNFCCC, recognizes the importance of carbon sinks but has so far focused mainly on terrestrial ecosystems and coastal 'blue carbon' habitats. The BCP, operating largely in the high seas, remains almost invisible in climate strategies. The lack of binding commitments and the jurisdictional limits of the UNFCCC, which cannot regulate the oceans directly, reinforce this gap.

UNCLOS provides the foundational legal framework for ocean governance, including obligations to prevent pollution and protect marine ecosystems. Yet, its provisions are weak when it comes to addressing land-based sources of pollution and fisheries management. Although UNCLOS has outlined and established the International Seabed Authority, which is tasked to develop a Mining Code to determine and reduce the environmental impacts of deep-seabed mining. Regional seas conventions, such as OSPAR and HELCOM, have begun integrating climate considerations, but efforts remain uneven and fragmented across regions.

6.1.2. Institutional Gaps

The 2023 BBNJ Agreement represents a landmark step forward, being the first multilateral treaty to refer to the ocean's carbon cycling services explicitly. It introduces tools for establishing marine protected areas, conducting environmental impact assessments, and fostering capacity building and technology transfer. However, its effectiveness will depend on widespread ratification and ambitious implementation. Ensuring that the BCP is considered in the designation of protected areas and EIAs will be critical.

Other institutions also play important roles. The International Maritime Organization regulates pollution and dumping through MARPOL and the London Protocol, applying precautionary limits to geoengineering proposals such as ocean fertilisation. The Convention on Biological Diversity provides ecosystem-based management principles and has shaped global approaches to marine protected areas, but lacks direct tools for enforcement in areas beyond national jurisdiction. These examples highlight how responsibilities are spread across multiple frameworks without a central mechanism for integrating BCP concerns.

6.1.3. Conclusions and Way Forward

One of the strongest findings from this roadmap is the recognition that the BCP constitutes a global public good. Its benefits are diffuse, shared across all nations, and measured in avoided climate damages rather than immediate, tangible outputs. This creates inherent governance challenges: no single state can claim ownership of the BCP, and yet its degradation would impose costs globally. Addressing this requires collective international action, with mechanisms that transcend the fragmented regimes of climate, biodiversity, and fisheries policy.

The economic valuation work conducted under OceanICU provides a compelling rationale for this shift (see section 4.3 below). By quantifying the financial contribution of the BCP and demonstrating that several small island and developing states host carbon-sequestration services far in excess of their GDP, the project has opened pathways for integrating BCP conservation into climate finance, debt-for-nature swaps, and emerging carbon markets. This reframing—treating the BCP not merely as a biophysical process but as a service of measurable economic and social value—is critical for motivating political and financial investment in its protection.

The BCP remains under-recognized and insufficiently protected despite its central role in global climate regulation. Fragmentation across regimes, jurisdictional complexities in areas beyond national jurisdiction, and the absence of binding commitments in climate frameworks hinder progress.

Moving forward, the BBNJ Agreement offers an important opportunity to mainstream BCP into ocean and climate law. Fisheries management could be reformed to consider maximum Carbon sequestration alongside traditional harvest objectives. Regional seas organisations should explicitly integrate BCP into their mandates, and domestic implementation of international treaties must explicitly recognize carbon cycling services. The BCP should also be a priority in the development of marine protected areas, and considered in environmental impact assessments, as provided by the BBNJ.

6.2. Opportunities to Enhance the Protection of the Ocean's Biological Carbon Pump

This study draws on the perspectives of nine senior experts in international marine policy—policy advisors, legal scholars, scientists, and NGO representatives from the Global North and South, who participated in two semi-structured focus group interviews. With direct experience in negotiations, these participants reflected on how the Biological Carbon Pump (BCP) is understood, overlooked, and potentially integrated into governance processes. From their discussions, nine themes emerged, each pointing to the challenges and opportunities for elevating the BCP in global policy.

One of the clearest issues was that many policymakers have limited awareness of the BCP and its role in climate regulation. Participants felt strongly that scientific evidence by itself rarely shapes negotiations. Instead, research findings need to be translated into language and narratives that resonate with political and economic priorities. The BCP is a complex process, and unless this complexity is communicated in clear and accessible terms, it is unlikely to gain policy traction. Social scientists were seen as particularly important in this respect, as they were able to bridge technical knowledge and institutional realities. Access to informal negotiation spaces, such as side meetings and advisory committees, was also highlighted as essential for shaping agendas before positions become fixed.

The question of economic valuation was another recurring theme. As the BCP is rarely included in natural capital assessments or ecosystem service models, its contributions to climate mitigation are often overlooked in policy decisions. Participants argued that developing methods to value the long-term economic and ecological benefits of the BCP would help governments and negotiators to weigh these alongside short-term economic interests. This is particularly important for small island states, whose ecological contributions to carbon sequestration remain largely unrecognised.

Interviewees also stressed the importance of transdisciplinary research. Natural sciences alone, they argued, cannot deliver the kinds of institutional change needed. Collaboration among economics, law, and political science is essential if complex ocean processes are to be effectively translated into regulatory and financial mechanisms that decision-makers can actually utilize. Linked to this was the idea of developing negotiation strategies that frame the BCP within broader marine governance, rather than limiting it to discussions on climate policy. Venues such as the United Nations General Assembly, the UN Environment Assembly, and the European Union were repeatedly mentioned as strategic platforms for gradually integrating the BCP into international policy frameworks.

Concerns were also raised about weak compliance mechanisms in existing agreements. Although the new Biodiversity Beyond National Jurisdiction (BBNJ) treaty offers opportunities through its Environmental Impact Assessment provisions and references to “best available science”, its enforcement powers are contingent upon voluntary contributions and actions by state parties. Several participants suggested that rather than designing a new treaty specifically for the BCP, a coordinated umbrella approach linking it to existing regimes on biodiversity, fisheries, seabed mining, and climate might be more effective. This could prevent further fragmentation and make it easier to integrate the BCP into different policy areas simultaneously.

Finally, interviewees discussed the role of power dynamics in ocean governance. Economic sectors with immediate political value, such as fisheries or extractive industries, often dominate negotiations, which makes it harder to prioritise long-term environmental concerns. However, there may be openings through partnerships with responsible industry actors and the growing focus on regenerative ocean economies. Some participants noted that the measurability of carbon presents a rare opportunity to directly link ecological processes to financial and legal systems, a feature that has been underutilized so far.

Overall, the findings suggest that better protection of the BCP will depend on both regulatory innovation and much more targeted communication. Building political relevance for the BCP will require not only robust scientific evidence but also careful attention to how and where that evidence is shared, and who is involved in shaping its message.

6.3. Valuation and distribution of the BCP carbon sequestration service

We quantified the amount of carbon sequestered annually through the BCP and that remains in the ocean for at least 50 years. We refer to this carbon as the “50-year sequestration rate” and use 25 and 75 years as upper and lower bounds. We used carbon-export estimates from the ocean biogeochemical model called NEMO-PISCES-APECOSM model, which simulates physical circulation, two plankton groups, two zooplankton size classes and a size-structured fish community that includes diel vertical migrants. Because only a fraction of the exported carbon remains in the ocean over many decades, we employed an ocean circulation inverse model to estimate the amount of exported carbon that remains sequestered for at least 50 years. We then overlaid these spatial data on marine governance maps—national exclusive economic zones, areas beyond national jurisdiction and existing marine protected areas or ecologically important regions—and computed per-country and global totals. For the financial valuation of carbon sequestration service, we applied a market price of $US90/t of CO2, and discounted future flows at 2% real interest rate over investment horizons to 2030 and 2050 (with a 4% as sensitivity analysis and $US45 carbon price). The price of carbon is based on a suggested price corridor identified by the World Bank to produce a functional global carbon market. Please see the published article by Berzaghi et al. 2025 in Nature Climate Change for all the details on this study; the full reference is available at the end of this document.

Our analysis shows that the BCP stores 2.81 GtC each year, which will remain stored in the ocean for at least 50 years. Of this, nearly 61% lies in the high seas and 40% within national waters. Existing marine protected areas capture only 7% percent of this service. In comparison, areas flagged as ecologically significant account for 27% percent (Fig.1). Sequestration intensity peaks in tropical upwelling regions—particularly along the eastern Pacific and western coasts of Africa and the Americas—as well as in temperate oceans (Fig.1) When normalized by area, several Small Island Developing States in the Pacific, Indian and Atlantic Oceans emerge as disproportionately valuable carbon-sequestration jurisdictions, together contributing over 10% of the global 50-year pump.

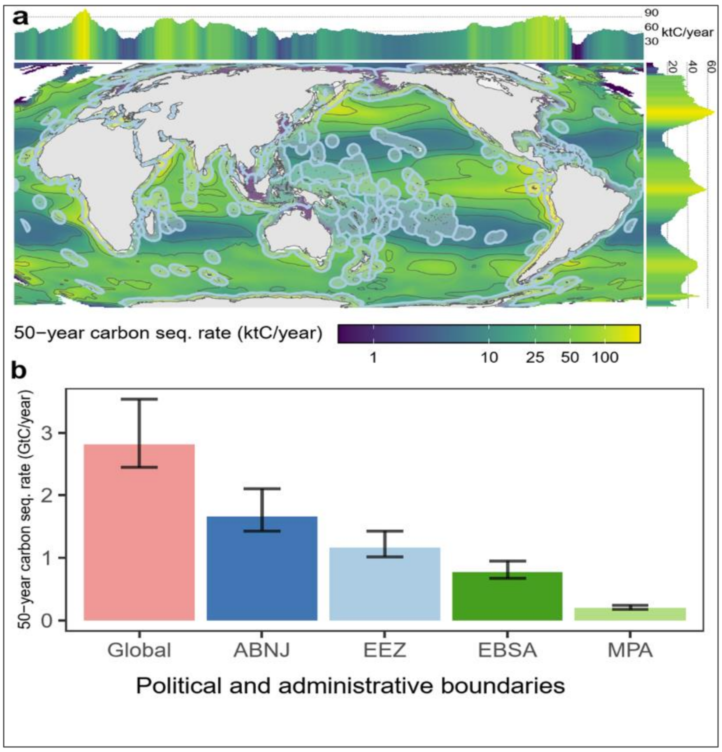

Figure 1- *Spatial and geopolitical distribution of BCP carbon sequestration. Fifty-year carbon sequestration rate (**a**) spatial distribution and (**b**) within management and political boundaries. Fifty-year sequestration rate is the fraction of annually exported carbon that remains in the ocean for at least 50 years through passive and active processes driven by phytoplankton, zooplankton, and fish. In (**a**): azure lines indicate EEZ boundaries; areas with sequestration rates <1 ktC/year were grouped for facilitating visualization; contour lines indicate areas between 1, 10, 25, 50, and above 100 ktC/year. Margin bar plots (top & right) show average seq. rate across latitude/longitude bands. In (**b**): bars indicate the sum of 50-year sequestration rate globally and in ABJN, EEZ, ecologically and biologically significant areas (EBSA), and MPA. Whiskers indicate the total 25-year (lower) and 75-year (upper) sequestration rates for each group.*

6.3.1. Value of the BCP sequestration service

In financial terms (see Table 1), the total annual service value reaches close to one trillion $US, split roughly three to two between high seas and national waters. Present values of the national service—discounted to 2030—sum to 2.2 trillion $US and rise to about 7.0 trillion by 2050 under a 2% discount rate. For some low-income and small island nations, the annual carbon value exceeds 10% of gross domestic product.

PV in trillions of US$ summed through year @ price of carbon	2% discount rate	4% discount rate
2030 @ US$ 90 t/CO2	2.2 (1.9 - 2.7)	2 (1.8 – 2.5)
2050 @ US$ 90 t/CO2	7.0 (6.1 - 8.7)	5.5 (4.8 – 6.9)
2030 @ US$ 45 t/CO2	1.1 (1.0 - 1.4)	1.0 (0.9 – 1.3)
2050 @ US$ 45 t/CO2	3.5 (3.1 - 4.4)	2.7 (2.4 - 3.4)

***Table 1** - Effects of price of carbon and discount rates on valuation of the BCP service in all EEZs combined. Present Value is expressed in trillions of US$ summed from 2023 through 2030 or 2050. The lower and upper bounds of the Present Value is indicated in parenthesis and was calculated by using a residence time of carbon of respectively 25 and 75 years (see methods for more details).*

We analyzed the importance of the financial value of BCP carbon services for national economies by analyzing the value in relation to the gross domestic product (GDP). For many low, lower-middle, and upper-middle income countries, the market value of the BCP carbon service accounted for a major percentage of their GDP. In many cases, market value represented 10% or more of the GDP. The countries with the highest market value:GDP ratio are Pacific Small Island Developing States, including Kiribati, where the market value is 38 times its GDP (US$8.5 billion/year). Even though these percentages are highly dependent on the price of carbon, which does not have a global price and is variable from country to country, the majority of countries with a high value were small countries that are either highly indebted or have limited lending power. The list includes Small Island Developing States that are already being affected by climate change, as well as other countries that need funding to cope with climate change and the energy transition. If a viable market for ocean carbon existed, several "Highly-indebted Poor Countries", as defined by the World Bank, could significantly reduce their debt and potentially turn from debtors to creditors by obtaining payments for their BCP carbon services.

In the context of the 30x30 goal set by the Convention of Biological Diversity, we also identified spatial "hotspots" (Fig. 2) where protecting 30% of the global ocean surface would secure 58% percent of the BCP 50-year sequestration, and note that conserving just 10% would cover 30% of the service.

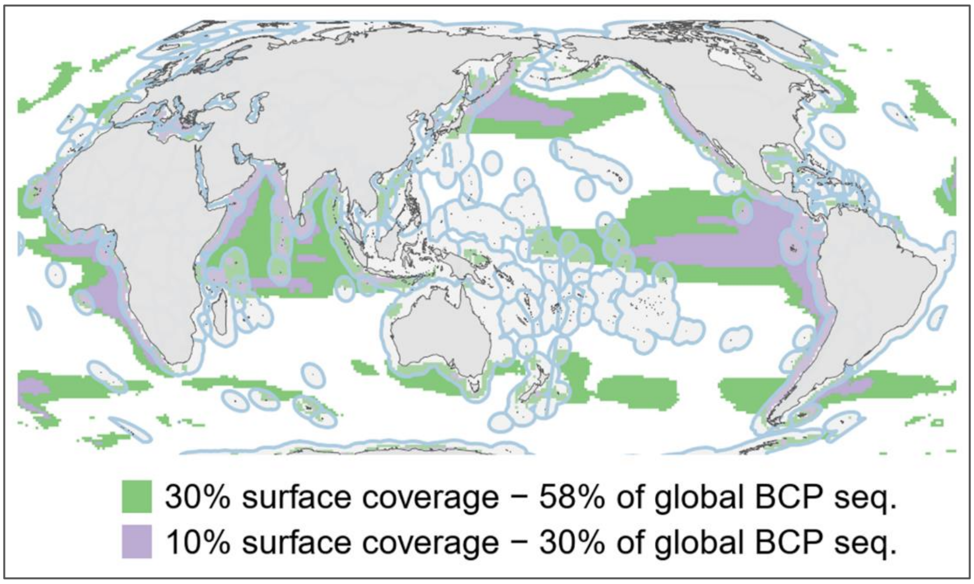

Figure 2 - BCP 50-year sequestration hotspots covering 10% and 30% of the ocean surface and relative global coverage. *EEZ are indicated with azure lines. The EEZ of certain countries are fully covered by the carbon hotspots; countries might not be able to fully protect their EEZ just for carbon services.*

These findings suggest that the open-ocean biological pump is a major, largely untapped component of natural climate solutions. By placing a tangible dollar figure on its service, we laid the groundwork for integrating the BCP into carbon-credit markets, debt-for-nature swaps, marine-conservation bonds and other innovative finance instruments. But most of all, by quantifying this service, we can measure the climate and economic loss if the BCP is damaged, diminished, or destroyed. This also creates awareness of the BCP importance and the cost for society if lost. We emphasize that Small Island and Developing States, whose carbon service value often exceeds their economic output, can play a crucial role in protecting the BCP but require climate financing to do so. Integration of the BCP in carbon markets is also possible if verification systems can measure additionality, permanence, leakage and monitoring criteria. We also highlight methodological challenges—such as harmonizing multi-model projections, agreeing on acceptable storage durations and quantifying the impacts of fishing, deep-sea mining and climate change on carbon export pathways.

6.4. Arctic fisheries expansion under climate change

As sea ice melts and new areas become accessible, the Arctic is drawing increased attention for its untapped marine resources. While fishing activity has historically been limited by ice cover, resulting in relatively little conflict between conservation and exploitation, this dynamic is shifting, especially after the expiration of the Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean (CAOFA) in 2037. If no permanent framework is established, fisheries—both pelagic and demersal—could expand rapidly, outpacing scientific understanding and policy development. Despite this, current conservation and fisheries policies seldom incorporate the risk of fisheries expansion on ocean carbon stores and CO2 emissions, as critical knowledge gaps remain regarding how future fisheries will evolve under different climate scenarios and how they will interact with the ocean's carbon pump and seabed carbon stocks.

Using tracking data of the Global Fishing Watch project from 2017 to 2022 of vessels registered as fishing vessels on the Arctic Ship Traffic Data, we modeled the evolution of fishing hours in the Arctic under several climate change scenarios: SSP1-2.6 (+1.6°C of warming in 2100 relative to preindustrial), SSP2-4.5 (+2.4°C of warming in 2100 relative to preindustrial), and SSP5-8.5-8.5 (+4.3°C of warming in 2100 relative to preindustrial), for two decades, 2040 and 2090. Our preliminary results on bottom-trawling fisheries suggest that from 2017 to 2022, a total of 46 million fishing hours were recorded. Fishing hours are expected to increase by approximately 80% in the Arctic by 2040, compared to 2010, totaling slightly over 85 million fishing hours, with no apparent differences between climate change scenarios (Figure 3). The effect of climate change on bottom-trawling fisheries expansion is more visible in 2090, with an increase in fishing hours staying around 80% under SSP1-2.6, but reaching 135% and 190%, under SSP2-4.5 and SSP5-8.5, respectively (Figure 3).

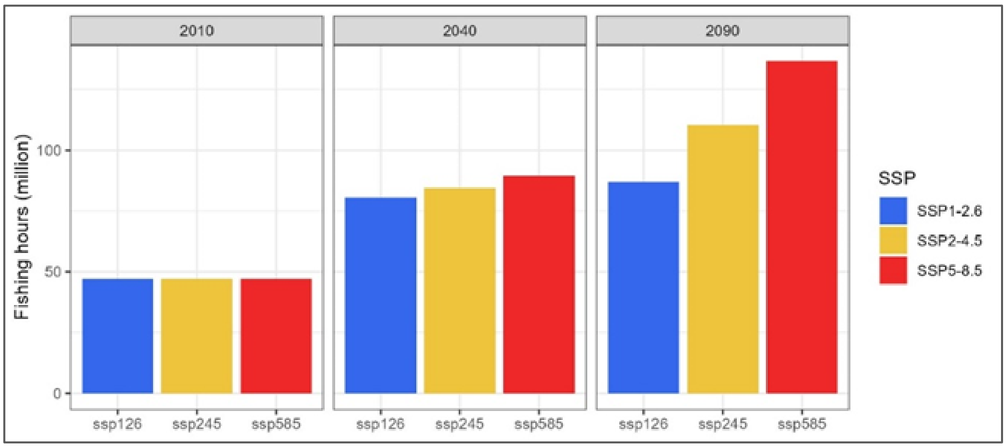

Figure 3 *- Observed fishing hours by bottom-trawling fisheries in 2010', and predicted increase in fishing hours by bottom-trawling fisheries for the 2040 and 2090 decades, under several climate change scenarios (SSP).*

Our preliminary findings reveal that bottom-trawling fisheries are projected to expand progressively with increasing climate change, as warmer, ice-free waters open new fishing grounds throughout the Arctic. We will further analyse how this expansion will have a double impact on climate, by (1) increasing CO_2 emissions from fossil fuel burning, and (2) increasing the CO_2 release from seabed disturbance. These new insights will feed into international frameworks, such as the Agreement on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction (COAFA), thereby playing a critical role in limiting fishing expansion in the Arctic and preventing additional CO_2 emissions associated with this activity.

6.5. The combined impact of fisheries and climate change on future carbon sequestration by oceanic macrofauna

The role of marine macrofauna in the ocean carbon cycle is becoming increasingly clear, with recent estimates showing that they contribute 16.1% of carbon export and 28% of carbon sequestration in the ocean interior. Despite the significance and growing interest of stakeholders, NGOs, and governments in accounting for fish carbon in their policies, little is known about how fisheries and climate change may alter these processes. Quantifying these impacts is crucial for assessing whether marine macrofauna could be incorporated into future ocean-based Nature-based Climate Solutions. Here, we use the BiOeconomic mArine Trophic Size-Spectrum model to investigate how fisheries and climate change affect the biomass of commercial marine macrofauna and their carbon export through fecal pellets and carcasses from 1950 to 2100. We compared two contrasting scenarios to assess the impact of climate change: the low-emission (Shared Socioeconomic Pathway (SSP) 1-2.6) and the high-emission (SSP 5-8.5) scenarios. To explore the cumulative impact of climate change and fisheries, we ran climate change scenarios with and without fishing effort.

Our analysis shows that in the 1950s, marine macrofauna of commercial interest exported an estimated 0.21 ± 0.11 GtC yr^{-1} to the ocean interior. Historical fishing has already reduced total fish driven carbon export to 0.12 ± 0.037 GtC yr^{-1} in the 2010s, representing a ~47% decrease compared to 1950–1959. On average, a 1% biomass loss from fishing results in a 0.8% decline in fish driven carbon export. Our analysis suggests that each degree of warming reduces macrofauna carbon export by 2.46%, leading to a projected 13.5% ± 6.6% decline in export by 2100 relative to the 1990s, under SSP5-8.5. By the end of the century, the combined pressures of fishing and climate change are projected to reduce carbon export by up to 56.7% ± 16.3%, creating a cumulative sequestration deficit of 14.6 ± 10.3 GtC by 2100.

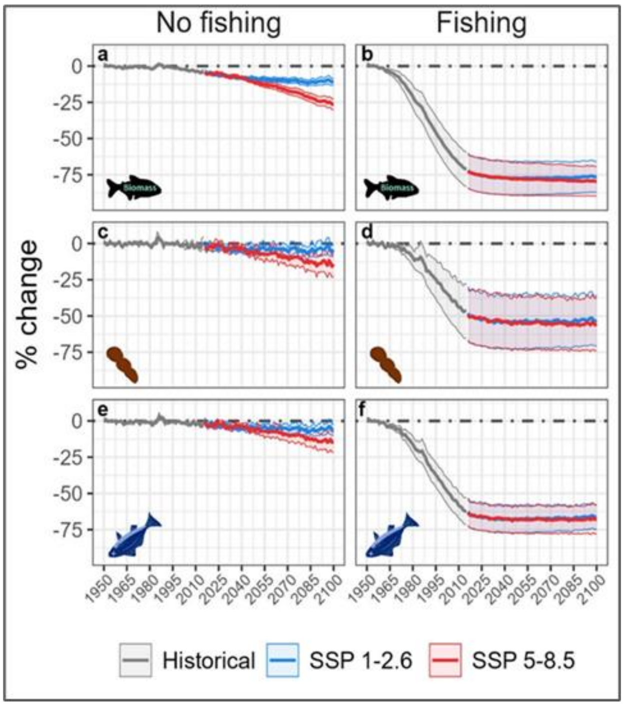

Figure 4- *Impacts of climate change and fishing on commercial macrofauna biomass and related carbon export. BOATS ensemble projections of global change (%) in carbon stock (biomass), fecal pellets and carcasses production in the absence (a, c, e) and presence (b, d, f) of fishing, with and without climate change (SSP 1-2.6 in blue and SSP 5-8.5 in red), relative to the reference period (1950-1959). In panels b, d, f (red curves), fishing mostly affects the historical period because fishing is kept constant after 2014, while climate change mostly affects the future trends. The thick solid lines represent the average value, while shading represents the standard deviation calculated from BOATS simulations for the five sets of parameters and forced with two Earth System Models (n=10, see Methods).*

The recent IPBES-IPCC co-sponsored workshop on biodiversity and climate change suggests that climate change should "become part of the broader ecosystem-based approach to fisheries management, not only in terms of adaptation but also in terms of mitigation". Our findings suggest that restoring commercial marine macrofauna to a pristine level has a climate change mitigation potential of 0.11 GtC yr^{-1} (equivalent to 0.40 Gt CO2 yr^{-1}), an estimate of the same order of magnitude as that of mangrove restoration. Although this finding supports the IPCC-IPBES rationale of incorporating fish-carbon into fisheries management, substantial uncertainties and knowledge gaps limit the inclusion of fisheries management measures in the Nature-based Climate Solution portfolio, highlighting the need for further research. For instance, although the contribution of commercial species to carbon sequestration has declined due to fisheries, this role could have been fulfilled by other organisms, such as mesopelagic fish or zooplankton species, that are not targeted by fisheries. Similarly, we need to understand how restoring commercial fish might affect their prey, which also play a role in carbon sequestration. Indeed, an increase in the biomass of commercial fish, and by extension in their sequestration potential, will be at the expense of a reduction in the biomass and sequestration potential of their prey.

6.6. Ocean literacy

6.6.1. Background and trends in ocean literacy

Work carried out in OceanICU can directly contribute to increasing ocean literacy, enabling people across Europe and beyond to understand better how the ocean influences us and how human activities influence the ocean, thereby allowing for informed decision making in their daily lives.

With the Ocean Literacy Programme, IOC-UNESCO aims to build an ocean-literate society capable of conserving and sustainably using the ocean for generations to come. Through the Ocean Literacy Portal, UNESCO-IOC provides educational resources, tools, and guidance to support educators, policymakers, and communities in developing the knowledge and values needed for responsible ocean stewardship.

- The EU4Ocean Coalition is the European hub for ocean literacy. EU4Ocean is a project funded by the European Commission and implemented by a consortium of partners across Europe. The EU4Ocean Coalition brings together organisations, individuals, young people, and schools from all over Europe. It is composed of three communities:
- the EU4Ocean Platform for organisations (e.g., research institutes, non-governmental organisations, associations, companies), projects, networks, clusters and individuals engaged in ocean literacy initiatives;
- The Youth4Ocean Forum for young people between 16 and 30, including Young Ocean Advocates who have obtained accreditation for the project they have submitted.
- The Network of European Blue Schools, which includes schools that connect students with the ocean through the development of a project they have submitted to be officially recognised. Blue Schools are thus educational institutions - whether primary, secondary, or vocational (VET) - that integrate ocean literacy and sustainability into their teaching.
- Since its launch in 2020, the EU4Ocean Coalition has grown substantially, now reaching over 1,400 members across the three communities.

The article 'Evolving trends in Ocean Literacy', co-written by EU4Ocean Coalition partners and EU4Ocean Platform members, highlighted that, over time, ocean literacy has evolved from a focus on education to a movement that increasingly also involves businesses and society as a whole. It also emphasised that ocean literacy and sustainability are closely interconnected. Another article by EU4Ocean Coalition partners and EU4Ocean Platform, titled 'Why is Ocean Literacy Key to a Sustainable Blue Economy?' discussed how ocean literacy and the blue economy can support each other to the benefit of sustainability and people working in the blue economy.

6.6.2. Connecting OceanICU to Ocean Literacy networks

As part of Task 8.3 of the OceanICU project dedicated to connecting the project to wider society, synergies between OceanICU and EU4Ocean have thus been developed. The Ocean ICU project has joined the EU4Ocean Platform as a member. As such, OceanICU has an online member page and members of the OceanICU team can participate in EU4Ocean meetings, activities and events. This provides visibility of the project towards ocean literacy experts, education professionals and young people. For example, in March 2025, the OceanICU team participated in the Ocean Literacy Island networking exhibition organised by the EU4Ocean Coalition during the European Ocean Days. This allowed the team to discuss the project with ocean literacy experts and to demonstrate the pilot Decision Support tool (DST).

Figure 5*- Pilot DST demonstration during the Ocean Literacy Networking exhibition in 2025.*

In the future, results and outputs of the OceanICU project produced for wider society can also be disseminated across the three EU4Ocean communities as these will provide important tools and insight to better understand the impact of human activities on ocean carbon. This will be of interest to other members of the EU4Ocean Platform who are working, for example, on ocean conservation and the sustainable blue economy. Developed tools will be helpful for members of the Youth4Ocean Forum who are working on projects related to ocean conservation and the sustainable blue economy as well as policy and advocacy. Educational material will be useful to teachers working in European Blue Schools.

6.6.3. Ocean education

The ocean is currently not included in school curricula across the world. In 2025, Brazil became the first country in the world to adopt a national school curriculum focused on ocean literacy. To increase ocean literacy and facilitate teaching about the ocean, IOC-UNESCO has developed multiple initiatives including the release of ‘A new blue curriculum: a toolkit for policy-makers', 'Promoting Ocean Literacy: an education policy brief' and the 'Blue School Global Network: a toolkit'.

The Network of European Blue Schools has developed a Handbook for Teachers and a MOOC titled 'Bring The Ocean into Your School'.

By connecting the project to youth, OceanICU can further trigger interest in ocean education and indirectly support existing initiatives to include the ocean in the curricula in the long term.

6.6.4. Existing educational tools and material on the ocean

The European Atlas of the Seas, an initiative of the European Commission, enables the wider public to learn about the ocean with a catalogue of 270 map layers available in 24 languages and a Teachers Corner that includes ready-to-use exercises, quizzes and games. Operated by the European Marine Observation and Data Network (EMODnet), the Atlas is continually updated with new and new maps. The Atlas 'My Locations' and 'My Notes' tools allow users to create their own maps in the Atlas. The Atlas includes map layers on Global Ocean Chlorophyll as an indicator of phytoplankton but no map layers on ocean carbon at this stage.

Many organisations and project teams have developed educational material that can be used by teachers to bring the ocean into their classrooms. A few examples of educational material that addresses ocean carbon, identified through desktop research and information available to the Task 8.3 team are included below.

7. Contribution to the overall objectives and relevant KPIs

The work described in this report has contributed to **ST1** by exploring and quantifying the role of key organisms in the ocean carbon cycle, **ST3** by quantifying the residence time and magnitude of carbon sequestration by the BCP.

We also contributed to **O1** and **O2** through analysis of legal framework and stakeholder engagement at various levels (high-level decision-makers and negotiators, ocean literacy experts, and the general public). For **O1**, we have been working to co-develop the OceanICUs Decision Support Tool (DST) in collaboration with a diverse array of relevant stakeholders. We have hosted workshops to get feedback and input on the preferences of participants for how to configure the tool, including what levers they would want included. This co-development of the tool ensures that it will be relevant and tailored to stakeholder needs, facilitating the long-term use of the tool in decision-making. These workshops were a first iteration of this co-development and further workshops, led by WP8 and in collaboration with WP7, will be carried out to refine the DST. Additionally, the DST was demonstrated at the Ocean Literacy Island networking exhibition during the European Ocean Days, providing policymakers, educators, and civil society groups the opportunity to learn more about the DST and a chance to discuss the BCP and its role in climate mitigation.

The work described in this report contributed to the achievement of **KPI 1** through the description of the abundance of functional groups involved in the ocean carbon cycle, and their biogeochemical rates, **KPI 2** by developing numerical code describing these new processes, and **KPI 5** by submitting papers on the role of biology in anthropogenic carbon uptake. This work also contributed to the achievement of **KPI 22** and **27** as it makes managers and policymakers aware of the impact of fishing on the biological carbon pump. As a consequence, in the long term, this work may foster the inclusion of fish carbon in future management plans. Finally, one WP8 member applied to the IPBES Fellowship Programme, thereby contributing to **KPI 15** (if the application is successful).

In terms of policy and management-related KPIs and **O2**, this work contributes to achieving short-term impact by creating awareness on the importance of the BCP for global climate, biodiversity, and socio-economic stability. This has already been done through stakeholder engagement activities (including five stakeholder workshops held to date with the fishing and deep-sea mining industry, NGOs, managers, advisory bodies, and researchers - further detail in D8.2 and upcoming D8.4), outreach activities, and interventions at policy fora (UNFCCC COP, UN Ocean conference, CITIES General Assembly, BBNJ implementation discussions).

Long-term impact: The described results have the potential to influence cooperation under international agreements and promote consideration of the BCP in their implementation. At the multilateral level, this includes fora under the law of the sea, the UNFCCC and the CBD. In addition, with the BBNJ treaty that will be ratified by at least 60 countries by the end of 2025, will come into force and will open opportunities and challenges for area-based management in the ocean. The work described outlines several obstacles to overcome for a more effective implementation of the BBNJ and highlights priority areas but also contributes with the science needed for guiding BBNJ negotiations and how the BCP can be effectively considered and promoted in the development of processes and measures, foremost connected to EIAs and MPAs. The information on the climate and economic value of the BCP and priority conservation area are key in the context of climate finance, debt-for-nature swaps, and climate adaptation and mitigation funds. All these elements have high potential for impact as our society needs to manage the ocean more sustainably and effectively given the limited economic resources dedicated to SDG 14 “Life below water”, which is one of the least funded SDG 14. Overall, these activities contribute to **KPIs 22, 23, 27, 28.**

8. Impact and progress beyond state of the art

The project has strived to Identify barriers and entry points for integrating the BCP into policy. The most important learning from this work is that while climate cooperation may set objectives relating to the BCP, the UNFCCC lacks necessary tools to promote consideration of the BCP in ocean governance. The mandate to adopt relevant measures falls under the law of the sea, which, until recently, paid little regard to climate elements. The lack of consideration to BCP in multilateral law and policy thus connects to fragmentation. With the recently adopted BBNJ Agreement, the law of the sea has however for the first time come to recognise the importance of the BCP. References to the BCP are included in the guiding principles of the BBNJ, which builds on cooperation among actors involved and aims to promote a more holistic and coordinated ocean governance. The implementation of the BBNJ thereby marks a strategic opportunity to integrate the BCP not only in the work of the new agreement and its secretariat, but in ocean governance at large. As a key outcome of the Ocean ICU, the project has contributed to disseminating this message in policy forums as well as discussions with key central stakeholders. Further work is planned with outreach in connection with the first COP of the BBNJ expected to be held in 2026.

We have produced the first global quantification and valuation of the BCP analysed across political and administrative boundaries. We have also accounted for carbon residence time which is a key parameter in carbon sequestration projects but rarely accounted for or transparently reported. We also quantified for the first time the past, current and future impacts of climate change and fisheries on the contribution of the marine macrofauna to carbon sequestration, delivering key new information on the potential inclusion of fish restoration measures in the Nature-based Climate Solutions portfolio. We believe that providing such methodology will assist bringing investment in ocean conservation projects.

9. Lessons learnt and links built

9.1. Lessons Learnt:

Several important lessons have emerged through the work conducted so far. Science-policy communication remains a major challenge. Awareness of the BCP among decision-makers is limited, and technical findings alone are unlikely to influence negotiations without clear, accessible communication. Demonstrating the economic value of the BCP came up as a potential way to bridge this gap, giving policymakers a tangible sense of its importance to climate stability and national economies. The project also underlined the value of transdisciplinary collaboration: linking ocean science with economics, law, and the social sciences is essential to produce recommendations that are both credible and usable in a policy context. While it should be further explored how BCP could be better integrated in policy it is clear that the fragmented multilateral governance landscape represents a difficult challenge. The legal mandate to set climate objectives and apply marine management measures are divided between different regimes. The impending entry into force of the BBNJ represents a valuable opportunity to promote a better integration of the BCP.

9.2. Links Built:

Alongside these findings, the project has built strong and lasting links across science, policy, and society, by directly engaging with stakeholders in the following ways:

- Identification of gaps in multilateral law and policy relating to the BCP, and highlighting this in interviews and outreach with stakeholders such as representatives of marine governance institutions and national policy officials.
- Collaboration with the Environmental Defence Fund to estimate the impact of fisheries expansion on seabed carbon stocks in the Arctic.
- Collaboration with the PAME (Protection of the Arctic Marine Environment) to get access to the Arctic Ship Traffic Data System.
- Involvement in the Fish-Carbon working group led by the International Council for the Exploration of the Sea (ICES)
- Engagement with key stakeholders in ocean governance, including the IMO, UNDOALOS, The European Commission and policy officials responsible for law of the sea and ocean governance work in several states.
- Partnerships with EU4Ocean Coalition, Blue Schools, and Youth4Ocean Forum to embed ocean carbon awareness into education and civic life.

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