Policy brief for UNFCCC COP31

The roles of marine biology in helping the ocean store carbon

Key messages for COP31 policymakers and observers

- Marine life stores vast amounts of carbon in the oceans interior through the biological carbon pump (BCP), but this process does not absorb our CO_2 emissions[1]. The amount of carbon stored through this natural process is stable, but likely to change in the future[2].
- Marine biodiversity is worth preserving regardless of its impact on carbon cycling. The climate-biodiversity linkage is becoming increasingly policy relevant across UN treaties, but this linkage is not straightforward in the ocean. Conflating marine biodiversity protections with biodiversity as a carbon sink can be scientifically misleading[1].
- Earth System Models are the best tools we have for global climate projection, but they significantly simplify biological processes. This limitation affects their accuracy in projecting future changes and responses of the biological carbon pump to both climate change, industrial exploitation, and marine carbon dioxide removal (mCDR) approaches.
- mCDR approaches that rely on or affect marine biology require a precautionary approach because additional research is needed to predict how marine life will respond. For mCDR to count as climate mitigation, it must store more carbon than would have been stored without the intervention, keep that carbon stored for the long term, and allow that storage to be verified[3].
- Sustained ocean observations are a cost-effective investment in climate policy[4] and provide the evidence base for climate assessments, carbon accounting, and effective climate action. Long-term observations, including Biogeochemical-Argo and expanded deep-ocean monitoring using ship- and net-based surveys, are essential for tracking how the ocean carbon sink is responding to anthropogenic perturbations.

The ocean as a carbon sink and the role of biology

The ocean plays a key role in the global carbon cycle (Figure 1). Since 1850, as atmospheric concentrations of CO_2 have increased due to human activities, 27% of this extra CO_2 has been taken up by the ocean - the so-called ocean carbon sink. Climate change is expected to weaken this sink by reducing how much atmospheric CO_2 the ocean would otherwise absorb[5]. Understanding the oceans' role in climate mitigation centers on describing the expansion or contraction of the major ocean carbon reservoirs. Within the bounds of uncertainty, the oceanic uptake of anthropogenic emissions can be entirely attributed to the physics and chemistry of the ocean[6], as these set how the surface ocean takes up increased atmospheric CO_2. Marine biology influences how carbon is captured, transformed, transported, and stored in the ocean. Marine life helps store carbon through the biological carbon pump (BCP). This set of biological, physical and chemical processes moves carbon captured through photosynthesis from surface waters into the deep ocean. While the BCP plays an indirect role in the uptake of anthropogenic CO_2 by keeping the ocean surface able to absorb more CO_2, its direct role in offsetting anthropogenic CO_2 appears minimal[7]. However, results from a modeling study suggest that if the BCP is entirely shut down (i.e. no marine life), atmospheric CO_2 levels in 2100 would be 35-65% higher across three tested emission scenarios[8]. While an ocean with no marine life is an unrealistic condition, it nevertheless shows that biological processes affect the ocean's uptake of anthropogenic emissions through many non-linear interactions and feedback processes.

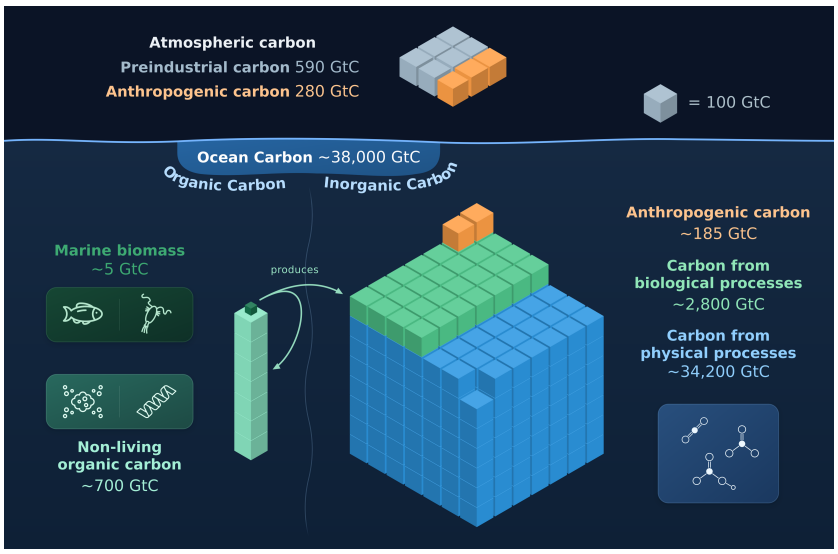

Figure 1. ***Ocean carbon stocks and the role of marine life.*** *The ocean stores approximately 38,000 gigatonnes of carbon (GtC), compared with around 870 GtC in the atmosphere. Most ocean carbon is dissolved inorganic carbon: approximately 34,200 GtC associated with physical and chemical processes, 2,800 GtC accumulated through biological processes, and 185 GtC from human activities. Marine biomass itself contains only around 5 GtC, yet marine organisms sustain much larger carbon reservoirs by producing non-living organic matter (~700 GtC) and transforming organic carbon into dissolved inorganic carbon through respiration (~2,800 GtC). The arrows illustrate these biological pathways. Cube volumes are proportional to carbon stocks, with each full-sized cube representing 100 GtC. Image credit: Mathieu Poupon.*

Clear and consistent messaging is critical for informing wider society about the role of marine biology in ocean carbon storage. In Table 1, we highlight several misconceptions that may arise on the role of marine biology in helping the ocean store carbon and the available scientific evidence. These misconceptions are important to address especially as Parties include ocean-based climate solutions in their Nationally Determined Contributions and under the Global Climate Action Agenda at COP31.

Table 1. Several misconceptions that can appear in communications regarding the role of marine biology in helping the ocean store carbon, and the contrasting scientific evidence.

Misconception	Scientific evidence
Biological processes control the ocean's uptake of human derived CO_2 emissions	Physical and chemical processes control the uptake of anthropogenically derived atmospheric CO_2 into the ocean[1,6]. The direct role of biological processes in offsetting anthropogenic CO_2 appears minimal[7] though there are important indirect interactions[8].
The magnitude of the biological carbon pump (BCP) as a carbon sink has globally been measurably reduced by human activities and climate change	At the global level, the BCP is thought to be operating at a steady state. Increases in the strength of the BCP are however expected with climate change[2]. These changes may take several decades to detect and current capability to detect change is limited by insufficient observations[9].
Marine carbon storage is a function of biodiversity (i.e. protecting marine biodiversity protects ocean carbon storage)	There is limited evidence to support a broad rule that marine biodiversity affects ocean carbon storage. This is however an area of ongoing active research and biodiversity is crucial for other ecosystem services. Preserving blue carbon ecosystems protects both biodiversity and stored carbon.
Removal of fish biomass by fishing decreases the strength of the ocean carbon sink	Reduction in biomass of fisheries species can lead to increases in their prey; food-web feedback that rebalances carbon flows. This is an active area of research[10], but changes appear minimal.
Restoring coral and other calcareous reefs (e.g. mussel beds) increases the strength of the ocean carbon sink	Biological formation of calcium carbonate increases the acidity of seawater, thus making it less able to absorb anthropogenic CO_2. Habitat forming calcifying organisms provide important ecosystem services and support marine biodiversity, but they do not increase the ocean carbon sink.

The Biological Carbon Pump in Earth System Models: Current Status and Opportunities for Improvement

Earth System Models (ESMs) are the best tools we have for projecting the future state of the climate and they inform the Intergovernmental Panel on Climate Change (IPCC). They describe the global carbon cycle by linking models of ocean circulation, atmosphere, cryosphere, land and ocean biology and biogeochemistry. Since these global, complex models are computationally expensive to run, they necessarily simplify biological processes and only include an explicit representation of groups of organisms when they play a primary role in biogeochemical cycles (e.g. carbon or nutrient cycling). ESMs vary greatly in how groups of organisms (e.g., bacteria, phytoplankton, and zooplankton) and how food web processes are represented. For example, zooplankton are represented in ESMs but their rate of feeding[11] and depth distribution varies substantially across models. ESMs do not typically include groups such as fish, jellyfish, squid, sharks, or marine mammals

and those contributing to previous IPCC reports do not represent animal-mediated carbon fluxes. This is the active movement of carbon that results from the daily and seasonal migrations between shallow and deep depths performed by many marine animals (e.g., krill, midwater fish, some squid, sharks, and whales). There are also significant uncertainties across ESMs in predictions of end-of-century net primary production, which is the base of the food chain, with models not even agreeing on whether net primary production will increase or decrease[12]. While ESMs represent tremendous scientific innovation and progress for understanding the future evolution of climate, it is important to recognize that the simplified representation of biological processes limits the accuracy of ESMs for projecting responses in the BCP to climate change and marine carbon dioxide removal (mCDR) approaches, as well as their subsequent climate feedbacks.

International Ocean Carbon Community Perspectives on Key Areas for Improvement

Improving ESM representations of biological processes is a high priority for climate and ecosystem management. To identify key priority areas for improving the representation of marine biology in ESMs, an international activity drew on the expertise across the BCP research community. A 3-day workshop (2-4 March, 2026) attracted 182 participants from 27 countries across Africa, Asia, Europe, North America, South America, and Oceania and included scientists from observation, laboratory and modelling backgrounds and from 9 major national and international projects. During the workshop, participants decided on the most important processes/characteristics across 10 themes for improving the representation of marine biology in ESMs. These themes can broadly be grouped into those related to 1) how organismal traits and food-web pathways affect ocean carbon uptake, 2) processes that affect how carbon is moved into the deep ocean and the way marine animals interact with this transport such as by breaking up sinking particles of organic matter ("marine snow") or by moving between shallow and deep waters, and 3) how physical, chemical, and biological processes interact to control ocean carbon uptake and storage. The discussed themes are shown in Figure 2, grouped into these topical categories. Concrete scientific recommendations will be provided in Martin et al. (in prep)[13].

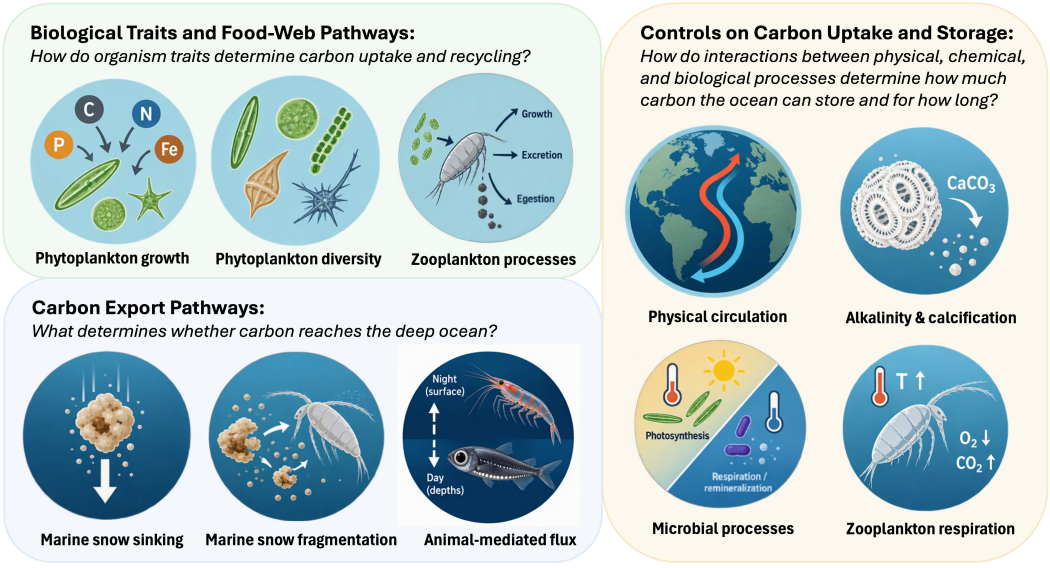

Figure 2. ***Priorities for improving marine biology in Earth System Models.*** *Icons represent the 10 themes that were discussed during the workshop as priority areas for improving the representation of marine biological processes in Earth System Models. They are shown grouped into three topical categories. Image credit: Natalya Gallo, icon graphics developed in Copilot.*

Implications for marine carbon dioxide removal (mCDR) as a climate mitigation measure

One key reason for assessing how well we capture marine biological processes in ESMs is the growing urgency of evaluating mCDR approaches as potential climate mitigation options. The United Nations Environment Programme recently concluded that exceeding 1.5°C is now likely unavoidable and that limiting and reversing overshoot will require CDR alongside rapid emissions reductions[14]. ESMs are key tools for evaluating the large-scale effects of CDR approaches on global climate and carbon uptake, including through community efforts such as the Carbon Dioxide Removal Model Intercomparison Project. Since many ocean biological processes are currently not well-represented in ESMs, these large-scale mCDR modeling experiments carry substantial

uncertainty in their predictions of biological responses to mCDR. This applies both to proposed mCDR techniques where the BCP is directly altered (e.g. ocean fertilization), and where methods based on physical or chemical processes have the potential to impact biological processes (e.g. ocean alkalinity enhancement)[3]. A recent decision from the London Convention and London Protocol (at LC 48/LP 21) has provided new guidance on ocean alkalinity enhancement, ocean fertilization, and ocean sinking of biomass. The decision adopted assessment frameworks as a non-binding guidance tool (only in effect if the underlying amendment from 2013 enters into force) which includes risk management, environmental impact assessments, and the use of a strict precautionary approach that limits activities to legitimate scientific research which does not sell carbon credits and prohibits commercial scale deployments. The lack of sufficient scientific understanding of potential ecological responses and the current weaknesses of ESMs warrant the precautionary approach to mCDR interventions. Enhancing the ability for ESMs to accurately predict biological processes can contribute to addressing this gap in knowledge.

Improved resolution of the following processes discussed during the workshop would be especially relevant to the three mCDR approaches addressed in the recent LC/LP decision (Table 2). Note that certain additional processes such as secondary mineral precipitation and sediment interactions are important for mCDR but were not identified as priority areas in the workshop due to the workshop's broader focus.

Table 2. Examples of identified biological processes for improvement in Earth System Models from Figure 2 and their relevance to predictions of the efficacy and impacts of mCDR approaches. The table is meant to be illustrative; if a process is not listed for a certain method, it does not mean it would have no effect.

mCDR method	Relevant processes	Impact
Ocean alkalinity enhancement	Alkalinity & calcification; Physical circulation; Phytoplankton diversity	ESMs do not represent the impact of organisms on alkalinity and its distribution in the ocean well enough to match even the "un-enhanced" system.
Ocean fertilization	Phytoplankton growth; Phytoplankton diversity; Marine snow sinking; Marine snow fragmentation; Animal-mediated flux; Zooplankton processes; Zooplankton respiration; Microbial processes	The uncertainty is not just how phytoplankton respond to extra nutrients at the ocean surface. It is also what happens to the organic carbon they produce as it moves through the food web before being converted back into CO_2.
Biomass sinking	Physical circulation; Zooplankton respiration; Microbial processes	The efficacy of storing carbon as biomass sunk to the seafloor depends on how much is consumed by organisms on the way down and how quickly water above the seafloor returns to the surface.

Terminology – Carbon Sequestration

For a climate policy audience, **carbon sequestration** refers to the storage of carbon away from the atmosphere. In marine systems, carbon is transported from surface waters to the ocean interior, where it can remain isolated from the atmosphere for years to millennia. However, climate mitigation benefits arise only when actions lead to a **net increase in long-term carbon storage** (> 100 years), thereby reducing atmospheric CO_2. Because carbon can return to the surface ocean and atmosphere on different timescales, both the **amount of carbon stored** and the **duration of storage** are important considerations when assessing mitigation outcomes. This is especially relevant for mCDR methods such as ocean fertilization which aim to stimulate primary production, but may not lead to durable, long-term storage in the deep ocean. Furthermore, not all uses of "carbon sequestration" in the ocean science literature are equivalent to climate mitigation services[15].

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