Deep Ocean Stewardship Initiative (DOSI) - Recommendation to the Article 6.4 Supervisory Body on Activities involving removals.

This document provides DOSI's input to the Supervisory Body's consultation provided in A6.4-SB005-A02: "Guidance and questions for further work on removals".

Here we speak to the deep-ocean effects of ocean-based carbon dioxide removal technologies proposed. Nearly all of these employ the deep ocean (below 1000 m) as the primary disposal site. Below, we respond to specific questions from the guidance document.

Cross Cutting Questions:

1. *Discuss the role of removals activities and this guidance in supporting the aim of balancing emissions with removals through mid-century.*
    a. Removal processes that involve altering natural processes and ecosystems will have complex feedbacks and, in most cases, unintended and undefined consequences that can impair the natural carbon cycle. Before removal activities are given a major role in tackling climate change their carbon removal benefits should be weighed carefully against environmental impacts that will directly and indirectly feedback to climate and human wellbeing. Further, in work to approximate emission reduction amounts for removal activities, research is required to determine the 'net sequestration' amount of the activity, from source (e.g., kelp farm, alkalinity addition) to sink (carbon sequestration in sediments or deep ocean currents).
2. *What are the roles and functions of the following entities in implementing the operations referred to in this guidance: Activity proponent(s), Article 6.4 mechanism Supervisory Body (6.4SB), 6.4 mechanism registry administrator, Host Party, stakeholders?*
    a. Because evidence-based decisions should be grounded on science, scientists have much to contribute to the implementation and may be considered a type of stakeholder. An independent scientific body can advise the 6.4 Supervisory Body, including through facilitating an assessment report.

Questions on Specific Elements.

C. Accounting for removals:

1. *Discuss any further considerations to be given to the core elements for accounting for removals in A6.4-SB003-A03; where possible, identifying their applicable scope, i.e., relevance to all 6.4 mechanism activities, to removals activities, or to specific removal activity categories or types.*

a. Accounting for removals should effectively involve a whole life cycle analysis (source to sink) and should include greenhouse gas release or lost carbon sequestration services associated with environmental impacts. In many cases these will have to be studied and monitored over long time periods. Most ocean-based carbon removal technologies (e.g., iron fertilization, macroalgal or crop waste sinking, ocean alkalinity enhancement, etc.) will disrupt finely balanced marine ecosystems in midwater and at the seafloor. Because these marine ecosystems play major roles in carbon uptake, transformation, transfer, storage, and burial (all part of sequestration) any changes that affect the carbon cycle or other greenhouse gasses should be understood, and accounted for, including long-term effects.

G. Avoidance of other negative environmental, social impacts

1. *Discuss considerations to be given to core elements for avoidance of other negative environmental, social impacts; where possible, identifying the applicable scope, i.e., relevance to all 6.4 mechanism activities, to removals activities, or to specific removal activity categories or types.*
    a. Carbon removal technologies that target the ocean will have major negative environmental impacts on ocean ecosystems that may disrupt natural carbon cycling and sequestration, as well as patterns of productivity and ocean health.

Strong connectivity between the surface and deep ocean will transfer impacts through the water column and to the seafloor, as detailed below (summarized from Levin et al., 2023; see figure within article).

Alterations to ocean albedo and reflectance:

The introduction of very fine inorganic particles (e.g., carbonates or silicates) into ocean waters (or ice) to enhance alkalinity, modify albedo, or inject CO_2 would alter turbidity and light fields. Artificial upwelling, ocean fertilization (OF), and afforestation (AF) will change surface ocean color and albedo.

Impacts to ocean stratification:

Cooling techniques will alter ocean stratification and the distribution of heat, which will alter midwater processes including particle flux, vertical migrations, metabolic rates, larval distributions, oxygenation, and remineralization rates, with effects cascading to the seabed. Resulting changes in the distribution and productivity of plankton will affect ecosystem connectivity and food supply to other organisms. Smaller inorganic and organic particles are unlikely to reach the deep seafloor as detectable deposits but may be ingested or entrained in aggregations of sinking particles (marine snow) and transported to the deep ocean.

<u>Shifts to ocean biogeochemistry:</u>

OF, artificial upwelling, and Ocean Thermal Energy Conversion (OTEC) are likely to enhance phytoplankton growth, which may increase local particulate organic carbon flux to the seabed. Extensive nitrogen and phosphorus uptake by macroalgal culture could exacerbate open-ocean nutrient limitation and lower rates of nitrogen and phosphorus recycling, which could affect nutrient stoichiometry and phytoplankton composition or productivity. These changes would alter the supply, composition, and lability of organic carbon to the deep sea, leading to changes in food webs, communities, biodiversity, and ultimately in carbon sequestration. Macroalgae and crop waste could release particulate or dissolved organic matter on descent, altering microbial production, oxygen consumption, and food supply in the mesopelagic realm and beyond.

<u>Implications for ocean life:</u>

Algae and crop waste may create physical resuspension and disturbance upon reaching the seabed, introduce unnatural amounts of food into a typically food-limited system, and smother animals in or on the sediment. The resulting increased food supply will attract large numbers of opportunist scavengers and predators and alter species interactions. These changes could harm commercially harvested fish and invertebrates.

Hypercapnia (excessive CO2) and deoxygenation are serious concerns. Liquid CO_2 injected just above the seabed will form a blanket that initially might suffocate animals; dilution will eventually cause differential effects on deep-sea life. Artificial upwelling and OF-enhanced phytoplankton production will intensify oxygen consumption and increase CO_2 production in midwater, with possible negative effects on the behavior, growth, and survival of mesopelagic organisms. Decay of phytodetritus, macroalgae, or crop waste at the seafloor will deplete oxygen. At very low oxygen concentrations, biodiversity is reduced, and anoxia is lethal to nearly all animals. Other effects of severe oxygen depletion can include smaller body size, reduced abundance of large taxa, loss of carnivory, reduced bioturbation, and animal emergence or avoidance. Intense organic enrichment by phytodetritus or seaweed could produce hydrogen sulfide, which is toxic to most life, and/or methane, a potent greenhouse gas. Their release would drastically alter the species composition of the communities below or around sites of carbon removal technologies.

Other indirect effects on deep-ocean ecosystems may occur. If silicate materials are used for alkalinity enhancement, they may release associated trace elements (e.g., cadmium, nickel, or chromium) into deeper waters and affect deep-sea biota. Additionally, proposals to use artificial upwelling from deep water as a source of nutrients for macroalgae would also exacerbate ocean acidification. Macroalgal rafts associated with AF might serve as vectors introducing coastal contaminants, microbes, parasites, and other associated species to the open ocean and potentially the deep sea.

Effects on society:

The consequences of ecosystem change for humans have yet to be assessed but merit thorough consideration. Services ranging from storm surge protection by reefs and wetlands, altered production of fisheries, impaired tourism, recreation, shipping or endangered species are all possible when removal technologies are implemented at scale.

In summary, the changes described above may have unforeseen or unwanted consequences for critical ecosystem services provided by the deep ocean, including carbon and nutrient cycling, remineralization, pelagic and demersal fisheries production, or the support of threatened or endangered species. These indirect effects on carbon flux, transport, transformation, and burial need to be factored into assessment of scaling and effectiveness and incorporated into carbon measurement, verification, and reporting. For further information, please see: Levin et al. (2023) Deep sea impacts of climate interventions. Science 379: 978-981. *https://www.science.org/stoken/author-tokens/ST-1072/full*

About the Deep Ocean Stewardship Initiative (DOSI):

DOSI is a global network of experts which integrates science, technology, policy, law, and economics to advise on ecosystem-based management of resource use in the deep ocean, and on strategies to maintain the integrity of deep-ocean ecosystems within and beyond national jurisdiction.