Blue Carbon: At a Glance

"Blue carbon" methods are a wide-ranging category of nature-based climate solutions that aim to preserve or enhance the ocean's natural CO_2 capture and storage capacity by protecting, restoring, or better managing specific ocean ecosystems. These include the conservation and restoration of coastal blue carbon ecosystems such as mangroves, salt marshes, seagrasses, and naturally occurring kelp forests, as well as approaches based on rebuilding populations of various fish species and great whales by reducing harvests or other key stressors.[7] When these methods involve restoring damaged ecosystems or rebuilding the populations of animals that have been previously harvested or hunted by humans, they are referred to as blue "ecosystem recovery" methods. A critical feature of these methods is their ability to produce a host of valuable co-benefits for both human society and nature, many of which can be realized even if the amount of carbon sequestered in a particular instance is small. Compared with many technological CDR approaches, the ecological risks associated with blue carbon methods are judged to be extremely low.[8]

Potential Scale of Carbon Storage: Estimates of the amount of carbon that can be stored via these approaches vary widely; several different methods fall into this category of CDR, and each has its own potential contribution and unique sources of scientific uncertainty. One recent study concluded that pathways based on rebuilding whale and fish populations could remove 0.02–0.3 gigatonnes of carbon per year (GtC yr^{-1}).[9] Meanwhile, restoration of mangroves and salt marshes could net an additional 0.008–0.3 GtC yr^{-1} in new storage relative to present-day baselines.[10] Conservation of existing mangroves, salt marshes, and seagrass beds globally would avoid about 0.08 GtC yr^{-1} in new emissions.[11] The potential scale of carbon dioxide removal based on these coastal blue carbon ecosystems is limited in part by the relatively small spatial area they occupy relative to the ocean as a whole.[12]

Duration of Carbon Storage: As with storage capacity, estimates of the timescale of sequestration vary widely across blue carbon methods. The carbon transported to the deep ocean and seafloor in dead matter such as kelp fronds and the carcasses of whales and fish can be reliably sequestered from the atmosphere for more than 100 years at depths below 1,500 meters, and for timescales of more than 1,000 years upon reaching the deepest ocean depths.[13] Some carbon can be stored in mangrove, salt marsh, and seagrass soils for centuries, though the fate of this carbon is increasingly uncertain in the face of climate-driven changes in sea level, frequency and severity of major storms, and changes in species ranges.[14]

Cost: Mangrove restoration can remove CO_2 for $1,800 per ton C.[15] The conservation of existing mangrove stands can be accomplished for as little as $37 per ton C.[16] Costs for most other blue carbon pathways are not as well understood, with estimates ranging from $17 to $40,820 per ton C.[17] There are no existing per-ton cost estimates for sequestration based on rebuilding fish or whale populations.

Technical Readiness: Methods for restoration of mangroves and salt marshes are well developed and increasingly cost effective, though the cost of these projects often cannot be justified on the basis of CO_2 removal alone. However, cost may be justified when other ecosystem benefits, such as the protection of fish nurseries, are considered. Restoration of seagrass beds is expensive and at times ineffective, and there is significant uncertainty as to whether seagrasses store more carbon than they release; at least one study has concluded there is little to no cost-effective potential in large-scale seagrass restoration as a carbon removal solution.[18] There are no existing carbon market standards for CDR via rebuilding of fish or marine mammal populations. It is additionally not clear, in the case of many whales, what policy interventions could be imposed to support species growth beyond naturally occurring rates. However, this does not negate the benefits of efforts to rebuild the populations of these animals for reasons other than carbon sequestration.

Potential Risks and Benefits (Social and Environmental): The co-benefits of blue carbon CDR methods are among these approaches' greatest strengths relative to technological approaches. They include physical protection against storms and coastal erosion, increased resilience of ecosystems in the face of climate change through increased biodiversity, provision of food for growing human populations, and support of human livelihoods in industries as diverse as outdoor recreation, agriculture, and marine operations.[19] Social and governance challenges may be less significant than with other CDR approaches because of general public support for ecosystem conservation and positive synergy with existing environmental protection laws. However, any blue carbon CDR method should be accompanied by projects or policy interventions to ensure that the benefits are distributed equitably to avoid the serious injustices that accompanied many carbon crediting projects conducted under the original Reducing Emissions From Deforestation and Forest Degradation (REDD) framework.

Outstanding Questions: A significant challenge for all blue carbon–based CDR pathways is monitoring, reporting, and verification (MRV) of the quantity and durability of carbon stored, especially considering the unpredictability of climate change and human development patterns. There are also substantial uncertainties surrounding emissions of other greenhouse gases, including methane, from mangroves and salt marshes; in some cases, these emissions could severely limit the climate mitigation potential of these ecosystems.[20] The amount of carbon that fish and marine mammals help sequester from the atmosphere has not been quantified with precision, making animal-based pathways the least ready for deployment of the natural CDR methods. However, there is ample scientific evidence that conserving existing fish and whale populations produces multiple co-benefits and can help us avoid substantial new CO_2 emissions from the ocean.[21]

7 The establishment of new seaweed farms in the offshore environment, a CDR method known as ocean afforestation, is covered separately in the companion chapter "Macroalgal Open-Ocean Mariculture and Sinking: At a Glance"

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9 Ibid.

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13 NASEM, *A Research Strategy*; David A. Siegel et al., "Assessing the Sequestration Time Scales of Some Ocean-Based Carbon Dioxide Reduction Strategies," *Environmental Research Letters*16, no. 10 (2021), https://doi.org/10.1088/1748-9326/ac0be0.

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15 Pierre Taillardat et al., "Climate Change Mitigation Potential of Wetlands and the Cost-Effectiveness of Their Restoration," *Interface Focus* 10, no. 5 (2020), https://doi.org/10.1098/rsfs.2019.0129.

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17 NASEM, *A Research Strategy*; Taillardat et al., "Climate Change Mitigation Potential of Wetlands."

18 Griscom et al., "Natural Climate Solutions."

19 Williamson and Gattuso, "Carbon Removal Using Coastal Blue Carbon Ecosystems"; NASEM, *A Research Strategy*.

20 Judith A. Rosentreter et al., "Methane and Nitrous Oxide Emissions Complicate Coastal Blue Carbon Assessments," *Global Biogeochemical Cycles* 35, no. 2 (2021), https://doi.org/10.1029/2020GB006858.

21 James R. Collins et al., *Natural Climate Solutions in the Open Ocean: Scientific Knowledge and Opportunities Surrounding Four Potential Pathways for Carbon Dioxide Removal or Avoided Emissions*," Environmental Defense Fund, 2022, https://www.edf.org/sites/default/files/2022-10/Natural%20Climate%20Solutions%20in%20the%20Open%20Ocean.pdf.