Coastal wetlands

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Inorganic blue carbon sequestration

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Restoring coastal vegetated habitats can remove carbon from the atmosphere and store it as organic matter in sediments. A study now shows that these habitats also support seawater to store more carbon, and for longer, in its dissolved inorganic form.

Mangrove forests are highly productive coastal ecosystems that drive the storage of organic carbon within the plants and in the sediments below, and the associated release of alkalinity.

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Coastal wetlands such as mangrove forests, seagrass meadows and salt marshes have lost about half of their global areal coverage since 1900 AD[1]. Habitat loss is due to multiple factors, including urban development, pollution and agriculture or aquaculture pressures. Today, coastal vegetated habitats may account for about half of the carbon stored in ocean sediments[2]. Restoring those ecosystems is seen as an easy way to lock carbon away from the atmosphere, storing it as organic matter in marine sediments. Writing in *Nature Sustainability*, Fakhraee et al.[3] report that, in addition to their organic carbon storage potential, restoring coastal vegetations would modify seawater inorganic carbon in such a way that it can take up more CO_2 from the atmosphere. This calls for more research on the restoration of coastal wetlands as a solution to mitigate climate change.

To limit warming to 2 °C by 2100, actively removing CO_2 from the atmosphere will be required[4]. The ocean already acts as a major, anthropogenic carbon remover, storing about 25% of annual CO_2 emissions[5]. Boosting this ocean CO_2 storage further is currently the focus of extensive research and field trials, notably including by restoring, maintaining or developing ecosystems producing 'blue carbon', that is, the carbon stored as organic matter by marine organisms and their remains[6] — an ocean equivalent of planting trees to store carbon[7].

To mitigate climate change with blue carbon ecosystems (BCEs), the proposed methods need to be scalable, provide long-term carbon storage and be free of undesirable social, environmental or ecosystem consequences[8]. Coastal BCEs, such as mangrove forests, tidal marshes and seagrass meadows, are of particular interest because they provide numerous environmental and human co-benefits, such as coastal protection, biodiversity and the support of tourism and fisheries[9].

Scaling up and constraining the global importance of BCE conservation and restoration to mitigate climate change requires quantification of present and potential surface areas where BCEs can exist and of the amount of additional greenhouse gas removed from the atmosphere per unit area of habitat. The latter is particularly challenging, as restoring or developing BCEs disrupts the functioning of pre-existing and adjacent ecosystems. Part of the organic carbon produced in BCEs is exported and degraded in the water column or sediment of adjacent systems, and part of the organic matter accumulating in BCEs is imported from elsewhere[9]. Finally, the effects of the restoration of BCEs have, until now, been mostly contemplated through the fate of organic carbon, often overlooking consequences on inorganic carbon forms and alkalinity.

Alkalinity is the capacity of seawater to neutralize an acid, such as dissolved CO_2. In marine environments, the precipitation of calcium carbonate minerals ($CaCO_3$, for example, from coral skeletons) removes alkalinity from seawater, decreasing its capacity to take up atmospheric CO_2. Conversely, the dissolution of calcium carbonate releases alkalinity in seawater, increasing its CO_2 uptake potential. In addition, anaerobic (that is, in the absence of oxygen) degradation of organic matter produces alkalinity, while the reoxidation of the reduced metabolites depletes it. Thus, if restoring BCEs affects either $CaCO_3$ reactions or the amount of oxygen in sediments, it should also affect seawater alkalinity and the associated CO_2 neutralization or production. This key role of alkalinity in integral CO_2 uptake by BCEs is often ignored. This is surprising because most other ocean-based approaches to stimulate CO_2 sequestration focus on ocean alkalinity enhancement[8,9].

Using a new stochastic sediment biogeochemical model, Fakhraee et al. show that the restoration of mangroves and seagrasses in environments where they were previously absent results usually in increases in seawater alkalinity. While some BCEs, in particular seagrass meadows, may stimulate $CaCO_3$ production and increase alkalinity consumption and CO_2 release[10], most BCEs are sites of $CaCO_3$ dissolution and alkalinity release, in accordance with previous research[11], particularly when external $CaCO_3$ supply is high, for example via nearby coral reefs.

BCEs are sites of high organic matter accumulation compared with non-vegetated systems[9], because they produce a disproportionately high amount of organic matter, and through canopy effects they trap externally produced organic materials. This organic matter is used by respiring animals and microorganisms, which consumes oxygen and eventually leads to anoxia. As shown by Fakhraee et al., in the absence of oxygen, the degradation of organic matter generates alkalinity. A substantial fraction of this alkalinity is consumed again through efficient reoxidation processes, but a small fraction escapes the sediments. This balance between alkalinity production during anaerobic organic matter degradation and alkalinity consumption during reoxidation processes is likely to vary with the maturity or age of the BCEs. Younger, restored systems have lower organic matter stocks and their vegetations have lower below-ground biomass, releasing more oxygen via their roots. Consequently, reoxidation processes may be relatively important, and alkalinity release is smaller in younger BCEs than in older, natural and conserved BCEs. In this study, Fakhraee et al. use sediment data from both young and mature mangrove systems to calibrate their model, without discussing their alkalinity generation potential separately. We speculate that while the organic carbon contribution to carbon sequestration may be more important in younger, restored systems, the alkalinity release and the potential additional carbon dioxide uptake, that is, the inorganic carbon contribution, may increase with the age of the forest or meadow.

As argued by Fakhraee et al., a proper assessment of BCEs' restoration potential to remove atmospheric CO_2 requires integration of both the organic and inorganic carbon system, a consideration of the environmental context (whether external sources of organic matter or $CaCO_3$ are involved) and timescales. Indeed, while organic carbon storage is vulnerable to coastal dynamics, storms and sea level rise, dissolved inorganic carbon storage as alkalinity is much more permanent.

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Competing interests

The authors declare no competing interests.