RESEARCH UPDATE

BLUE CARBON OCEAN ALKALINITY ENHANCEMENT

A New and Additional Mechanism to Finance Mangrove Restoration

Mangrove forests provide a range of well-documented benefits, including enhanced biodiversity, healthy fisheries, coastal resilience, and low-cost carbon sequestration through organic carbon storage in biomass and soils. There is growing evidence that mangroves drive further carbon drawdown, which is not accounted for in current carbon crediting protocols, by increasing alkalinity in surrounding estuarine and coastal seawater.[1, 2] The Yale Center for Natural Carbon Capture (YCNCC) is bridging the fields of coastal ecology and geochemistry to demonstrate this additional mode of carbon dioxide removal (CDR) that mangrove systems deliver via ocean alkalinity enhancement ("Blue Carbon OAE").

Blue Carbon OAE offers a significant new means to finance mangrove restoration. The YCNCC plans to deploy field trials alongside existing mangrove restoration projects in multiple geographic regions to demonstrate this concept. In parallel, the YCNCC will partner with registries to develop high-integrity commercial protocols for the monitoring, reporting, and verification (MRV) of the durable CDR that mangrove restoration delivers by increasing alkalinity. Beyond the potential for new long-term financing for mangrove restoration projects, this protocol for Blue Carbon OAE will broadly advance MRV for marine CDR.

THE SCIENCE

The ocean is a "carbon sponge," which plays an integral role in the geologic cycle that controls carbon dioxide concentrations in the atmosphere, and has absorbed 30% of global carbon dioxide emissions since the Industrial Revolution. Ocean alkalinity enhancement (OAE) increases the efficiency and size of that sponge, enabling the ocean to store more carbon dioxide.

Blue Carbon OAE is facilitated in mangrove soils via two processes: 1) The dissolution of calcium carbonate, or limestone, by CO_2 in the system; and 2) microbially mediated anaerobic decomposition of organic matter coupled with the burial of mineral pyrite (Figure 1). Both processes create bicarbonate, a non-gaseous stable form of dissolved inorganic carbon that is stored in the ocean for thousands of years.[3]

1 Fakhraee, M., Planavsky, N. J., & Reinhard, C. T. (2023). Ocean alkalinity enhancement through restoration of blue carbon ecosystems. *Nature Sustainability,* 6(9), 1087–1094. https://doi.org/10.1038/s41893-023-01128-2

2 Alongi, D. M. (2022). Lateral export and sources of subsurface dissolved carbon and alkalinity in mangroves: Revising the blue carbon budget. *Journal of Marine Science and Engineering,* 10(12), Article 1916. https://doi.org/10.3390/jmse10121916

3 Middelburg, J.J., Soetaert, K. and Hagens, M., 2020. Ocean alkalinity, buffering and biogeochemical processes. *Reviews of Geophysics,* 58(3), p.e2019RG000681. https://doi.org/10.1029/2019RG000681

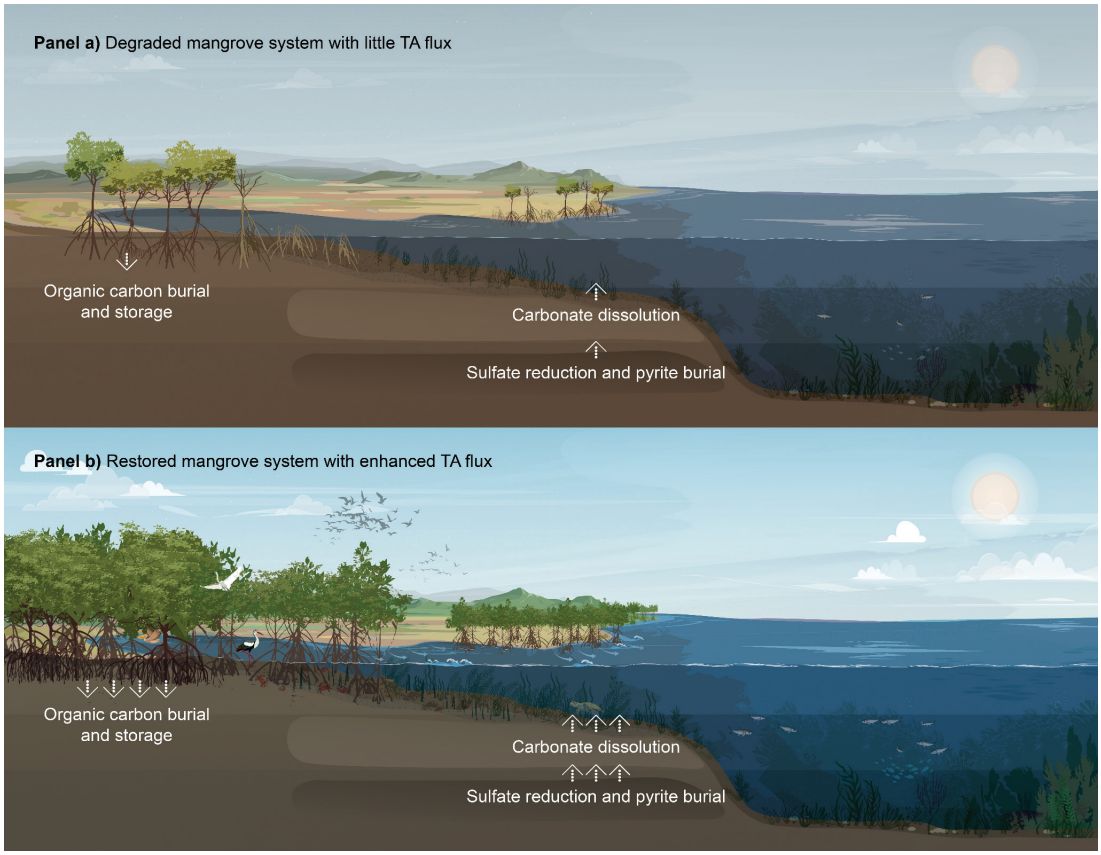

FIGURE 1:
The biogeochemistry of Blue Carbon OAE
(Source: YCNCC)

MONITORING, REPORTING, AND VERIFICATION

There is a growing scientific foundation for the monitoring, reporting, and verification (MRV) of alkalinity fluxes from blue carbon ecosystems, which YCNCC scientists have pioneered and continue to advance.

FIELD MONITORING: Researchers at the YCNCC have developed extensive capability to measure and monitor carbonate chemistry, ecosystem biochemical exchanges, tidal flow, and other key aspects of blue carbon systems. The Blue Carbon OAE initiative will build on this work to test a range of techniques for eventual inclusion in open commercial protocols–with an end goal of low-cost, high-integrity MRV that will be operable at scale, and that can ideally employ members of nearby coastal communities for ongoing implementation.

MODELING: YCNCC scientists are advancing a range of biogeochemical models for river, estuarine, and ocean dynamics. Specifically, a concurrent and complementary research project seeks to reconcile small-scale, regional, and global ocean modeling with a computationally efficient and high-fidelity forecasting system for geochemical CDR interventions, including OAE. The Blue Carbon OAE initiative will be an important early use-case for this system, which can be used to forecast and estimate initial CDR, as well as long-term marine carbon storage.

Yale researchers taking measurements in a mangrove stand in the Florida Coastal Everglades Long Term Ecological Research site
Courtesy of Yale School of the Environment

THE OPPORTUNITY

VALORIZING ALL CARBON FLUXES FROM MANGROVES

When alkalinity generation is factored, mangrove systems store substantially more carbon than the organic carbon accounted for in current commercial protocols for mangrove restoration. Recent modeling work from the YCNCC shows that up to 40-50% of a mangrove system's total carbon benefit could come from alkalinity enhancement.[1] Quantifying this additional inorganic carbon storage will enable mangrove restoration projects to deliver substantially greater verified carbon removal.

CREATING A STRONGER BUSINESS CASE FOR RESTORATION

When projects can claim both organic and inorganic carbon benefits, they will have the potential to earn significant additional revenue from durable CDR credits. This brings new streams of financing to restoration work that is already proven to generate habitats for biodiversity and coastal protection benefits. Critically, these extra carbon fluxes continue to be produced even in stable mangrove forests.

ALIGNING WITH COMMUNITY AND REGULATORY PRIORITIES

Mangrove restoration is widely supported by coastal communities, governments, and civil society because it protects coastlines, enhances fisheries health, and supports local livelihoods. Blue Carbon OAE builds on conservation projects under existing regulatory frameworks and with strong social license, reducing permitting risk for investors.

LOW-COST, NATURALLY SCALABLE SOLUTION

Alkalinity is produced by natural processes in mangrove systems. Blue Carbon OAE thus has low operating costs, no need for expensive material or energy inputs, and the ability to scale through existing conservation and restoration networks.

ADVANCING THE BROADER MARINE CDR FIELD

Developing protocols and best practices for measurement, monitoring, and verification for Blue Carbon OAE does not just benefit mangroves. It will advance MRV for the broader field of marine CDR, helping bring down costs and accelerate development globally.

CONTACT

For feedback, partnerships, or further information, please contact ycncc@yale.edu or visit https://naturalcarboncapture.yale.edu.