Blue Carbon Potential of Coastal Fisheries: Implications for Climate Changes

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ABSTRACT

This article investigates the potential of coastal fisheries to contribute to climate change mitigation through blue carbon ecosystems. It focuses on habitats like mangroves, seagrasses, and salt marshes, which not only capture atmospheric carbon but also support marine biodiversity and fishery productivity. The objective is to assess how integrating blue carbon science with fisheries resource management can enhance ecological sustainability and climate resilience. This article reviews blue carbon practices and policies, highlighting challenges like data gaps, weak coordination, and limited community involvement. It calls for integrated strategies that link climate goals, livelihoods, and carbon finance, emphasizing inclusive, science-based approaches to enhance both environmental sustainability and socio-economic resilience in coastal regions.

INTRODUCTION

Climate change presents a growing threat to marine ecosystems and coastal livelihoods worldwide. In this context, "blue carbon" the carbon captured and stored by marine and coastal ecosystems has emerged as a critical nature-based solution for climate mitigation (Hilmi *et al*., 2021). Coastal vegetated ecosystems such as mangroves, seagrasses, and salt marshes have the unique ability to sequester large amounts of carbon both in their biomass and deep sediment layers, often at rates surpassing terrestrial forests. These blue carbon ecosystems are closely interlinked with coastal fisheries, serving as breeding grounds, nurseries, and feeding areas for a wide range of commercially important species (Huxham *et al*., 2018). Coastal fisheries, particularly small-scale and artisanal sectors, are not only dependent on these ecosystems for their productivity but also play a crucial role in managing and protecting them. With increasing interest in low-carbon development and ecosystem-based management approaches, understanding the blue carbon potential of coastal fisheries is vital (Thoni and Rummukainen, 2025). Not only does this help align fisheries with climate goals, but it also creates opportunities for inclusive carbon financing, sustainable livelihoods, and ecosystem restoration. This article explores the scientific basis, linkages, and policy implications of blue carbon in the context of coastal fisheries, aiming to highlight its untapped potential for climate change mitigation.

Understanding Blue Carbon Ecosystems

Definition and Types: Mangroves, Seagrasses, and Salt Marshes

Blue carbon ecosystems refer to coastal and marine environments that capture and store significant amounts of atmospheric carbon dioxide (CO_2). The primary blue carbon habitats include mangroves, seagrass meadows, and salt marshes, all of which play essential roles in global carbon cycling (Islam, 2025; Jahan, 2025). Mangroves are intertidal forests found in tropical and subtropical regions. Their dense root systems stabilize sediments and facilitate carbon burial beneath the forest floor. Seagrasses, submerged flowering plants found in shallow coastal waters, sequester carbon in both their biomass and the sediments below, often trapping organic material transported by currents. Salt marshes, located in temperate coastal zones, are dominated by halophytic (salt-tolerant) grasses and are particularly efficient in trapping suspended carbon in sediment layers. These ecosystems not only act as carbon sinks but also support rich biodiversity and protect coastlines from erosion and storm surges (Moritsch *et al*., 2025).

What Is Carbon Sequestration?

Carbon sequestration is the process of removing carbon dioxide (CO_2) from the Earth's atmosphere and storing it in various natural or artificial reservoirs, known as carbon pools. Since CO_2 intensifies the greenhouse effect, this process plays a vital role in combating climate change (Chlela and Selosse, 2025). Sequestration occurs naturally on a large scale but can also be enhanced through human interventions using both natural and technological approaches. There are two main forms of carbon sequestration:

Natural Sequestration: Ecosystems such as forests, oceans, soils, and all organic life including plants, animals, and microorganisms act as natural carbon sinks. As organisms grow and eventually decompose, much of their carbon is transferred into the soil or sediment, where it remains stored and contributes minimally to atmospheric CO_2 levels.

Artificial Sequestration: Human-engineered methods involve capturing CO_2 emissions from industrial processes and power generation, then storing them underground (geological sequestration) or reusing them in various applications. These technologies are designed to reduce the amount of CO_2 released into the atmosphere, supporting climate mitigation efforts.

Carbon Sequestration Mechanisms

Blue carbon ecosystems remove CO_2 from the atmosphere through photosynthesis, converting it into organic matter. Unlike terrestrial ecosystems, a significant portion of this carbon is stored below ground, in anaerobic (low-oxygen) sediments that slow down decomposition, allowing carbon to remain locked for centuries or even millennia (Liu *et al*., 2025; Wang and Fan, 2025). Blue carbon ecosystems are uniquely efficient at long-term carbon storage due to several key mechanisms. Carbon is stored in above-ground biomass such as leaves, stems, and roots, which act as immediate reservoirs. A significant portion of carbon is also sequestered below ground in sediments, where it becomes buried and protected from oxidation, allowing for long-term storage. Additionally, these ecosystems trap and store allochthonous carbon organic material like plankton and algae that originates from outside the system. Together, these processes contribute to exceptionally high carbon sequestration rates, often surpassing those of most terrestrial ecosystems. The types and methods of carbon sequestration, organized clearly with mechanisms, and examples are presented in table 1& Fig. 1.

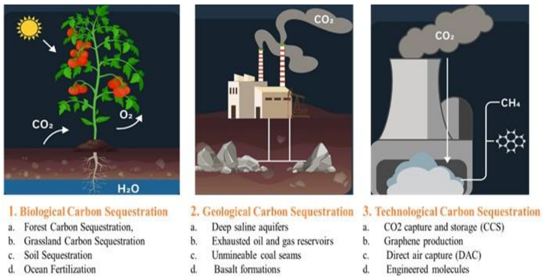

Fig. 1 Different methods of carbon sequestration (Source: Eos data analytics, 2024)

Table 1. Different types of carbon sequestration, their mechanism and applications

Type	Method	Mechanism	Examples / Applications
1. Terrestrial	Afforestation & Reforestation	Trees absorb CO_2 via photosynthesis and store carbon in biomass and soils	Forest plantations, reforestation of degraded lands
	Soil Carbon Sequestration	Organic carbon is stored in soil via plant residues and microbial activity	Conservation tillage, composting, cover cropping
	Agroforestry	Combining trees with agriculture increases carbon storage in land systems	Silvopasture, alley cropping
	Biochar Application	Biomass is converted to biochar and applied to soil, improving carbon retention	Biochar from crop waste added to farmland
2. Oceanic	Biological Carbon Pump	Phytoplankton absorb CO_2; carbon sinks as marine snow to deep ocean layers	Natural phytoplankton cycles
	Ocean Fertilization *(experimental)*	Nutrients (e.g. iron) stimulate phytoplankton growth to increase CO_2 uptake	Iron fertilization experiments
	Ocean Alkalinity Enhancement *(experimental)*	Adding alkaline minerals boosts ocean CO_2 absorption via chemical reactions	Adding olivine or lime to ocean water

3.Blue Carbon	Coastal Ecosystem Restoration	Vegetation like mangroves and marshes trap and store CO_2 in biomass and sediments	Mangrove reforestation, salt marsh conservation
	Seagrass Meadow Protection	Underwater plants fix and store carbon through photosynthesis and root systems	Marine Protected Areas (MPAs)
4. Geological	Carbon Capture and Storage (CCS)	CO_2 is compressed and injected into deep rock formations	CO_2 stored in saline aquifers or depleted oil fields
	Enhanced Oil Recovery (EOR)	Injected CO_2 helps extract more oil while being stored underground	CO_2 flooding in aging oil wells
	Mineral Carbonation	CO_2 reacts with minerals to form stable solid carbonates	CO_2 + basalt = magnesium carbonate
5. Technological	Direct Air Capture (DAC)	Machines pull CO_2 directly from the air and compress/store it	Clime works DAC systems
	Bioenergy with Carbon Capture (BECCS)	Biomass energy is produced, and the resulting CO_2 is captured and stored	BECCS-equipped biomass power plants
	Carbon Capture and Utilization (CCU)	Captured CO_2 is used to make products instead of being released	CO_2 used in concrete, fuels, beverages

Coastal Fisheries and Blue Carbon Linkages

Direct and Indirect Interactions

Coastal fisheries and blue carbon ecosystems are deeply interconnected, both ecologically and economically. Mangroves, seagrasses, and salt marshes serve as critical habitats for numerous life stages of commercially important fish and shellfish species (Preston *et al*., 2025). These ecosystems offer spawning grounds, nursery habitats, and feeding areas, directly supporting the productivity and resilience of coastal fisheries. Indirectly, blue carbon ecosystems also contribute to the stability of nearshore environments by reducing wave energy, preventing shoreline erosion, and maintaining water quality. This creates favourable conditions for traditional fishing practices and small-scale aquaculture systems that are highly dependent on healthy ecosystems (Guo *et al*., 2025).

Role of Artisanal and Small-Scale Fisheries in Blue Carbon Systems

Artisanal and small-scale fishers (SSF) play a dual role: they are both beneficiaries and stewards of blue carbon ecosystems. Many SSF communities depend on mangrove forests and seagrass beds for their daily catches, using low-impact gear and practices that traditionally helped sustain these environments. In recent years, community-based efforts such as mangrove reforestation, seagrass monitoring, and no-fishing zones have emerged in collaboration with fishers. These not only restore blue carbon habitats but also strengthen local fish stocks and food security. However, pressures such as overfishing, gear damage, and habitat conversion for shrimp farming or tourism pose threats. Thus, involving SSF communities in the co-management of blue carbon areas can align conservation goals with local livelihoods.

Case Studies from India and Abroad

India – Odisha and Gujarat: Community-driven mangrove plantation programs in regions like Kendrapara (Odisha) and Kachchh (Gujarat) have shown promise in restoring degraded habitats while improving fish catch over time. These efforts also offer opportunities for future blue carbon credit schemes.

Indonesia – Blue Forests Project: Local communities in Sulawesi have combined sustainable fisheries with mangrove conservation, supported by carbon credit mechanisms and eco-labelling, creating new revenue streams for fisher households.

Kenya – Mikoko Pamoja Project: A pioneering community-based mangrove conservation initiative that has generated verified carbon credits and funded health and education programs for local fishers.

Quantifying Blue Carbon Stocks in Coastal Fisheries

Methodologies for Estimation

Quantifying blue carbon stocks in coastal ecosystems requires an interdisciplinary approach that combines ecology, geospatial science, and biogeochemistry. Estimations typically focus on: 1. Above-ground biomass: Measuring the volume and density of vegetation (e.g., mangrove trunks, leaves), 2. Below-ground biomass: Estimating root biomass and associated carbon content and, 3. Sediment carbon stocks: Core sampling is used to assess carbon stored in the sediment layers, often to a depth of 1 meter or more. Standardized methods have been developed by organizations such as the IPCC, Blue Carbon Initiative, and Verra's Verified Carbon Standard (VCS) for use in carbon accounting and crediting projects. Some tools, models, and indicators used in quantifying blue carbon stocks in coastal ecosystems are given below in table 2.

Challenges in Data Collection and Accuracy

Despite growing interest, accurate quantification of blue carbon remains challenging due to:

Ecosystem variability: Carbon storage varies widely based on species composition, location, hydrology, and human interference.

Data scarcity: Many developing countries lack long-term, high-resolution datasets on sediment carbon stocks.

Technical expertise and funding limitations: Sampling, lab analysis, and remote sensing require specialized skills and infrastructure.

Inclusion of fisheries-linked impacts: Most current models do not adequately integrate the role of fisheries practices in enhancing or degrading carbon sinks.

Table 2. Tools, models, and indicators used in quantifying blue carbon stocks in coastal ecosystems

Category	Tool/Model/Indicator	Purpose / Application
Remote Sensing	Landsat, Sentinel satellites	Large-scale habitat mapping and temporal ecosystem monitoring
Spatial Analysis	Geographic Information Systems (GIS)	Analyse spatial distribution, ecosystem boundaries, and threats
Biomass Estimation	Allometric equations & carbon content models	Estimating biomass and carbon stock in mangroves and seagrasses
Carbon Flux Monitoring	Chambers, Eddy covariance towers	Measure real-time CO_2 exchange in selected ecosystems

Indicators	CSR (Carbon Sequestration Rate)	Rate of carbon storage in a given ecosystem
	SOC (Soil Organic Carbon)	Carbon stored in soil organic matter
	TOC (Total Organic Carbon)	Sum of all carbon in organic compounds within a sample (e.g., soil or sediment)

Threats to Blue Carbon Ecosystems

Overfishing, Habitat Destruction, and Pollution

Blue carbon ecosystems face significant threats from both human activities and climate change. Unsustainable fishing practices, particularly those using destructive gear like bottom trawls and drag nets, can severely damage seagrass beds and disturb carbon-rich sediments, leading to the resuspension and oxidation of stored carbon converting these vital carbon sinks into sources (Hershey and Nandan, 2024). Additionally, habitat destruction due to mangrove clearing for shrimp aquaculture, coastal infrastructure development, and sand mining results in the permanent loss of above- and below-ground carbon stocks. Pollution from urban runoff, agricultural chemicals, and plastic waste further undermines the health and resilience of these ecosystems (Rao *et al*., 2021). Climate change compounds these threats through sea-level rise, which may submerge mangroves and salt marshes where landward migration is blocked; shifts in salinity and temperature that disrupt species composition and productivity; and extreme weather events like cyclones and storm surges that uproot vegetation and trigger massive erosion, releasing carbon that has been sequestered over decades.

Coastal Development and Aquaculture Encroachment

Rapid urbanization and tourism development along coastlines have resulted in large-scale conversion of mangroves and other coastal wetlands. Ports, roads, hotels, and gated communities often replace ecologically rich areas, prioritizing short-term economic gains over long-term environmental security. Similarly, unregulated aquaculture expansion, particularly shrimp farming, has been a major driver of mangrove loss in many parts of Asia, including India. Such conversions not only destroy blue carbon habitats but also alter local hydrology and water quality, further degrading nearby fisheries. Addressing these threats requires an integrated approach that includes coastal zone planning, stricter environmental regulations, and community-based management. Recognizing the value of blue carbon in both climate and fisheries policies can help reverse degradation trends and restore the integrity of these vital ecosystems.

Conservation and Restoration for Enhanced Carbon Sequestration

Mangrove and Seagrass Restoration Techniques

Restoration of blue carbon ecosystems plays a pivotal role in enhancing natural carbon sinks while also revitalizing fisheries. Effective restoration practices include:

Mangrove rehabilitation through planting native species in degraded areas, improving tidal flow, and protecting natural regeneration zones. Seagrass meadow restoration by replanting shoots or seeds, stabilizing sediments, and reducing turbidity to allow photosynthesis and recolonization. Salt marsh enhancement using sediment deposition and native grass transplantation in areas affected by erosion or human encroachment. Scientific restoration practices that account for local hydrology, species diversity, and community use patterns significantly increase success rates and long-term carbon storage.

Role of Fisheries Stakeholders in Conservation

Engaging fisherfolk and coastal communities in blue carbon conservation fosters local ownership and integrates ecological stewardship with economic well-being. These communities can play a vital role in monitoring and protecting sensitive habitats by participating in the surveillance of protected areas, planting and maintaining mangrove buffer zones, and managing community-based marine protected areas (CB-MPAs). Encouraging a shift toward low-impact fishing gear helps safeguard benthic ecosystems like seagrass beds, which are critical blue carbon reservoirs. Moreover, the traditional ecological knowledge (TEK) possessed by many fishers offers valuable insights for designing effective, culturally grounded conservation strategies that respect local livelihoods and enhance long-term sustainability.

Nature-Based Solutions and Community Engagement

Nature-based solutions (NbS) harness the resilience and regenerative capacity of ecosystems to address climate change and support sustainable development. In blue carbon ecosystems, NbS include integrated mangrove-fisheries co-management models, living shorelines that utilize natural vegetation to prevent coastal erosion instead of artificial seawalls, and blue-green infrastructure to enhance resilience in rapidly urbanizing coastal zones. Community engagement is essential to the success and longevity of these initiatives. Participatory approaches that offer tangible incentives such as eco-tourism opportunities, carbon credit schemes, or payments for ecosystem services can drive active local involvement and stewardship. By empowering local institutions and investing in community capacity for habitat restoration, NbS lay the groundwork for resilient coastal fisheries, enhanced carbon sequestration, and effective climate adaptation.

Policy Frameworks and Blue Carbon Credits

Global Frameworks: UNFCCC, IPCC, and Blue Carbon Initiative

At the international level, several frameworks have recognized the climate mitigation potential of blue carbon ecosystems:

- ✓ The United Nations Framework Convention on Climate Change (UNFCCC) encourages countries to include coastal ecosystems in their Nationally Determined Contributions (NDCs).
- ✓ The Intergovernmental Panel on Climate Change (IPCC) provides guidelines for the inclusion of wetlands in national greenhouse gas inventories.
- ✓ The Blue Carbon Initiative, led by Conservation International, IOC-UNESCO, and IUCN, promotes blue carbon conservation through research, policy, and finance. These frameworks are essential in standardizing methodologies and promoting the integration of blue carbon into global climate strategies.

Integration into National Climate Policy (India's NDCs)

Many countries have begun incorporating blue carbon into their national climate plans, although progress varies:

India's NDC (2022) mentions ecosystem restoration and sustainable coastal zone management but lacks a formal blue carbon policy. However, national programs like ICZM (Integrated Coastal Zone Management) and the National Mangrove Conservation Programme (NMCP) support activities that contribute to blue carbon enhancement. State-level efforts, particularly in Gujarat, Odisha, and Tamil Nadu, show growing interest in linking mangrove restoration with carbon sequestration and resilience-building. Formal recognition of blue carbon in India's climate accounting could unlock new avenues for finance, reporting, and cross-sectoral coordination.

Carbon Trading and Financing Mechanisms

The growing carbon market offers opportunities for blue carbon ecosystems through carbon credits from restored or conserved habitats. These operate under Voluntary Carbon Markets (VCMs) for corporate sustainability goals and Compliance Markets for regulatory targets. Standards like Verra's VCS and Plan Vivo support mangrove and wetland projects. Blue carbon credits provide financial incentives for conservation but must ensure equity, transparency, and environmental integrity to be effective.

Socio-Economic Implications

Livelihood Benefits and Co-Benefits of Blue Carbon Projects

Blue carbon initiatives provide significant socio-economic benefits for coastal communities, particularly those reliant on fisheries. Key livelihood advantages include job creation in restoration and monitoring, better fish catches from healthier ecosystems, and alternative income through carbon credit revenues. These projects also boost disaster resilience, helping reduce losses from storms and floods. When inclusively designed, they can further enhance local infrastructure, health, and education, especially if project revenues are reinvested within the community.

Equity, Gender, and Access to Carbon Finance

While blue carbon projects hold great promise, ensuring equitable access to their benefits remains a key challenge. Many fishers and community leaders lack awareness of carbon markets and financing mechanisms, limiting participation. **Gender disparities** persist, with women despite their active roles in post-harvest activities and conservation often excluded from decision-making and benefit-sharing. Additionally, **power imbalances** between local communities and external developers or financiers can undermine fairness. Overcoming these issues requires **capacity building, legal safeguards**, and **inclusive governance frameworks**. Gender-responsive, community-led approaches not only promote equity but also improve the long-term success of blue carbon initiatives.

Incentives for Fisherfolk and Local Communities

To ensure sustained community participation in blue carbon initiatives, it is essential to provide timely and tangible incentives. These include Payments for Ecosystem Services (PES) tied to restoration efforts, access to finance and technical support for sustainable fishing and aquaculture, and recognition through policies, subsidies, or green certification. Integrating blue carbon objectives into broader fisheries development and livelihood diversification plans can create a win–win strategy enhancing both climate resilience and socio-economic well-being for coastal communities.

Challenges and Knowledge Gaps

Despite growing interest, blue carbon initiatives face key challenges. There is a lack of ecosystem-specific data especially for seagrasses and salt marshes in tropical regionsalong with weak baselines and limited standardized measurement protocols. Many countries struggle with insufficient technical capacity for carbon accounting and long-term monitoring. Short project cycles and underused tools hinder data continuity and decision-making. Governance is fragmented across sectors like climate, fisheries, and finance, with poor coordination among stakeholders. To bridge these gaps, blue carbon must be integrated into national strategies (e.g., ICZM, fisheries co-management), supported by research, policy alignment, and inclusive stakeholder engagement.

CONCLUSION

Blue carbon ecosystems like mangroves, seagrasses, and salt marshes offer a powerful solution for climate change mitigation while supporting coastal fisheries. Their long-term carbon storage capacity and ecological value make them vital for both environmental and livelihood goals. However, challenges such as data gaps, weak governance, and limited awareness hinder progress. Strengthening conservation, ensuring community participation, improving coordination across sectors, and integrating blue carbon into national policies and carbon markets are essential steps toward realizing their full potential.

REFERENCES

Chlela, S., & Selosse, S. (2025). The co-benefits of integrating carbon dioxide removal in the energy system: A review from the prism of natural climate solutions. *Science of the Total Environment*, *976*, 179271.

Eos data analytics, (2024). https://eos.com/blog/carbon-sequestration/#ref-anchor-4

Guo, X., Liu, Y., Xie, T., Li, Y., Liu, H., & Wang, Q. (2025). Impact of Ecological Restoration on Carbon Sink Function in Coastal Wetlands: A Review. *Water*, *17*(4), 488.

Hershey, N. R., & Nandan, S. B. (2024). Preserving the Blue Carbon: The Role of Coastal Wetlands in Sustainable Development. In *Ecosystem Services Valuation for Sustainable Development* (pp. 213-236). Singapore: Springer Nature Singapore.

Hilmi, N., Chami, R., Sutherland, M. D., Hall-Spencer, J. M., Lebleu, L., Benitez, M. B., & Levin, L. A. (2021). The role of blue carbon in climate change mitigation and carbon stock conservation. *Frontiers in Climate*, *3*, 710546.

Huxham, M., Whitlock, D., Githaiga, M., & Dencer-Brown, A. (2018). Carbon in the coastal seascape: how interactions between mangrove forests, seagrass meadows and tidal marshes influence carbon storage. *Current forestry reports*, *4*, 101-110.

Islam, F. S. (2025). The Convergence of AI and Nature: Advancing Carbon Dioxide Capture, Removal, and Storage Technologies through Integrated Ecosystem-Based Strategies. *International Journal of Applied and Natural Sciences*, *3*(1), 90-130.

Jahan, F. (2025). A s ystematic Review of Blue Carbon Potential in Coastal Marshlands: Opportunities for Climate Change Mitigation and Ecosystem Resilience.

Liu, L., Du, N., YE, S., LI, X., WEI, J., GUO, Y., ... & GUO, W. (2025). Ecological Mechanisms of Carbon Sequestration in Vegetated Coastal Wetland Ecosystem: Exploring the Roles of Biodiversity and Environmental Changes. *Journal of*

Marine Environmental Engineering, *12*(1).

Moritsch, M. M., Gallagher, A. J., Harris, S. D., Howe, W., Fu, C., Bervoets, T., & Duarte, C. M. (2025). Carbon dynamics under loss and restoration scenarios in the world's largest seagrass meadow. *Scientific Reports*, *15*(1), 17071.

Preston, J., Debney, A., Gamble, C., Hardy, M. J., Underwood, G. J. C., Garbutt, A., ... & Zu Ermgassen, P. S. E. (2025). Seascape connectivity: evidence, knowledge gaps and implications for temperate coastal ecosystem restoration practice and policy. *npj Ocean Sustainability*, *4*(1), 1-29.

Rao, K., Ranjan, P., & Ramanathan, A. L. (2021). Estimation of blue carbon stock of mangrove ecosystem and its dynamics in relation to hydrogeomorphic settings and land use-land cover. *Mangroves: Ecology, Biodiversity and Management*, 177-199.

Thoni, T., & Rummukainen, M. (2025). Global governance of coastal ecosystems, the making of blue carbon: Co-production, abstraction and enactment. *Sustainable Environment*, *11*(1), 2502207.

Wang, L., & Fan, Y. (2025). Carbon sequestration technology in concrete: A review of mechanism, application and optimization strategy. *Journal of Building Engineering*, 111862.