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BLUE CARBON ECOSYSTEMS AS A TOOL FOR AQUATIC ENVIRONMENT MANAGEMENT

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Seagrass meadows, salt marshes, and mangroves are examples of blue carbon ecosystems, which are the most efficient natural ecosystems for the biosphere's long-term carbon sequestration and storage. In order to regulate atmospheric carbon dioxide levels, these coastal vegetation ecosystems are essential for maintaining fisheries, stabilising shorelines, enhancing water quality, and boosting coastal resilience. In recent years, blue carbon has become a central concept in the management of aquatic environments, linking climate change mitigation, sustainable resource use, and biodiversity preservation. This article reviews the concept of blue carbon, its primary ecosystems, carbon sequestration mechanisms, and its significance in aquatic environment management.

Aquatic environments, especially nearshore and coastal ecosystems, supply a variety of ecological and socioeconomic functions and are essential to global biogeochemical cycles. Nature-based solutions that meet human and environmental demands are becoming more and more popular as worries about climate change, coastal degradation, and diminishing fisheries. The capacity of blue carbon ecosystems to absorb and retain atmospheric carbon dioxide while preserving high levels of biodiversity and ecosystem production has led to their rise in popularity. In contrast to terrestrial carbon sinks, the majority of carbon in blue carbon ecosystems is stored in wet sediments with slow rates of decomposition, allowing for carbon storage over centuries to millennia. As a result, there is growing recognition for their protection and restoration which are an useful strategies for managing aquatic environments and reducing the effects of climate change.

Concept of Blue Carbon

The term "blue carbon" describes carbon that is sequestered, stored, and trapped by coastal and marine vegetation ecosystems, particularly seagrass meadows, salt marshes, and

mangroves. Through photosynthesis, these ecosystems absorb carbon dioxide from the atmosphere and store it in the biomass of plants and the sediments below them. This is because the organic matter is buried under anoxic conditions by tidal action and sediment deposition, which inhibits microbial decomposition, blue carbon systems are very effective. As a result, on a per-unit-area basis, carbon stores in blue carbon ecosystems frequently surpass those of terrestrial forests. The idea of "blue carbon" highlights the need of protecting coastal habitats as a natural climate solution in addition to their relevance for fisheries and biodiversity.

Major Blue Carbon Ecosystems

Mangrove ecosystems: Tropical and subtropical coastlines are home to mangroves, which refers to plants that can withstand salinity. Their massive root systems below the ground and dense biomass above ground make them one of the planet's most carbon-rich ecosystems. Thick soil layers rich in carbon are created when mangrove roots trap sediments and organic debris. Mangroves not only sequester carbon but also support local livelihoods, shield coasts from erosion and storm surges, and serve as fish and shellfish spawning grounds. Mangroves are crucial for managing aquatic environments because their loss due to deforestation and land conversion can release significant amounts of stored carbon back into the atmosphere.

Mangrove habitats are vital for the preservation of biodiversity and the productivity of fisheries. They serve as breeding and nursery grounds for a diverse range of molluscs, finfish, and crustaceans, many of which are significant to the economy. Before moving to offshore fishing grounds, juvenile fish and prawns utilise mangrove ecosystems for food and shelter. Mangrove habitats have abundant supply of organic matter and debris fosters leads to complex food webs that connect primary producers to higher trophic levels. Therefore, decreased fish catches and a loss of livelihoods for coastal fishing communities are frequently the outcomes of mangrove degradation. Anthropogenic activities like coastal development, aquaculture expansion, pollution, and deforestation pose a serious threat to mangrove ecosystems. In addition to causing habitat loss, the conversion of mangrove regions into urban infrastructure or shrimp farms releases significant amounts of carbon that were previously stored in the mangroves into the atmosphere, which converts them from carbon sinks to carbon sources. In order to preserve their blue carbon potential and guarantee the long-term sustainability of aquatic environments, sustainable mangrove management which includes protection, restoration, and community based conservation is crucial.



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Salt Marshes: Salt marshes are intertidal wetlands that are typically found in high latitude and temperate zones. They are dominated by grasses and herbaceous plants. These ecosystems store substantial amounts of carbon in their sediments and biomass below ground, and they are very productive. Regular tidal flooding encourages the deposition of sediments, whereas soggy soils slow down decomposition and decrease oxygen availability. Additionally, salt marshes improve the quality of coastal water by acting as natural filters by retaining pollutants and nutrients. They play an important part in integrated aquatic environment management strategies because of their ability to stabilise shorelines and support fisheries. By capturing pollutants, nutrients, and sediments that are carried out from the land to coastal waterways, they serve as organic biofilters. By removing excess nitrogen and phosphorus through microbial processes like denitrification and plant absorption, nearby estuarine and coastal environments experience less eutrophication and toxic algal blooms. Maintaining healthy fisheries and aquaculture operations depends heavily on this nutrient regulating role. Salt marshes also support rich bird populations, contributing to overall biodiversity conservation.

Salt marshes serve as organic barriers against erosion, wave action, and storm surges, protecting the coastline. Through they have vast root networks, the dense vegetation stabilises sediments and lowers wave energy. Salt marshes can absorb floodwaters and lessen damage to coastal infrastructure during heavy weather events. The importance of salt marshes in climate adaptation and reducing the risk of disasters is growing as a result of rising sea levels and stronger storms.



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Seagrass meadows: Seagrasses are blooming plants that grow in shallow coastal waters while submerged. Seagrass meadows contribute disproportionately to carbon burial despite their relatively tiny global area because of their high sediment trapping efficiency. By stabilising sediments and decreasing resuspension, seagrass rhizomes and roots improve carbon storage. Invertebrates, young fish, and endangered species like sea turtles and dugongs depend on these ecosystems for vital habitat. Seagrass meadow declines brought on by eutrophication, pollution, and physical disturbance can drastically lower fisheries productivity and blue carbon storage.

Additionally, seagrasses help stabilise sediment and protect the coast. Their root systems bind sediments and thus cause lesser erosion, leaves attenuate wave energy and increase water movement. This natural coastal defence mechanism aids in shielding shorelines from harms caused by waves and storm surges. Seagrass meadows are crucial for coastal ecosystem resilience and climate adaptation in the face of rising sea levels and more frequent storms. The loss of seagrass meadows disrupts their blue carbon function by lowering biodiversity and fisheries productivity as well as releasing stored carbon back into the atmosphere.



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Mechanism of Carbon Sequestration

Seagrass meadows, salt marshes, and mangroves are examples of blue carbon ecosystems that effectively sequester carbon through sedimentary and biological processes.

Photosynthesis, in which plants take up atmospheric or dissolved CO₂ and transform it into organic matter, is the first step in carbon sequestration. Roots and rhizomes, or below-ground biomass, account for a sizable amount of this carbon and are essential for long-term storage.

Sediment burial and trapping is another important method. Because dense vegetation slows water flow, fine sediments and suspended organic particles can settle and be buried. These sediments are usually anoxic and wet, which significantly slows down microbial breakdown and stores carbon for generations or even millennia. Methane generation is further suppressed by high sulphate concentrations in coastal sediments, which increases net carbon retention. While biogeochemical interactions between organic matter and minerals improve carbon stability, sediment stabilisation by roots and rhizomes stops stored carbon from oxidising and resuspending. Furthermore, some carbon is laterally transferred to nearby marine systems, where it might be buried in layers that are deeper. Blue carbon ecosystems are extremely efficient natural carbon sinks and useful instruments for managing aquatic environments and mitigating climate change because of these processes.

Role of Blue Carbon Ecosystems In Aquatic Environment Management

Blue carbon ecosystems are essential for the management of aquatic environments as they control the climate, enhance water quality, and promote ecosystem sustainability. These ecosystems mitigate climate change by acting as effective carbon sinks, storing significant amounts of carbon in biomass and sediments. They are crucial for managing water quality because they reduce eutrophication and toxic algal blooms in coastal waters by capturing sediments, nutrients, and contaminants from land-based runoff. Additionally, blue carbon ecosystems safeguard coastlines naturally by stabilising sediments, decreasing erosion, and protecting shorelines from storms, waves, and sea level rise.

Additionally, many commercially significant species use blue carbon ecosystems as nidification and feeding grounds, supporting fisheries and biodiversity. Aquatic biodiversity is preserved and fish stock sustainability is improved through their protection and restoration. Including blue carbon ecosystems in frameworks for coastal planning and management provides a practical, natural method of preserving thriving aquatic environments.

Benefits of Blue Carbon Ecosystems for Coastal Communities and Fisheries

Blue carbon habitats not only sequester carbon but also gives significant co-benefits to coastal populations and fisheries. Many commercially significant fish and shellfish species use them as nurseries and feeding grounds, which improves recruitment and creates sustainable fish stocks. This increases the productivity of fisheries. In addition to providing resources and chances for ecotourism, these ecosystems maintain traditional fishing, shellfish gathering, and small-scale aquaculture, all of which contribute to coastal livelihoods. By preventing erosion and storm damage to fishing villages, boats, and infrastructure, blue carbon environments naturally defend the coast. These habitats improve fisheries and aquaculture conditions by filtering nutrients and sediments, which improves water quality. Local involvement, resilience, and sustainable coastal management are further strengthened by community-based conservation and restoration of these ecosystems.

Threats to Blue Carbon Ecosystems

Natural and man-made hazards are putting more and more strain on blue carbon ecosystems, like seagrass meadows, salt marshes, and mangroves, which reduces their ability to store carbon and deliver ecosystem services. Coastal growth and land-use change, including port construction, urbanisation, industrial expansion, and tourism infrastructure, are among the

main risks. Habitat loss and the release of previously stored carbon into the atmosphere have resulted from the clearing or reclamation of large areas of salt marshes and mangroves for aquaculture and towns. The growth of aquaculture and irresponsible fishing methods, especially in tropical areas pose significant threat to blue carbon ecosystems. Destructive fishing practices, overuse of pesticides, and the conversion of mangroves into prawn farms damage vegetation and sediments, lowering biodiversity and deteriorating habitat structure. These actions impair the function of blue carbon ecosystems in regulating the climate and interfere with carbon burial processes. Blue carbon environments are also negatively impacted by pollution and nutrient enrichment. Eutrophication, hypoxia, and decreased light penetration are caused by increased nutrient and pollutant loads in coastal waterways brought on by sewage discharge, plastic trash, industrial effluents, and agricultural runoff. Because increasing turbidity and algae development restrict photosynthesis and result in widespread die-offs, seagrass meadows are particularly vulnerable to poor water quality.

Blue carbon habitats are at the risk of pressures associated with climate change. In addition to stressing seagrasses and related creatures, rising sea levels have the potential to submerge salt marshes and mangroves more quickly than they can deposit sediments. Storms that occur more frequently and with greater intensity have the potential to physically harm vegetation and erode sediments, releasing stored carbon. Degradation of ecosystems is also a result of inadequate management and bad governance. Conservation efforts are hampered by a lack of awareness, a lack of enforcement of coastal legislation, and the alienation of local groups from decision-making. Blue carbon habitats continue to deteriorate in the absence of integrated coastal zone management and restoration projects, reducing their ecological advantages and functions.

Management and Policy Implications

The protection of current habitats and the rehabilitation of damaged regions must be given top priority in an integrated, ecosystem-based strategy for the effective management of blue carbon ecosystems. Coastal protection services, fisheries production, and carbon reserves are all maintained through the preservation of mangroves, salt marshes, and seagrass meadows. Nature-based approaches to mitigating climate change are strengthened when blue carbon habitats are incorporated into environmental and climate policies, such as national greenhouse gas inventories and climate action plans. To strike a balance between conservation and sustainable coastal development, policy frameworks like Marine Spatial Planning and

Integrated Coastal Zone Management are crucial. For successful implementation, community involvement, sound governance, and ongoing research and monitoring are essential. Blue carbon ecosystems are more resilient and sustainable over the long run when local livelihoods are supported and policies are aligned across sectors.

Conclusion

Blue carbon ecosystems have high capacity to sequester carbon and provide a variety of ecosystem services, blue carbon ecosystems like seagrass meadows, salt marshes, and mangroves are essential tools for managing aquatic environments. They are essential in reducing the effects of climate change and in promoting fisheries, biodiversity preservation, water quality enhancement, and coastal protection. However, habitat loss and carbon emissions from human activity and climate change are posing an increasing threat to these ecosystems. It is crucial to preserve and restore blue carbon ecosystems via community involvement, supportive legislation, and coordinated management. For long-term environmental and socioeconomic resilience, integrating blue carbon into aquatic and coastal management plans offers a natural, sustainable effects.

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