**ROLE OF MANGROVES IN CARBON SEQUESTRATION**

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 **Abstract:**

Mangrove forests are extremely productive, producing carbon at rates comparable to tropical humid forests. Mangroves allot more carbon belowground than terrestrial trees and have larger below-to-above-ground carbon mass ratios. The majority of mangrove carbon is retained as huge pools in soil and dead roots. Despite occupying just 0.5% of the worldwide coastal area, mangroves contribute 10- 15% (24 Tg C y-1) to coastal sediment carbon storage and export 10-11% of particulate terrestrial carbon to the ocean. Their disproportionate contribution to carbon sequestration is becoming increasingly recognised as a means of conservation and restoration, as well as a strategy to help reduce greenhouse gas emissions. Potential carbon losses due to deforestation (90-970 Tg C y-1) are of immediate concern since they are larger than the rates of carbon storage in these ecosystems. Large pools of dissolved inorganic carbon in deep soils, pushed via subterranean channels to surrounding streams, are a significant source of carbon loss, accounting for up to 40% of yearly primary output.

**Keywords:** Carbon sequestration, Mangrove ecosystem, Sedimentation, Wetland.

**Introduction**

The mangrove forests in tropical and subtropical areas are regarded as a distinctive and intricate main component of coastal zones. They stand for transitional environments where freshwater, land, and the ocean intersect. Typically, evergreen trees or shrubs that grow along coasts, saline estuaries, or delta ecosystems make up their primary vegetation. Mangrove habitats are easily identified since they are found on tideland mud or sand flats that get daily inundation from the sea. They are essential for maintaining the viability of coastal ecosystems as well as providing significant socioeconomic advantages to coastal communities.

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| Global distribution of mangroves , largely lying between latitudes 5ºN and 5ºS (Giri et al. 2010) |
| **Fig. 1 -** Global distribution of mangroves |

Mangroves grow in swampy environments where there is little oxygen present below a few centimetres of mud. Aerial roots produced by mangrove trees serve the three purposes of supporting elder plants, facilitating gas exchange, and absorbing water. More than one-third of the world's mangroves are found in Southeast Asia, which also has the richest species composition. To compensate for the low levels of oxygen, numerous mangrove trees, such as *Sonneratia* spp., *Avicennia* spp., *Brugueira* spp., *Ceriops* spp., and *Rhizophora* spp., grow there. Develop aerial root systems above the anaerobic substrate to enable root lenticels to exchange gas (Tomlinson, 1986; FAO, 1985). Tropical coastal waters may benefit from vital nutrients and organic carbon provided by mangrove forests (Alongi, 1996). Mangroves are found all across the world, primarily between latitudes 5o N and 5o S (Giri *et al*. 2011).

**Carbon cycle in mangrove ecosystem**

 In low latitudes, mangrove ecosystems also supply a disproportionate amount of various kinds of carbon to the coastal ocean. Mangroves contribute roughly 5% of net primary production as well as 12% of ecosystem respiration, although occupying only 1.5% of the world's subtropical and tropical coastal ocean area (Alongi, 2020). The biggest organic carbon (CORG) stores of any tropical terrestrial or marine ecosystem can be found in mangrove forests.

These significant levels of organic carbon are a result of the high primary productivity of mangroves, which is comparable to that of coral reefs and tropical wet evergreen forests, as well as the fast rates of soil deposition on the forest (Donato *et al.,* 2011; Alongi, 2014). Macroalgae that colonise aboveground roots and microalgae that cover some of the forest floor contribute the second-largest amount of carbon to the atmosphere. Transport and deposition of materials from upstream and the nearby coastal zone account for the third-largest carbon input. The position of forests and the pace of river flow in proportion to the strength of tidal pulses determine the respective contributions of terrestrial and marine sources. Over the long run, the majority of carbon is created in situ and stored belowground, ultimately as peat (Krauss *et al.,* 2010, Ray *et al*.*,* 2011, Osland *et al*.*,* 2012).

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| **Fig. 2- C**arbon and nutrient cycling within mangrove and sandflat ecosystems (Bulmer *et al.,* 2017) |

**Sedimentation**

Mangroves aggressively and passively absorb carbon from tidal water containing fine particles from the near shore ocean and from river water discharged from upstream. Mangroves that grow in soft sediment deposits tend to accumulate fine sediment particles. Numerous researchers have identified the processes by which sediments and the related carbon accrete and estimated the amount of deposition onto the forest floor. The tidal prism, tidal pumping and trapping, baroclinic circulation, flocculation, microbial mucus formation, and physicochemical mechanisms that disaggregate flocs of cohesive sediment regulate the transit of suspended solids in overlying water (Wolanski, 1995). Sedimentation is significantly influenced by the size, form, and distribution patterns of trees (Mazda *et al.,* 1997, 1999). The flow around the trees creates turbulent waves that keep flocs stationary when tides approach the forest. A brief period of particle settling happens as the tide shifts from high to low and the waters become calm. This is made possible because the particles attach to mucus on surfaces. Larger particles with quicker settling velocities are produced by particle flocculation, and high tree densities additionally impede water velocity.

The accuracy of different soil accretion measurement techniques varies; some are quite incorrect (such as the mass balance approach), while others only measure short-term accumulation rates. Measurement of the vertical reduction in radioactive element concentrations from atomic bomb fallout (excess 210Pb and 137Cs) is the least controversial technique, and when combined with soil organic carbon concentrations, it can offer a chronology of sedimentation over the last century or more. In mangroves, the rate of soil accretion ranges from 0.1 to 10.0 mm/yr, with an average of 5 mm/yr (Alongi 2012). Net erosion and significant accretion are observed in a few forests. The primary factor influencing the rate of sedimentation is the frequency of tidal upwelling (Adame *et al*., 2010); as upwelling frequency decreases with increasing surface elevation, particles have less opportunity to accumulate, so forests farther from the sea interaction less soil accretion than forests closer to mean sea level (Cahoon et al. 2006). Some forests may experience stronger vertical accretion than particle accretion as a result of belowground root growth, surface algal mats, and litter accumulation (McKee, 2011).

In the majority of the tropics, mangrove sedimentation is now keeping up with local sea level rises (Alongi, 2008). This is not the case in the Caribbean and South Atlantic (Lopez-Medell"n *et al.,* 2011, McKee, 2011), nor is it the case on Pacific islands (Krauss *et al.,* 2010), where sedimentation varies significantly in connection to changes in climate variability. Net sedimentation is significantly influenced by storms, hurricanes, and other climatic disturbances in mangrove ecosystems (Smith *et al.,* 2009, Whelan *et al.,* 2009, Smoak *et al.,* 2013).

**Carbon sequestration**

Mangroves, shallow underwater coral reefs, and sea grasses dominate coastal habitats, which are small transitional zones between terrestrial and oceanic areas. Numerous factors, in particular the rates of primary productivity and decomposition, influence the rate at which carbon cycles through the ecosystem. Environmental factors like temperature and precipitation have a significant impact on both processes. Autotrophs from terrestrial and coastal environments absorb atmospheric CO2 through photosynthesis by diffusion through leaf stomata, integrating the CO2 into their biomass as a necessary component of the carbon cycle. As a result of respiration, some biomass is used as a source of carbon by consumers. Terrestrial and coastal ecosystems are connected to the atmosphere through photosynthesis and respiration. The release of carbon during respiration counteracts the carbon loss caused by photosynthesis.

Although photosynthesis and respiration play a significant role in ocean ecosystems, the interaction of CO2 with water makes the carbon cycle more complicated. Carbonate and dissolved CO2 react to make bicarbonates and carbonate ions when they are combined with water to create carbonic acid. Bicarbonates are transformed back to CO2 via the photosynthesis process, which uses CO2. As a result, bicarbonates act as a storage space for CO2, and some aquatic autotrophs can utilise dissolved bicarbonates as a direct supply of carbon. Mangrove forests may have a significant impact on the carbon cycle by sequestering atmospheric CO2 and depositing it as carbon in organic materials and soils. Mangrove forests have the ability to store a significant quantity of carbon, and they might be the largest carbon stores in coastal zones because nearly half of a tree's biomass is comprised up of carbon.

**Services and Functions Provided by Mangroves**

1. **Resources and Socio-economic Contribution**

Mangrove forests cover just around 8% of the world's coastline (World Resources Institute, 2000). Nonetheless, despite their diminutive size, they serve critical functions in the global environment. Mangrove forests have traditionally been used by indigenous and local people in many developing nations in the tropics for a number of reasons. For ages, they have relied on mangrove waterways for fish, prawns, crabs and mollusks, and they will continue to rely on these items from mangrove environments. Mangroves also supply a wide range of timber for building, fuel, charcoal, poles, fishing gear, and so on. Other mangrove products include fruit, honey, pulp, tannin, and traditional remedies made from various portions of the plants.

1. **Ecological and Biodiversity Conservation**

A lot of studies have identified mangroves' crucial ecological services and biodiversity protection. Providing coastal protection from storms, waves, and water currents, therefore minimising erosion and floods, is one of the most well-known and debated roles of mangroves. Mangroves also play a vital role in preventing saltwater intrusion. Because mangrove forests are located in hurricane and typhoon-prone tropical zones, they have the capacity to provide coastal stabilisation and storm protection. Prop roots, which are firmly embedded in mud, aid in soil consolidation and stability, providing a natural kind of coastal protection. According to Danielsen et al. (2005), a 100-meter-wide region of mangroves with a density of two or three trees per metre might reduce wave height by up to 70%. Although natural disasters might destroy some young mangroves, adult mangroves can survive due to their complex root systems.

Several research have been conducted to demonstrate the positive impact of mangrove natural characteristics in reducing the damage caused by extreme natural phenomena such as tsunami. Many papers emphasised mangrove habitats since they are one of the most dominating ecosystems in coastal areas, particularly in tsunami-affected areas. According to Dahdouh-Guebas (2006), mangrove-covered regions in the Andaman Islands got just 7% of the damage, but degraded mangrove areas sustained an estimated 80% to 100% of the damage. Ghosh (2005) observed that in southern India with extensive mangroves, fewer people had been injured by a tsunami and less property was damaged than in places without mangroves. In Malaysia, Emmanuel and John (2005) observed that the presence of mangrove forests on Penang Island reduced the impact of the waves.

 The value of mangrove habitats in biodiversity conservation remains a hot subject. Mangroves provide a safe haven for spawning, nursery, and feeding for juvenile fish and crustaceans that spend a portion of their lives in these ecosystems. Mangroves contribute to fisheries in a variety of useful ways. These include supplying nutrients to maintain an intricate food web within the mangroves, exporting nutrients offshore to improve fisheries, and giving habitat to wildlife for protection and nursery grounds. Mangroves also provide habitat for a diverse range of animals, amphibians, and reptiles. Many other creatures, including birds and marine and terrestrial mammals, use or frequent the mangroves on a daily or seasonal basis for roosting, breeding, or foraging (Hamilton and Snedaker, 1984). The diversity of flora and fauna in mangrove habitats allows for scientific research as well as tourism potential. Mangroves play a crucial part in the development of healthy coastal ecosystems. According to Adeel and Pomeroy (2002), leaf litter from mangroves is a primary source of nutrients for trophic food because the ecosystems create a high productivity of organic matter. For example, the average of leaf litter input rate is 100 g m−2 year−1 despite relatively low standing biomass accumulation averaged at 1,500 g m−2. The high productivity is often attributed to high litter degradation rates and efficient recycling of nutrients.

**Future perspectives**

The importance of mangroves is currently being emphasised in climate change efforts like REDD+ and blue carbon. Blue carbon projects need to solve the following specific actions and problems, according to McLeod *et al.* (2011) and Alongi (2011).

* Considering factors that are believed to affect carbon sequestration rates, such as the frequency of wave action, primary productivity, and rates of exchange with nearby ecosystems, when choosing a site is important. Preferably, the site should be on the seaward edge. It is necessary because, all mangrove forests do not accumulate carbon.
* Determine a set of indicators that may be used to quickly assess changes in carbon storage and fluxes by measuring and mapping the geographical and temporal fluctuations in carbon sequestration and burial rates, linking these factors to environmental and biological forces.
* In order to promote modifications in restoration/rehabilitation approaches and to identify changes in land use, remote sensing and aerial photography may be helpful.
* Standardization of techniques for calculating carbon stocks and burial rates in soil and biomass.
* Planting with a variety of species to increase ecosystem productivity, food web connectedness, and biodiversity.
* Studies should be carried out simultaneously to evaluate the circumstances that decide whether or not climate change consequences, such as sea level rises, will occur.

Although there are many unknowns regarding future ocean climate scenarios, it is necessary to assume that regional changes in ocean circulation, temperature, salinity and pH patterns, and sea level will likely have a significant impact on the capacity of mangroves to store carbon (Sen and McNeil, 2012).

**References**

Adame, M. E., Neil, D., Wright, S.F. and Lovelock, C. E. 2010. Sedimentation within and among mangrove forests along a gradient of geomorphological settings. *Estuar. Coast. Shelf Sci.* 86: 21–30.

Adeel, Z., Pomeroy, T. (2002). Assessment and management of mangrove ecosystems in develop ing countries. Trees, 16, 235–2.

Alongi, D. M., 1996. The dynamics of benthic nutrient pools and fluxes in tropical mangrove forests. *Journal of Marine Research*, 54, 123–148.

Alongi, D. M., 2008. Mangrove forests: resilience, protection from tsunamis, and responses to global climate change. *Estuar. Coast. Shelf Sci.* 76: 1–13.

Alongi, D. M., 2011. Carbon payments for mangrove conservation: ecosystem constraints and uncertainties of sequestration potential. *Environmental science & policy*, 14(4), 462-470.

Alongi, D. M., 2012. Carbon sequestration in mangrove forests. *Carbon management*, *3*(3), 313-322.

Alongi, D. M., 2014. Carbon cycling and storage in mangrove forests. *Annu. Rev. Mar. Sci*. 6, 195–219.

Alongi, D. M., 2020. Carbon cycling in the world’s mangrove ecosystems revisited: Significance of non-steady state diagenesis and subsurface linkages between the forest floor and the coastal ocean. *Forests*, 11(9), 1-17.

Alongi, D. M., De Carvalho, N. A., Amaral, A. L., Da Costa, A., Trott, L. A. and Tirendi, F., 2012. Uncoupled surface and belowground soil respiration in mangroves: implications for estimates of dissolved inorganic carbon export. *Biogeochemistry,* 109: 151–62.

Bouillon, S., Borges, A. V., Castañeda‐Moya, E., Diele, K., Dittmar, T., Duke, N. C., Kristensen, E., Lee, S. Y., Marchand, C., Middelburg, J. J. and Rivera‐Monroy, V. H., 2008. Mangrove production and carbon sinks: a revision of global budget estimates. *Global biogeochemical cycles*, 22(2).

Bulmer, R. H., Schwendenmann, L., Lohrer, A. M. and Lundquist, C. J., 2017. Sediment carbon and nutrient fluxes from cleared and intact temperate mangrove ecosystems and adjacent sandflats. *Science of the Total Environment*, 599, 1874-1884.

Cahoon, D. R., Hensel, P., Spencer, T., Reed, D., McKee, K. L. and Saintilan, N., 2006. Coastal wetland vulnerability to relative sea-level rise: wetland elevation trends and process controls. *In Wetlands and Natural Resource Management*, 1093–105.

Danielsen, F., Sørensen, M.K., Olwig, M.F., Selvam, V., Paris F., Burgess, N.D., Hiraishi, T., Karunagaran, V.M., Rasmussen, M.S., Hansen, L.B., Quarto., A., Suryadiputra, N. (2005). The Asian tsunami: A protective role for coastal vegetation. Science, 310, 5748, 643.

Donato, D. C., Kauffman, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M. and Kanninen, M., 2011. Mangroves among the most carbon-rich forests in the tropics. *Nat. Geosci.*, 4, 293–297.

Emmanuel, M., John, E. (2005). Counting the cost. The New Straits Times. 9 January 2005.

FAO (1985). Mangrove management in Thailand, Malaysia and Indonesia. *FAO Environment Paper, Rome*, pp. 60.

Ghosh, N. (2005). Singapore not safe from tsunami. The New Straits Times, 15 October 2005.

Giri, C., Ochieng, E., Tieszen, L. L., Zhu, Z., Singh, A., Loveland, T., Masek, J. and Duke, N., 2011. Status and distribution of mangrove forests of the world using earth observation satellite data. *Global Ecology and Biogeography*, 20(1), 154-159.

Hamilton, L.S., Snedaker, S.C. (Eds.) (1984). Handbook for mangrove area management. IUCN/

Krauss, K. W., Cahoon, D. R., Allen, J. A., Ewel, K. C., Lynch, J. C. and Cormier, N., 2010. Surface elevation change and susceptibility of different mangrove zones to sea level rise on Pacific high islands of Micronesia. *Ecosystems*, 13:29–43.

Lal, R., 2008. Carbon sequestration. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363(1492), 815-830.

Lopez-Medeliın, X., Ezcurra, E., Gonzalez-Abraham, C., Hak, J., Santiago, L. S. and Sickman, J. O., 2011. Oceanographic anomalies and sea-level rise drive mangroves inland in the Pacific coast of Mexico. *J. Veget. Sci.* 22:143–51.

Mazda, Y., Kanazawa, N. and Kurokawa, T., 1999. Dependence of dispersion on vegetation density in a tidal creekmangrove swamp system. *Mangroves Salt Marshes,* 3:59–66.

Mazda, Y., Wolanski, E., King, B., Sase, A., Ohtsuka, D. and Magi, M., 1997. Drag force due to vegetation in mangrove swamps. *Mangroves Salt Marshes*, 1:193–98.

McKee, K. L., 2011. Biophysical controls on accretion and elevation change in Caribbean mangrove ecosystems. Estuar*. Coast. Shelf Sci.* 91:475–83.

Mcleod, E., Chmura, G.L., Bouillon, S., Salm, R., Björk, M., Duarte, C.M., Lovelock, C.E., Schlesinger, W.H. and Silliman, B.R., 2011. A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. *Frontiers in Ecology and the Environment*, 9(10), 552-560.

Nyanga, C., 2020. The role of mangroves forests in decarbonizing the atmosphere. In *Carbon-Based Material for Environmental Protection and Remediation*.

Osland, M. J., Spivak, A. C., Nestlerode, J. A., Lessmann, J. M., Almario, A. E., Heitmuller, P. T., Russell, M. J., Krauss, K. W., Alvarez, F., Dantin, D. D. and Harvey, J. E., 2012. Ecosystem development after mangrove wetland creation: plant–soil change across a 20-year chronosequence. *Ecosystems*, 15(5), 848-866.

Ray, R., Ganguly, D., Chowdhury, C., Dey, M., Das, S., Dutta, M. K., Mandal, S. K., Majumder, N., De, T. K., Mukhopadhyay, S. K. and Jana, T. K., 2011. Carbon sequestration and annual increase of carbon stock in a mangrove forest. *Atmospheric Environment*, 45(28), 5016-5024.

Sanders, C. J., Smoak, J. M., Naidu, A. S., Sanders, L. M. and Patchineelam, S. R., 2010. Organic carbon burial in a mangrove forest, margin and intertidal mud flat. *Estuarine, Coastal and Shelf Science*, 90(3), 168-172.

Sen Gupta, A. and McNeil, B., 2012. Variability and change in the ocean. *The future of the world’s climate*, 141-165.

Smith, S. V. and Gattuso, J. P., 2009. Coral reefs. In The Management of Natural Coastal Carbon Sinks, *Gland, Switz.: Int. Union Conserv. Nat. Nat. Res.* 39–45.

Smoak, J. M., Breithaupt, J. L., Smith III, T. J. and Sanders CJ. 2013. Sediment accretion and organic carbon burial relative to sea level rise and storm events in two mangrove forests in Everglades National Park. *Catena,* 104: 58–68.

Suratman, M.N., 2008. Carbon sequestration potential of mangroves in Southeast Asia. In *Managing Forest ecosystems: The challenge of climate change,* 297-315.

Tomlinson, P. B., 1986. The botany of mangroves. *Cambridge University Press, Cambridge*, 419 pp.

UNESCO/UNEP. East-West Centre, Honolulu, HI.

Whelan, K. R. T., Smith III, T. J., Andersen, G. H. and Ouellette, M. L., 2009. Hurricane Wilma’s impact on overall sediment elevation and zones within the sediment profile in a mangrove forest. *Wetlands,* 29:16–23.

Wolanski, E., 1995. Transport of sediment in mangrove swamps. Hydrobiologia, 295: 31–42.

World Resources Institute (2000). World resources 2000–2001. People and ecosystems: The fray ing web of life. Elsevier Science, 389 pp.