



The ecological significance and environmental influence of mangrove ecosystems

V Mohan Raj*

Department of Zoology, Sir Theagaraya College, Chennai, Tamil Nadu, India

Abstract

Mangrove forests, apart from their carbon sequestration and coastal protection benefits, provide a wide range of ecosystem services to people in tropical developing countries. Local people living in and around forests in the developing tropics also depend heavily on these mangrove ecosystem services for their livelihoods. The mangrove forests help to stabilize shorelines and reduce the devastating impact of natural disasters such as tsunamis and hurricanes. They also serve as breeding and nursing grounds for marine finfish and shellfish species of commercial importance. Mangroves serve as vital components of coastal health, acting as biological buffers that stabilize shorelines and foster rich biodiversity. By sequestering significant amounts of carbon and shielding inland areas from storm surges, these unique intertidal forests play a critical role in mitigating climate change and maintaining marine productivity.

Keywords: Coastal water, estuary, biodiversity, marine, fishes

Introduction

Approximately one-fifth of India's citizenry resides along its coastlines. As the century progresses, these maritime zones are evolving into critical engines of economic growth, likely triggering significant inward migration from the hinterlands (Nayaka *et al.*, 2012) ^[12]. This shift is driven by rapid urbanization and intensified infrastructural expansion, which have, in turn, exerted severe ecological pressure on these fragile coastal environments (Mohan *et al.*, 2013; Vyas *et al.*, 2025) ^[10, 19].

Mangroves are specialized, salt-tolerant woody plants that flourish in the intertidal zones of tropical and subtropical latitudes. These resilient ecosystems have adapted to thrive in saline or brackish environments characterized by challenging conditions, including shifting tides, high concentrations of salt, and hypoxic, oxygen-poor soils. Typically situated at the junction of marine and terrestrial landscapes such as estuaries and shorelines mangrove forests exhibit lower botanical species diversity compared to the lush tropical rainforests. However, they serve as vital habitats for a vast array of biological life.

Botanically, these plants are categorized into "true mangroves," which are restricted to intertidal regions, and "mangrove associates," which can survive in both littoral and inland settings. These ecosystems rely on the influx of terrestrial freshwater and tidal currents to provide essential nutrients and sediment deposits, which are crucial for substrate stability. As noted by Kathiresan (2003) ^[8], mangroves are recognized as highly productive, renewable natural assets.

Globally, mangroves span an estimated 18 million hectares across 118 nations (Spalding, 1997) ^[17]. The most robust and diverse concentrations are found in South and Southeast Asia, which account for 42% of the world's total. India possesses roughly 3.1% of global mangrove cover, ranking as the third-largest region in Asia after Indonesia (63%) and Bangladesh (8%). Currently, India's 4,461 square kilometres of mangrove forests are spread across its 7,500-kilometre coastline, with 59.6% located on the eastern seaboard, 27% along the western coast, and the remaining 13.3% found throughout the Andaman and Nicobar Islands.

Importance of mangroves

The ecological and socio-economic contributions of mangrove ecosystems are profound and multifaceted. These coastal forests act as vital stabilizers by promoting sediment accumulation and reinforcing shorelines (Satyanarayana *et al.*, 2011) ^[16]. Furthermore, they serve as natural filtration systems, capturing heavy metals and excess nutrients to enhance water quality (Alongi, 1996) ^[1], a service that is critical for the health and clarity of adjacent seagrass meadows and coral reef communities. Beyond their environmental utility, select mangrove species are noted for their ethnobotanical and medicinal applications (Bandaranayake, 1998) ^[3].

These habitats also function as biodiversity hotspots, sheltering a wide array of avian, mammalian, and reptilian species (Ramasubramanian *et al.*, 2006) ^[14], while offering essential spawning and developmental grounds for various fish, amphibians, crustaceans, and shellfish (Nayak and Bahuguna, 2001) ^[11]. Specifically, mangroves are indispensable nurseries for juvenile fish, who are drawn to these areas by the abundance of food, reduced threat of predation, and the complex physical structure of the root systems (Laegdsgaard and Johnson, 2001) ^[9].

In addition to their biological significance, mangroves serve as a protective barrier, shielding coastal regions from the destructive forces of typhoons, tsunamis, and cyclones (Bahuguna *et al.*, 2008). Finally, they play a critical role in global climate regulation as high-capacity carbon sinks. Mangroves possess a remarkable ability to sequester carbon, outperforming tropical forests such as the Amazon by capturing carbon two to four times faster and storing three to five times more carbon per unit of area.

Distribution of Mangroves

According to the 2021 India State of Forest Report (ISFR), India's mangrove forests span 4,992 square kilometers, accounting for 0.15% of the nation's landmass. Research by Shah and Ramesh (2022) indicates that these ecosystems are unevenly distributed: the eastern seaboard hosts 57% of the total cover, the western coast contains 31%, and the Andaman and Nicobar Islands hold the final 12%.

In terms of regional rankings, West Bengal leads the country in mangrove prevalence, with Gujarat and the Andaman and Nicobar Islands following in second and third place, respectively (Bhagora, 2021; ISFR, 2021) ^[4]. Collectively, India accounts for 3% of the total mangrove population in South Asia, with a clear density bias toward the east coast over the west. Globally, West Bengal's Sundarbans represent the most extensive mangrove forest, while the second-largest mangrove habitat in India is found at Bhitarkanika, a region formed by the confluence of the Brahmani and Baitarani river deltas (Bhagora, 2021) ^[4].

Adaptations and Characteristics of Mangrove Ecosystems

Coastal wetlands dominated by halophytic trees and shrubs define mangrove ecosystems, which predominantly flourish across tropical and subtropical coastlines in areas subject to regular tidal immersion. These distinctive habitats have evolved to prosper in saline or brackish aquatic environments, demonstrating remarkable resilience against challenging conditions including rhythmic tidal oscillations, elevated salt concentrations, and oxygen-depleted substrates. Mangrove woodlands serve as vital transitional zones linking terrestrial and marine environments, offering sanctuary to diverse assemblages of aquatic and land-dwelling organisms. Survival within these dynamic systems demands that mangrove species develop sophisticated physiological mechanisms to address the interconnected challenges of oxygen deprivation, hypersaline conditions, and recurrent seawater inundation.

Considerable variation exists in the strategies employed by different taxonomic groups to navigate these environmental pressures. Subtle differences in microtopography, salinity gradients, and inundation patterns within mangrove landscapes can result in markedly distinct adaptive responses among co-occurring species. Specialized aerial root systems represent a particularly critical adaptation, facilitating atmospheric gas exchange in waterlogged, compact soils where oxygen availability is severely limited. Additionally, these subterranean networks have evolved robust structural architectures, including extensive lateral buttressing, to stabilize the substantial vegetative biomass positioned above ground level. According to research documented by Bindu in (2000) ^[5], these morphological specializations enable mangroves to maintain functional integrity under conditions that would prove fatal to less adapted plant forms. The diverse morphological and physiological modifications observed across mangrove taxa include the development of specialized excretory glands for salt regulation, buttressed root systems for mechanical stability, viviparous reproductive strategies, and leaf modifications to reduce transpiration losses under high evaporative demand.

- **Stilt Roots:** Primarily characteristic of *Rhizophora* species, these complex, branching aerial root systems extend up to 3 meters above the soil. Their primary function is to act as a structural scaffold, anchoring the tree against the powerful mechanical forces of high winds and tidal currents.
- **Aerial Roots:** These thin, pliable appendages hang down from the tree's crown without making contact with the ground. While commonly associated with *Rhizophora*, they are also present in *Avicennia* species.

- **Plank Buttresses:** Found in species like *Bruguiera* and *Ceriops*, these are plate-like, flanged protrusions at the base of the trunk. They serve a dual purpose: expanding the base's surface area for greater stability and improving oxygen exchange at the root level.
- **Surface Roots:** While infrequent in many mangrove varieties, some species like *Ceriops tagal* feature plank buttresses that transition into irregularly flattened surface roots. By remaining above the soil, these roots facilitate essential gas exchange in oxygen-poor substrates (Bindu, 2000) ^[5].
- **Pneumatophores:** These specialized vertical roots emerge from the underground cable root system to poke above the mud. They appear in various forms, including knobby, tuberous, knee-like (geniculate), or slender pencil-shaped structures.
- **Vivipary:** To survive in harsh saline environments, some mangroves exhibit vivipary, where seeds germinate while still attached to the parent plant. This allows the seedling to anchor itself rapidly into the mud once it detaches.
- **Succulence:** Many mangroves have developed succulent tissues, a physiological reaction used to manage high internal chloride concentrations.
- **Salt Tolerance:** To thrive in high-salinity waters, mangroves employ advanced mechanisms, such as specialized root filters and leaf glands designed to excrete excess salt.
- **Prop Roots:** These serve as an essential defensive mechanism, offering structural reinforcement to protect the tree from storm surges and tidal oscillations.
- **Carbon Sequestration:** Mangroves represent some of the planet's most productive carbon sinks, serving as a critical natural tool in the global effort to combat climate change.

Biodiversity of mangroves in India

Serving as vital transition zones between terrestrial and marine environments, mangroves are centers of immense biological variety, establishing them as focal points for environmental study and preservation. India hosts a significant portion of these lush forests, spanning its eastern and western seaboards as well as its island archipelagos (Nisha *et al.*, 2022) ^[13]. Key Indian mangrove landscapes include:

- **Sundarbans (West Bengal):** Renowned as the globe's most expansive mangrove forest and a sanctuary for the Royal Bengal Tiger.
- **Mahanadi, Godavari, and Krishna Deltas (Odisha/Andhra Pradesh):** Vital for safeguarding the coast and teeming with varied species.
- **Pichavaram Mangroves (Tamil Nadu):** Recognized as one of the nation's most substantial mangrove networks.

- **Bhitarkanika Mangroves (Odisha):** A designated Ramsar wetland famous for its population of estuarine crocodiles.
- **Gulf of Kutch (Gujarat):** A rare example of mangrove growth within a dry, arid climate.
- **Andaman & Nicobar Islands and Lakshadweep:** Essential coastal zones that offer critical refuge for a wealth of marine organisms.

The Multifaceted Value of Mangroves Beyond their beauty, mangroves provide indispensable ecological, financial, and climate-mitigation services. They function as natural shields, powerful carbon stores, and the backbone of local economies.

- **Coastal Shielding:** By blunting the force of tsunamis, cyclones, and storm surges, they act as frontline defenses. For instance, Odisha's mangrove cover played a pivotal role in mitigating the devastation caused by Cyclone Amphan in 2020.
- **Climate Regulation:** These ecosystems are highly efficient carbon sinks, sequestering up to four times the amount of carbon found in traditional land-based forests.
- **Biological Sanctuaries:** They serve as essential nurseries and nesting sites for diverse populations of birds, crustaceans, and fish.
- **Economic Sustainability:** Local populations depend heavily on these forests for forestry products, honey harvesting, and artisanal fishing.
- **Tourism and Industry:** Mangrove regions serve as hubs for sustainable ecotourism, while their role in hatcheries underpins both small-scale and commercial fishing. Remarkably, the Gulf of Kutch mangroves contribute to roughly 40% of the total marine fish harvest in Gujarat.
- **Environmental Purification:** Often described as the "Kidneys of the Planet," these mangroves play an essential role in cleansing coastal waters by trapping heavy metals, organic pollutants, and excess nutrient runoff.

Mangrove Restoration

Following the catastrophic 2004 tsunami, there was an immediate, widespread push to rehabilitate mangrove forests, largely because these ecosystems had proven effective in buffering inland areas against surging waters. While the process of replanting might seem straightforward and economical, it is actually a highly intricate undertaking. Experts at the IUCN (2006) emphasize that successful restoration requires a sophisticated ecological balance rather than a haphazard assembly of vegetation and sediment; unfortunately, the reliance on monoculture planting has led to the downfall of many initiatives in the wake of the disaster.

Historically, mangrove zones were dismissed as worthless swamps, making them easy targets for industrial development and land clearance. In recent years, however, there has been a significant global push to shift these

perceptions and highlight that "wetlands are not wastelands" (Spray and McGlothlin, 2004) ^[18]. This change in mindset has been bolstered by the annual celebration of World Wetlands Day, observed every February 2nd since 1997^[17], which serves to reinforce the vital importance of these habitats.

Conclusion

Since mangroves are now widely viewed as profitable ecosystems, it should be simpler to encourage stakeholders to pay for the environmental services they provide. These forests act as massive carbon sinks but face constant pressure from land conversion; consequently, they are perfect models for carbon financing. By directing investment into these areas, we can protect vital environmental resources, improve community livelihoods, and deploy affordable green technology to mitigate climate change.

References

1. Alongi DM. The dynamics of benthic nutrient pools and fluxes in tropical mangrove forests. *J Mar Res*,1996;54:123-148.
2. Bahuguna A, Nayak S, Roy D. Impact of the tsunami and earthquake of 26th December 2004 on the vital coastal ecosystems of the Andaman and Nicobar Islands assessed using RESOURCESAT AWiFS data. *Int J Appl Earth Obs Geoinf*,2008;10:229-237.
3. Bandaranayake WM. Traditional and medicinal uses of mangroves. *J Mangr Salt Marshes*,1998;2:133-148.
4. Bhagora FS. Mangrove plants in India, 2021.
5. Bindu Sulochanan. Mangrove ecosystem and its impact on fisheries. Central Marine Fisheries Research Institute, Research Centre, Mangalore, 2000.
6. ISFR. India State of Forest Report. Forest Survey of India, Ministry of Environment, Forest and Climate Change, 2021. <https://www.drishtiiias.com/summary-of-important-reports/india-state-of-forest-report-isfr-2021>.
7. IUCN. Lack of clear regulatory frameworks for coastal zone management. Issue # 2 Coastal Ecosystems <http://www.iucn.org/coastalinfo>, 2006.
8. Kathiresan K. How do mangrove forests induce sedimentation? *Rev. Biol. Trop*,2003;51:355-360.
9. Laegdsgaard P, Johnson C. Why do juvenile fish utilise mangrove habitats? *J Exp Mar Biol Ecol*,2001;257(2):229-53.
10. Mohan Raj V, Padmavathy S, Sivakumar. Water quality parameters and it influences in the Ennore estuary and near Coastal environment with respect to Industrial and Domestic sewage. *International Research Journal of Environmental Sciences*,2013;2(7):20-25.
11. Nayak S, Bahuguna A. Application of remote sensing data to monitor mangroves and other coastal vegetation of India. *Indian J Mar Sci*,2001;30:195-213.
12. Nayaka S, Upreti DK, Ingle KK. Mangroves of India: potential habitats for unique lichen flora. In: *Proc Int Day for Biological Diversity - Marine Biodiversity*,2012:68-74.
13. Nisha R, Mugade, Shubhangi S, Kale. Status and Distribution of Mangroves in India: A Review. *International Journal of Food and Nutritional Sciences*,2022;11:11.
14. Ramasubramanian R, Gnanappazham L, Ravishankar T, Navamuniyammal M. Mangroves of Godavari -

- analysis through remote sensing approach. *Wetl. Ecol. Manag*,2006:14:29-37.
15. Sahu SC, Suresh HS, Murthy IK, Ravindranath NH. Mangrove area assessment in India: implications of loss of mangroves. *J Earth Sci Clim Change*,2015:6(5):280.
 16. Satyanarayana B, Mohamad KA, Idris IF, Husain ML, Guebas FD. Assessment of mangrove vegetation based on remote sensing and ground truth measurements at Tumpat. *Int J Remote Sens*,2011:32:1635-1650.
 17. Spalding MD, Blasco E, Field CD. (Eds). *World Mangrove Atlas*. The International Society for Mangrove Ecosystems, Okinawa, Japan,1997:178.
 18. Spray SL, McGlothlin KL. *Wetlands*. UK: Roman and Little led, 2004.
 19. Vyas UD, Pithiya KG, Pathak N, Lende SR, Zankat HM. The vital role of mangroves in India: Status, challenges, and conservation outlook. *International Journal of Advanced Biochemistry Research*,2025:9(4):783-788.