Volume: 5 Issue: 2 Pages: 17-22

The Ecological and Socio-Economic Significance of Mangrove Forests: A Review

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Article Info.
E-ISSN: 2583-6528
Impact Factor (QJIF): 8.4
Peer Reviewed Journal
Available online:
www.alladvancejournal.com

Received: 08/Jan/2026
Accepted: 03/Feb/2026

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Abstract
Mangrove ecosystems are unique intertidal forests adapted to saline, waterlogged and low-oxygen environments forming a critical interface between terrestrial and marine ecological systems. Along India's extensive coastline, diverse mangrove communities occur across estuarine, deltaic and island ecosystems, supporting high biodiversity and productivity. These ecosystems provide essential ecological services including shoreline stabilization, nutrient cycling, carbon sequestration and nursery habitats for marine and coastal species. In addition to their ecological significance mangroves offer substantial socio-economic benefits by supporting fisheries, protecting coastal communities from storms and erosion and sustaining livelihoods through forest-based resources. This review synthesizes current knowledge on the ecological functions and socio-economic importance of mangroves in India, highlighting their role in environmental sustainability and community resilience under increasing pressures from climate change, coastal development and anthropogenic activities.

Keywords: Mangroves, Ecosystem services, Blue carbon, Coastal protection, Fisheries.

Introduction

Mangrove forests are unique and highly productive coastal ecosystems distributed across tropical and subtropical regions, primarily along sheltered shorelines, estuaries, river deltas and lagoons where freshwater and seawater interact (Alongi, 2014; Friess *et al*, 2019). These ecosystems are dominated by halophytic, salt-tolerant trees and shrubs that have evolved specialized physiological and morphological adaptations to survive in saline, waterlogged and oxygen-deficient soils (Alongi, 2014, 2018, 2020). Functioning as critical ecological interfaces between terrestrial and marine environments, mangroves support exceptionally high biological productivity and complex food webs, earning them recognition as the "roots of the sea" (Nagelkerken *et al*, 2008). They play a fundamental role in regulating coastal processes by stabilizing shorelines, trapping sediments, cycling nutrients and sequestering carbon, while also serving as vital nursery and breeding habitats for a wide range of fish, crustaceans, birds and other wildlife (Barbier *et al*, 2011; Alongi, 2014, 2018, 2020). Beyond their ecological importance, mangroves provide numerous ecosystem services that sustain human well-being, including coastal protection from erosion and extreme weather events, support for fisheries and resources for local livelihoods (Friess *et al*, 2019; UNEP, 2022). India harbors one of the largest and most diverse mangrove belts in Asia, characterized by species assemblages adapted to varying salinity gradients, tidal regimes and soil conditions (FSI, 2023). In the Indian context, mangroves are integral to maintaining coastal integrity, conserving biodiversity and supporting socio-economic stability in coastal communities, underscoring their critical role in sustainable coastal management and conservation efforts (Mitra, 2019).

Mangroves are widely recognized as an effective nature-based solution to climate change due to their exceptional capacity for long-term carbon sequestration and their role in enhancing the resilience of ecosystems and human communities to increasing climate-related vulnerabilities (Mcleod *et al*, 2011; Alongi, 2014, 2018, 2020). Globally, mangroves cover

approximately 150,000 km² and are distributed across more than 100 tropical and subtropical countries (Spalding *et al*, 2014; Friess *et al*, 2019). However, these ecosystems have declined by nearly 40 % from their historical extent, primarily due to direct anthropogenic pressures such as deforestation for aquaculture expansion, agriculture and infrastructure development as well as indirect impacts including habitat fragmentation, reduced freshwater inflows and altered salinity regimes (Goldberg *et al*, 2020; Spalding *et al*, 2010). Climate change further exacerbates mangrove degradation through sea-level rise and the increasing frequency and intensity of extreme weather events with losses being particularly acute in the Asia–Pacific region, where the rate of sea-level rise (~3.14 mm yr^{-1}) exceeds the global average (~2.5 mm yr^{-1}) (IPCC, 2021; Lovelock *et al*, 2015).

In India, mangrove ecosystems play a critical role in mitigating floods and protecting coastal regions from storm surges during cyclonic events while also supporting fisheries and providing essential resources for the livelihoods of coastal communities (Das & Crépin, 2013; FSI, 2023). These ecosystems harbor high biodiversity and deliver substantial ecological, economic and social benefits, making them integral to coastal sustainability (Mitra, 2019). Mangroves also have the potential to contribute significantly to India's Nationally Determined Contributions (NDCs) under the Paris Agreement and to serve as a key component of the country's emerging blue economy framework (UNEP, 2022).

Advancing the sustainable management and conservation of mangroves requires a comprehensive understanding of their dynamic relationships with coastal processes and the cumulative effects of natural and anthropogenic stressors (Alongi, 2014; 2018; 2020; Friess *et al*, 2019). Site-specific, long-term ecological data are essential for assessing changes in ecosystem health, vulnerability and resilience and for developing effective, adaptive and integrated coastal management strategies that remain robust under future climate scenarios (Lovelock *et al*, 2015; IPCC, 2021). High-quality localized measurements can provide critical baseline information on mangrove condition, structure and functioning, enabling timely and targeted responses to increasing environmental pressures (Goldberg *et al*, 2020).

To address existing data gaps, CIFOR–ICRAF, in collaboration with local governments and research institutions is establishing a long-term ecological monitoring network at selected mangrove sites across India (CIFOR–ICRAF, 2024). This pan-India initiative aims to generate standardized and scientifically robust datasets on key parameters including sedimentation dynamics, salinity and tidal fluctuations, vegetation structure and composition and carbon stocks (CIFOR–ICRAF, 2024). India currently supports approximately 5,000 km² of mangrove forests, distributed across the Andaman Islands (13 %), the east coast (60 %) and the west coast (27 %) (FSI, 2023). Despite sporadic research efforts in the past, the absence of nationally consistent datasets has limited the effectiveness of mangrove management and policy development at local and regional scales. Addressing these information gaps through coordinated long-term monitoring is essential for strengthening evidence-based decision-making and ensuring the long-term sustainability of India's mangrove ecosystems and coastal landscapes (Alongi, 2014; 2018; 2020; CIFOR–ICRAF, 2024).

Ecological Functions and Ecosystem Services of Mangrove Forests

1. Coastal Protection

Mangrove forests function as effective natural barriers against coastal hazards, including erosion, storm surges, cyclones and tsunamis. Their complex root systems attenuate wave energy, stabilize sediments and reduce shoreline erosion, thereby safeguarding coastal settlements, agricultural lands and infrastructure (Alongi, 2008; Barbier *et al*, 2011). Mangrove forests provide substantial physical protection to coastal environments. Their dense and complex root systems act as natural buffers against coastal hazards including storm surges, cyclones and tidal waves by dissipating wave energy and reducing hydrodynamic forces (Barbier *et al*, 2011; Alongi, 2015). Mangroves also play a vital role in sediment trapping and stabilization, promoting land accretion and reducing shoreline erosion which contributes to the long-term stability of coastal landscapes (Krauss *et al*, 2013; Friess *et al*, 2019).

Case Study: Sundarbans, India and Bangladesh

The Sundarbans, the largest contiguous mangrove forest globally provides significant protection to the coastal regions of India and Bangladesh. Evidence from extreme weather events such as Cyclone Amphan (2020), indicates that areas with intact mangrove cover sustained comparatively lower levels of damage than regions where mangroves were degraded or absent, highlighting their role in disaster risk reduction (Ghosh *et al*, 2015; Das & Crépin, 2013; Rodriguez *et al*, 2023).

2. Biodiversity Conservation

Mangrove ecosystems support high levels of biological diversity and serve as critical habitats for numerous terrestrial and aquatic species. They function as breeding, nursery and feeding grounds for fish, crustaceans, mollusks and avifauna. Additionally, several threatened and endangered species including marine turtles and certain fish species depend on mangroves for survival (Nagelkerken *et al*, 2008; Kathiresan & Bingham, 2001). Mangroves function as essential breeding, feeding and nursery grounds for numerous commercially important fish and shrimp species, thereby sustaining marine food webs (Lee *et al*, 2014).

Case Study: Bhitarkanika Mangroves, Odisha

The Bhitarkanika mangrove system is recognized for its exceptional biodiversity, hosting species such as the saltwater crocodile, migratory birds and a wide range of commercially important fish. This ecosystem plays a crucial role in maintaining regional coastal and marine biodiversity (Shyamal, 2023).

3. Carbon Sequestration and Climate Regulation

Mangroves are among the most efficient ecosystems for carbon sequestration, capturing and storing substantial amounts of atmospheric carbon dioxide in both above-ground biomass and underlying sediments. Their high primary productivity combined with slow rates of organic matter decomposition facilitates long-term storage of carbon in both above-ground biomass and below-ground sediments, classifying them as important "blue carbon" ecosystems with an important role in climate change mitigation. (Donato *et al*, 2011; Alongi, 2014; UNEP, 2022).

Case Study: Indonesian Mangroves

Indonesia possesses one of the world's largest extents of mangrove forests. Scientific studies have demonstrated that these mangroves store considerably higher amounts of carbon per unit area compared to many terrestrial tropical forests, underscoring their global significance in carbon management strategies (Murdiyarso *et al*, 2015).

4. Water Quality Regulation

Mangrove forests enhance coastal water quality by trapping sediments and filtering pollutants and excess nutrients from terrestrial runoff. This regulatory function helps protect adjacent ecosystems such as coral reefs and seagrass meadows from eutrophication and sedimentation (Alongi, 2008; Lee *et al*, 2014).

5. Nutrient Cycling and Coastal Productivity

Mangroves play a vital role in nutrient cycling by contributing organic matter, primarily through leaf litter and detritus to coastal and estuarine waters. This process supports marine food webs and enhances primary and secondary productivity in connected aquatic ecosystems (Bouillon *et al*, 2008; Kamruzzaman *et al*, 2019). Additionally, mangroves influence biogeochemical cycling by regulating the availability of nutrients such as nitrogen and phosphorus, thereby enhancing primary productivity in adjacent coastal waters (Alongi, 2008; Bouillon *et al*, 2008).

Socio-Economic Significance of Mangrove Forests

1. Support to Fisheries

Mangrove ecosystems play a critical role in sustaining coastal and marine fisheries by providing essential habitats for various commercially important fish and shellfish species during different stages of their life cycles. These nursery and feeding functions enhance fish stock productivity, thereby supporting artisanal and commercial fisheries and contributing significantly to coastal food security (Nagelkerken *et al*, 2008; Barbier *et al*, 2011).

Case Study: Kerala Backwaters, India

Mangroves along the backwaters of Kerala contribute substantially to local fisheries by offering suitable breeding and nursery grounds for fish and prawns. Small-scale fishing communities in the region derive direct economic benefits from the presence of healthy mangrove ecosystems (Biju Kumar & Deepthi, 2006).

2. Livelihood Opportunities

Mangrove forests provide diverse livelihood opportunities to millions of people living in coastal regions. These ecosystems supply a range of natural resources including fuelwood, timber, honey collection, medicinal plants, fodder and fishery products. In many developing regions mangrove-dependent activities constitute a major source of income and subsistence for rural and marginalized communities (FAO, 2007; FAO, 2020; Walters *et al*, 2008).

Case Study: Sundarbans Honey Collectors

In the Sundarbans region local communities traditionally depend on mangrove forests for the collection of honey, beeswax, fish and other forest products. These activities form an integral component of the local rural economy and support household livelihoods (Ghosh *et al*, 2015).

3. Protection of Human Life and Property

Mangroves significantly reduce the vulnerability of coastal populations to natural disasters such as cyclones, storm surges and floods. By attenuating wave energy and reducing flood intensity, mangrove forests help protect human lives, property and infrastructure, thereby minimizing economic losses during extreme climatic events (Alongi, 2008; Das & Vincent, 2009).

4. Tourism and Recreation

Mangrove ecosystems possess considerable potential for eco-tourism and recreational activities. Nature-based tourism including boat tours, bird watching and environmental education programs generates alternative income opportunities for local communities while promoting awareness of mangrove conservation (Spalding & Parrett, 2019; UNEP, 2022).

Case Study: Pichavaram Mangrove Forest, Tamil Nadu

The Pichavaram mangrove forest is a prominent eco-tourism destination in Tamil Nadu, where guided boat tours through mangrove channels provide employment to local residents and foster public awareness regarding the ecological importance of mangroves (Kathiresan, 2012).

5. Cultural and Traditional Values

Mangroves hold substantial cultural and traditional significance for coastal communities. Indigenous knowledge systems related to fishing practices, medicinal plant use and sustainable forest resource management have been transmitted across generations, reinforcing community identity, social cohesion and cultural heritage (Walters *et al*, 2008; UNEP, 2014). Collectively, these functions underscore the importance of mangrove ecosystems in sustaining coastal economies and human well-being.

Importance of Mangroves

1. Climate Resilience

Mangrove ecosystems play a crucial role in enhancing climate resilience by reducing the vulnerability of coastal regions to climate-related hazards. Through their capacity to attenuate wave energy and storm surges, mangroves protect coastal communities from extreme events such as cyclones and flooding. In addition, mangroves contribute to climate change mitigation by sequestering and storing large quantities of carbon in their biomass and sediments. For instance, the Sundarbans mangrove system significantly reduces the impacts of cyclonic storms for millions of inhabitants in the India–Bangladesh region, demonstrating the importance of mangroves as nature-based solutions for climate adaptation (Alongi, 2015; Friess *et al*, 2019; UNEP, 2022).

2. Biodiversity Conservation

Mangroves in India support high levels of biodiversity including a number of endemic, threatened and endangered species, thereby serving as critical conservation landscapes. These ecosystems provide habitat for iconic species such as the Bengal tiger (*Panthera tigris tigris*) in the Sundarbans, estuarine crocodiles, river terrapins and a wide diversity of resident and migratory bird species. Mangroves also support numerous fish and invertebrate species that depend on these habitats for breeding and survival, underscoring their importance in maintaining regional and national biodiversity (Kathiresan & Bingham, 2001; Nagelkerken *et al*, 2008; Lee *et al*, 2014).

3. Economic and Ecosystem Service Values

Mangrove ecosystems generate substantial economic benefits through the provision of a wide range of ecosystem services. These include support for fisheries production, coastal

protection from storms and erosion, carbon sequestration and livelihood opportunities for coastal populations. Economic valuation studies consistently demonstrate that the long-term benefits derived from intact mangrove ecosystems often exceed the short-term gains associated with land conversion for aquaculture, agriculture or infrastructure development. Furthermore, by stabilizing coastal geomorphology and reducing risks to human settlements, mangroves contribute significantly to disaster risk reduction and sustainable coastal development (Barbier *et al*, 2011; Spalding *et al*, 2014; UNEP, 2022).

4. Major Traps for Plastic and Coastal Waste

Mangroves trap large amounts of human waste. Plastic bottles, bags, food containers and broken items collect between roots and stay buried for long periods. New research from Colombia found that the mangroves turn into long term waste traps and nearby communities face growing risks. The mangroves act as effective natural sinks for macrolitter, largely shaped by waste generated in adjacent communities. Local residents were identified as the primary source of this debris, reflecting inadequate waste management practices. Plastics overwhelmingly dominated the macrolitter found in all mangrove types (accounting for 89.6%–93.1%). Floating debris was most common in fringe and riverine mangroves, whereas heavier materials tended to accumulate in basin mangroves (Garcés-Ordóñez *et al*., 2025).

The first documented evidence of plastic waste accumulation in Maldivian mangroves, drawing attention to an issue that had not previously been reported in this ecosystem. It shows that mangroves located along wave exposed coastlines especially those with flat terrain and dense vegetation have a greater tendency to retain plastic debris. Field observations indicated that plastic bottles were the most frequently encountered items, commonly lodged within the roots and stems of mangrove species such as *Pemphis acidula* and *Rhizophora mucronata* (Cerri *et al*., 2025).

Threats and Governance Challenges Affecting Mangrove Ecosystem

Despite their substantial ecological and socio-economic importance, mangrove forests are experiencing rapid degradation due to a combination of anthropogenic pressures and climate-related stressors. Large-scale habitat loss driven by coastal development, aquaculture expansion, agricultural encroachment and urbanization has resulted in significant reductions in mangrove extent worldwide. In addition, pollution from industrial effluents, oil spills, agricultural runoff and untreated wastewater adversely affects water quality and compromises mangrove health. Many mangrove ecosystems were destroyed by business people for the purpose of commercial shrimp farming.

Climate change further exacerbates these pressures with rising sea levels, increasing temperatures and altered salinity regimes influencing species composition, productivity and spatial distribution of mangrove communities. Unsustainable exploitation of mangrove resources including over-harvesting of timber, fuel wood and non-timber forest products also contributes to ecosystem degradation.

Beyond environmental drivers governance-related challenges play a critical role in mangrove decline. Inadequate enforcement of existing conservation regulations, fragmented institutional frameworks and limited involvement of local communities in decision-making processes often undermine effective mangrove management. Addressing these combined threats requires integrated governance approaches that strengthen policy implementation, promote sustainable resource use and enhance community participation in conservation initiatives.

Conservation and Management Strategies for Mangrove Ecosystems

The long-term survival of mangrove forests depends on the implementation of effective, science-based conservation and management strategies. Key approaches include afforestation and reforestation of degraded mangrove landscapes using native species, promotion of sustainable resource use and strict enforcement of legal frameworks to prevent deforestation and habitat conversion. Enhancing public awareness and fostering community participation are equally critical to ensure the success of conservation initiatives (Friess *et al*, 2019; UNEP, 2022).

1. Community-Based Conservation Initiatives

Case Study: Gujarat, India

In several coastal regions of Gujarat, community-based mangrove conservation programs have demonstrated positive ecological and socio-economic outcomes. Active involvement of local communities in mangrove plantation, protection and monitoring has resulted in improved coastal defense, increased fishery productivity and enhanced livelihood opportunities, underscoring the effectiveness of participatory management approaches (MoEFCC, 2022; Das & Crépin, 2013; Walters *et al*, 2008).

2. Integrated Conservation Framework for India

Effective mangrove conservation in India requires a multi-dimensional framework encompassing legal, ecological and socio-economic components. Strengthening the implementation of national environmental policies and adherence to international commitments such as the Ramsar Convention on Wetlands are essential for safeguarding mangrove habitats. Community participation should be integrated into restoration and sustainable use practices to ensure local stewardship and long-term sustainability (Ramsar Convention Secretariat, 2021; UNEP, 2022).

Scientific monitoring, employing tools such as remote sensing, geographic information systems (GIS) and systematic field surveys is crucial for assessing mangrove health, spatial extent and emerging threats. Restoration initiatives should prioritize replanting native mangrove species, controlling invasive species and stabilizing degraded coastal zones. Furthermore, the adoption of Integrated Coastal Zone Management (ICZM) approaches is vital to balance developmental pressures with ecological conservation, ensuring the resilience of mangrove ecosystems under changing environmental conditions (Lovelock & Reef, 2020; MoEFCC, 2023; Romañach *et al*, 2018).

Conclusion

Mangrove forests are ecologically, economically and socially vital coastal ecosystems in the Indian subcontinent. Their specialized adaptations enable survival under extreme conditions such as high salinity, tidal inundation and hypoxic soils. Indian mangroves provide essential ecosystem services including shoreline stabilization, carbon sequestration, climate regulation, biodiversity conservation and support for coastal livelihoods, thereby enhancing resilience to natural hazards. However, increasing anthropogenic pressures and environmental change threaten their sustainability. Therefore,

sustained conservation and restoration efforts guided by scientific monitoring, sustainable management practices, inclusive policies and community participation are essential to preserve their ecological integrity and socio-economic value.

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