



Mangrove Ecosystems: Distribution Patterns, Types, Adaptive Features, and Importance

Pansha Yendra¹, Vairaj Havda² and Akram Famaniya³

¹Department of Botany, University of Mumbai, Mumbai, Maharashtra, India

²Department of Environmental Science, University of Calcutta, Kolkata, West Bengal, India

³Department of Marine Biology and Oceanography, University of Kerala, Thiruvananthapuram, Kerala, India

Abstract

Mangroves are coastal ecosystems that have salt-tolerant evergreen forests. They play a crucial role in the environment. This paper explores the history and evolution of the term "mangrove," explaining their unique adaptations and ecological importance. Mangroves protect against coastal erosion, efficiently store carbon, and support diverse wildlife. Despite their ecological significance, mangroves face significant threats from human activities, such as habitat destruction due to aquaculture, agriculture, pollution, and oil spills. To effectively conserve and manage them, it is important to understand the global status and distribution of mangroves. Various methods, including satellite remote sensing, have been used to map mangrove forests worldwide. This review paper focuses on mangrove ecosystems in India, highlighting changes in their coverage over time. It also categorizes mangrove forests based on physical phenomena and adaptation strategies. Mangroves have unique adaptations, such as pneumatophores and salt-excreting leaves, that help them survive in harsh coastal environments. Additionally, they provide essential ecosystem services, including coastal protection, carbon storage, and water filtration. This review paper concludes by emphasizing the economic significance of mangroves for coastal communities, particularly in aquaculture and timber industries. It also highlights their role as storage for blue carbon and natural water filters. Mangroves are essential for protecting shorelines from coastal erosion, reducing the impact of storms, and serving as efficient carbon sinks. They also support rich biodiversity by providing habitat and breeding grounds for a wide variety of marine and terrestrial species. Despite their ecological significance, mangrove ecosystems are increasingly threatened by human activities such as aquaculture expansion, agricultural encroachment, pollution, urban development, and oil spills. Understanding the global distribution and current status of mangroves is crucial for effective conservation and management. Modern techniques, including satellite remote sensing, have greatly improved the mapping and monitoring of mangrove forests worldwide. This review also highlights the condition and changing extent of mangrove ecosystems in India over time. Mangroves possess unique adaptive features such as pneumatophores, salt-excreting leaves, and specialized root systems that enable them to survive in saline and waterlogged environments. In addition to their ecological functions, they provide important ecosystem services such as water purification, blue carbon storage, and economic resources for coastal communities, including fisheries and timber production. Overall, this study emphasizes the need for greater conservation efforts to protect mangrove ecosystems and sustain their environmental and economic benefits.

Keywords: Mangroves, coastal ecosystems, salt-tolerant vegetation, mangrove distribution, mangrove adaptations, pneumatophores, coastal protection, blue carbon, biodiversity conservation

Introduction

The term mangrove has a long historical origin. According to the Oxford English Dictionary, early forms such as mangrove and mangrove appeared in English during the 1600s. The words mangle and mangué, used by Spanish and Portuguese speakers in the Americas, were derived from the Haytian Arawak language and originally referred to specific coastal trees and shrubs. Over time, the term mangrove came to describe not only species of the genus *Rhizophora* but also other salt-tolerant genera such as *Avicennia*, *Laguncularia*, and *Pelliciera* that thrive in similar environments. Mangroves are salt-tolerant evergreen forests found in intertidal zones along sheltered coastlines, estuaries, lagoons, mudflats, tidal creeks, and marshes in tropical and subtropical regions. These ecosystems survive under harsh environmental conditions, including high salinity, waterlogged and oxygen-deficient soils, strong winds, and regular tidal flooding. The organisms living in mangrove habitats have evolved remarkable adaptations that allow them to survive and function effectively in such challenging environments (Spalding et al., 1997; Sandilyan, 2010).

Over time, mangrove plants have developed specialized features to cope with environmental stress. These include complex root systems that provide structural support and facilitate gas exchange, reproductive strategies such as vivipary (where seeds germinate while attached to the parent plant), and mechanisms for regulating salt concentration and conserving nutrients (Kathiresan and Bingham, 2001). Their intricate root networks also slow tidal currents, allowing suspended sediments to settle and stabilizing coastal soils, which helps reduce shoreline erosion. The distribution and zonation of mangrove species are influenced by environmental factors such as tidal inundation, salinity, soil composition, and geomorphology. The frequency and duration of tidal flooding play a major role in determining plant growth patterns and species arrangement within mangrove ecosystems. Previous studies have explored how these environmental conditions shape mangrove zonation and ecosystem structure (Chapman, 1976; Watson, 1928).

Mangroves provide numerous ecological services, including coastal protection, carbon sequestration, water purification, and support for biodiversity. They act as natural barriers against storms and erosion while serving as important habitats and breeding grounds for various marine and terrestrial species. However, mangrove sediments can also accumulate pollutants such as heavy metals, especially in areas affected by urbanization and industrial activity, posing environmental concerns in estuarine and coastal wetlands. Despite their immense ecological and economic importance, mangrove ecosystems are under severe pressure worldwide. Nearly one-third of global mangrove cover has been lost over the past fifty years due to activities such as aquaculture expansion, agricultural conversion, pollution, oil spills, and unsustainable coastal development. These threats highlight the urgent need for effective conservation and sustainable management strategies to protect mangroves, particularly in tropical and highly vulnerable coastal regions.

Mangrove Status and Geographical Distribution

The dependence on the littoral environment varies by species. Nonetheless, of the total number of species regarded globally as mangrove trees, 63 are solely found in mangrove communities, while 21 are essential but nonexclusive, expanding beyond the vicinity of upper tide levels. The latter is known as non-exclusive, back, or associate mangroves. Furthermore, (Tomlinson, 1986) has separated the 'exclusive' mangroves into major and minor mangroves based on the structural contribution of the particular species; however, this distinction has not been applied here because it is geographically too varied.

Mangrove forests found along coastlines are usually in thin strips and small patches as a result, the current global datasets of mangrove forests may not be enough to support in-depth scientific research and precise management. These datasets can be divided into two main categories: statistical reports from different sources and maps created using satellite images. The statistical reports were compiled by various institutions and organizations from 1981 to 2020 (FAO, 2007; Wilkie and Fortuna, 2003) providing an overview of mangrove forest areas in different administrative regions but without specific details about their spatial distribution. Satellite remote sensing offers a practical, speedy, and cost effective solution for generating consistent maps of mangrove forests worldwide (Friess *et al.*, 2019; Lu and Wang, 2021; Lu and Wang, 2022). An example of one of the earliest comprehensive datasets for global mangrove forest mapping was the

World Mangrove Atlas, first published in 1997 (Spalding, 2010; Spalding and Blasco, 1997) Mangroves are distributed across 118 countries and various terrains, covering a combined area of 147,000 square kilometres globally (Ochiai *et al.*, 2022) Figure 1 displays the overall distribution of mangrove forests worldwide. Approximately 75% of the total mangrove population is concentrated in just 15 countries with only 6.9% thriving within protected areas. The majority of mangroves can be found in the Southeast Asian region, particularly in Indonesia, Malaysia, and Myanmar

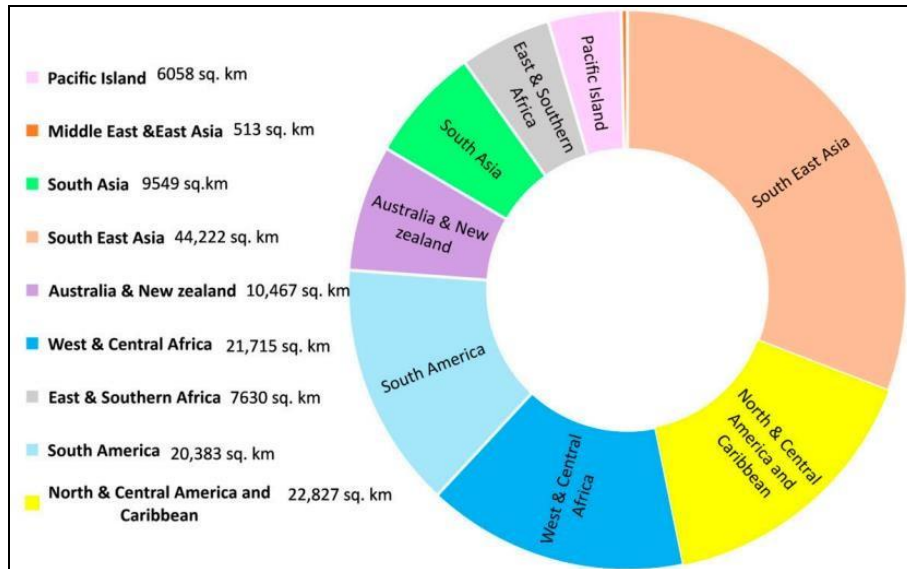


Fig 1: Shows the percentage cover of mangrove forests in various locations of the world

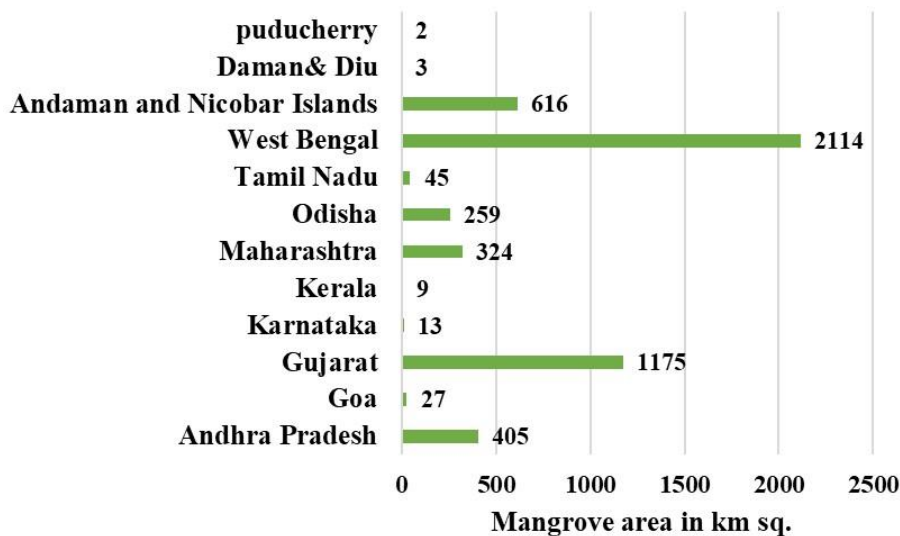


Fig 2: Mangrove cover in India

India (FSI) in 1987, the mangrove cover in India was estimated to span an area of 4975 km, making up approximately 3% of the total mangrove area in South Asia and 0.15% of the country's overall geographical area. The Sundarbans in West Bengal accounts for almost half of India's mangrove area. Over the past 32 years, the mangrove cover in the country has consistently increased, expanding from 4046 km sq. in 1987 to 4975 km sq. in 2019, indicating a growth rate of 22.96% as reported by the FSI. Out of the total 4975 km sq. of mangrove area, 2020 km sq. constitutes open mangroves, 1479 km sq. is moderately dense mangroves, and 1476 km sq. is very dense mangroves. While open mangrove areas have seen consistent growth over the past 16 years (2003-2019), there has been a significant decline in the moderately dense mangrove area of the country Maharashtra have made large advances in mangrove cover, with 8 and 4 square kilometres, respectively. In Odisha, the growth is primarily due to natural regeneration and plantation activities in

suitable sites such as riverbanks and intertidal mudflats, which are flooded by seawater daily. The districts of Kendrapara, Jagatsinghpur, and Balasore in Odisha have seen an increase. In Maharashtra, the growth is primarily attributable to natural regeneration. The South 24 Parganas district of West Bengal has also experienced a rise. The graph below shows the extent of Mangrove cover and changes in three canopy density classes by state/UT, compared to the 2019 assessment.

Types

There are six different categories of mangrove forests known as over-wash, fringe, riverine, basin, scrub, and hammock forests (Lugo and Snedaker 1974; Woodroffe 1992) The previous categorization does not include details about the actual physical phenomena occurring within mangrove forests. Because of the physical processes involved, an alternative categorization has been suggested, consisting of three types of mangrove forests: (1) those dominated by rivers, (2) those dominated by tides, and (3) interior mangrove forests that exhibit lesser impact from rivers or tides. There are six main types of mangrove environments categorized by tidal range and sedimentation. The first type is large deltaic systems with low tidal range and fine sediment, like Borneo and Sundarbans. The second type is tidal plains where mudflats form from alluvial sediments and mangroves grow there. The third type is composite plains influenced by tidal and alluvial conditions, like lagoons behind wave-built barriers. The fourth type is fringing barriers with lagoons found in regions with high wave energy and sediments of fine sand and mud, such as the Philippines. The fifth type is drowned bedrock valleys, like in Northern Vietnam or Eastern Malaysia. Lastly, the sixth type is coral coasts where mangroves grow on coral sand or platform reefs, like in Indonesia and Singapore

Adaptation

Mangrove species share a range of adaptations that allow them to survive in the challenging and unstable mangrove habitat. Around 84 plant species from 39 genera and 26 families are identified as mangroves due to their possession of these adaptations and their habitat preference (Tomlinson 1986, Duke 1992, Naskar and Mandal 1999, Kathiresan and Bingham 2001) Mangroves have developed specialized features to adapt to their coastal environment. These include exposed breathing roots, extensive support roots and buttresses, salt-excreting leaves, and water dispersed propagules that are viviparous. The specific adaptations vary among different species of mangroves and depend on the physical and chemical characteristics of the habitat they inhabit (Duke, 1992)

Among the various adaptations, the stilt roots of *Rhizophora*, pneumatophores (aerial roots) of *Avicennia*, *Sonneratia*, and *Lumnitzera*, root knees of *Bruguiera*, *Ceriops*, and *Xylocarpus*, and buttress roots of *Xylocarpus* and *Heritiera* are particularly remarkable (Emilio, 1997) These specialized roots play a vital role in facilitating gas exchange for mangroves living in oxygen-deprived soil. The exposed surfaces of these roots may contain numerous lenticels, which are small openings that enable gas exchange to take place (Tomlinson, 1986) *Avicennia*, for example, possesses pneumatophores equipped with lenticels that allow oxygen to diffuse passively. The degree to which the lenticels are open depends on the prevailing environmental conditions (Ish-Shalom-Gordon and Dubinsky, 1992) In *Avicennia marina*, the spongy pneumatophores are generally short (< 30 cm), but they become larger and more numerous in anaerobic and oil-polluted conditions. This increased growth enhances the surface area available for gas exchange (Saifullah and Elahi, 1992) *Sonneratia*, on the other hand, develops stout pneumatophores that can reach a length of 3 meters due to substantial secondary thickening (Tomlinson, 1986) Additionally, oxygen can also permeate through non-lenticellular sections of the pneumatophores. In cases where newly formed tips lack lenticels, horizontal structures known as subrisules play a significant role in facilitating air exchange, especially in rapidly growing pneumatophores (Hovenden and Allaway, 1992) Plants that inhabit environments with high salt concentrations have adapted in ways that minimize water loss to avoid dehydration and prevent the buildup of salts that could harm their metabolism. Previous studies by Barhoumi *et al.* (2007) and Maricle *et al.* (2009) focused on investigating the internal structure of grass leaves when exposed to salinity. However, there is a limited body of research that explores the connection between leaf anatomy, and the micro-morphology of stems, leaves, and roots in mangrove plants that have adapted to high saline and high light-intensity conditions (Gielwanowska *et al.*, 2005) In 1992, Munns put forward a hypothesis suggesting

that the salts absorbed by plants do not directly affect growth by influencing turgor, photosynthesis, or the activity of a specific enzyme. Instead, he proposed a two-phase response to salinity in plant growth. Initially, growth is hindered due to a decrease in soil water potential, which creates water stress. Subsequently, a specific aftereffect occurs as salt levels rise in older leaves. These leaves gradually perish due to the rapid accumulation of salt in the cell wall or cytoplasm, reaching a point where vacuoles can no longer sequester the incoming salts.

Importance Coastal Communities and Job Opportunities

Mangrove-associated aquaculture within the ASEAN region (Indonesia, Malaysia, and the Philippines), mangrove related aquaculture makes up 21% (about 1.4 million tonnes annually) of the fisheries along the coastline. These fisheries yield approximately 1.09 million tons of fin fish and 0.4 million tons of shrimp/prawn each year (Broszeit *et al.*, 2022) The foliage of mangrove trees, particularly *Avicennia marina*, is considered a healthy food source for domestic animals (Mitra, 2020) Mangrove wood is highly resistant to decay and pests, making it valuable for both timber and fuel wood. The timber from *Rhizophora* spp., *Xylocarpus* sp., *Bruguiera* sp., and *Sonneratia* sp. is particularly sought after due to the durability of their wood and the large size of their trunks (Olorunnisola, 2023). Certain mangrove-associated species, like *Abonnema* and *Nypa fruticans*, have exhibited antimicrobial activity against plant and animal pathogens. These extracts have been traditionally used to treat skin ailments and stomach issues.

Blue Carbon Storage (Carbon Sink)

Mangroves act as carbon sinks, with the capacity to store approximately 1023 megagrams of carbon per hectare. Several studies have demonstrated that mangroves have a higher ability to sequester carbon compared to other ecosystems like grasslands or tropical rainforests (Zhu & Yan, 2022) According to a 2022 report by the Global Mangrove Alliance (GMA), global mangrove forests store an estimated total of 21,896.56 million metric tons of CO₂ equivalents, with 2817.23 million metric tons in aboveground biomass and 19,079.32 million metric tons in the top meter of soil (Leal & Spalding, 2022).

Natural Water Filters

Mangroves have the remarkable ability to thrive in saline water and effectively remove 90% of sodium ions (Na⁺) from the surrounding seawater (Hastuti *et al.*, 2023) Their roots possess a three-layered pore structure in the root epidermis, aiding in the filtration of Na⁺ (Li, 2022) Furthermore, the pneumatophores and prop roots of mangroves create a low-energy environment that allows contaminants present in wastewater to persist for a prolonged duration. Mangrove plants also can sequester various metals, including zinc (Zn), manganese (Mn), and copper (Cu) (Wang, 2019).

Conclusion

This review discusses mangroves, including their distribution, types, adaptations, and ecological importance. Mangroves are special forests that can handle high salt levels and are vital to coastal ecosystems. They provide important services like protecting coasts, storing carbon, and filtering water. Mangroves thrive in harsh coastal environments and support diverse wildlife through adaptations like pneumatophores, viviparity, and saltexcreting leaves. However, human activities pose significant threats to mangroves. Habitat destruction, pollution, and oil spills are major challenges. To effectively conserve and manage mangroves, understanding their global distribution and current status is important. Satellite remote sensing is a useful method for achieving this. Mangroves also have economic value for coastal communities, especially in aquaculture and timber industries. This emphasizes the need for sustainable management practices to ensure their long-term survival and preserve their invaluable services. Protecting mangroves allows us to benefit from their resources while maintaining the health and balance of coastal environments.

References

- Adame MF, Connolly RM, Turschwell MP, Lovelock CE, Fatoyinbo T, Lagomasino D, *et al.* Future carbon emissions from global mangrove forest loss. *Global Change Biology*. 2021;27:2856-2866.
- Barhoumi Z, Djebali W, Chaibi W, Abdelly C, Smaoui A. Salt impact on photosynthesis and leaf ultrastructure of *Aeluropus littoralis*. *Journal of Plant Research*. 2007;120:529-537.
- Broszeit S, Langmead O, Praptiwi RA, Creencia L, Then AYH, Lim VC, *et al.* Ecosystem service provision by marine habitats in Southeast Asia; PML Publishing: Plymouth, UK; c2022.
- Caregnato FF, Koller CE, MacFarlane GR, Moreira JC. The glutathione antioxidant system as a biomarker suite for the assessment of heavy metal exposure and effect in the grey mangrove, *Avicennia marina* (Forsk.) Vierh. *Marine Pollution Bulletin*. 2008;56(6):1119-1127.
- Chapman VJ. Mangrove vegetation. Vaduz, Liechtenstein: J. Cramer; c1976.
- Choudhury TR, Acter T, Uddin N, Kamal M, Chowdhury AS, Rahman MS. Heavy metals contamination of river water and sediments in the mangrove forest ecosystems in Bangladesh: A consequence of oil spill incident. *Environmental Nanotechnology Monitoring and Management*. 2021;16:100484.
- Cruse B, Liedloff A, Vesik PA, Burgman MA, Wintle BA. Hydroperiod is the main driver of the spatial pattern of dominance in mangrove communities. *Global Ecology and Biogeography*. 2013;22(7):806-817. <https://doi.org/10.1111/geb.12063>.
- de Lacerda LD, Ward RD, Godoy MDP, de Andrade Meireles AJ, Borges R, Ferreira AC. 20-years cumulative impact from shrimp farming on mangroves of Northeast Brazil. *Frontiers in Forests and Global Change*. 2021; 4:653096.
- Du C, Khan S, Ke Y, Zhou D. Assessment of spatiotemporal dynamics of mangrove in five typical mangrove reserve wetlands in Asia, Africa and Oceania. *Diversity*. 2023; 15:148.
- Duke NC. Mangrove floristics and biogeography. In: Robertson AI, Alongi DM, editors. *Tropical Mangrove Ecosystems*. Washington DC, USA: American. Geophysical Union; 1992. p. 63-100.
- Ellison AM, Mukherjee BB, Karim A. Testing patterns of zonation in mangroves: Scale dependence and environmental correlates in the Sundarbans of Bangladesh. *Journal of Ecology*. 2000;88(5):813-824. <https://doi.org/10.1046/j.1365-2745.2000.00500.x>.
- Emilio O. Majagual: The tallest mangroves in the world. *International Newsletter of Coastal Management - Intercoast Network*. 1997; Special Edition 1:1-17.
- Food and Agriculture Organization of the United Nations. *Global forest resources assessment 2020: main report*. 2020.
- Food and Agriculture Organization of the United Nations. *The world's mangroves 1980-2005*. FAO Forestry Paper. 2007; 153:77.
- Friess DA, Rogers K, Lovelock CE, *et al.* The state of the world's mangrove forests: past, present, and future. *Annual Review of Environment and Resources*. 2019; 44:89-115.
- Friess DA, Yando ES, Alemu JB, Wong L-W, Soto SD, Bhatia N. Ecosystem services and disservices of mangrove forests and salt marshes. In: Hawkins SJ, Allcock AL, Bates AE, Evans AJ, Firth LB, McQuaid CD, Russell BD, Smith IP, Swearer SE, Todd PA, editors. *Oceanography and Marine Biology: An Annual Review*. 1st ed. New York, NY, USA: Taylor & Francis; c2020.