

Environmental degradation and mangrove - Insights from the Indian Sundarbans

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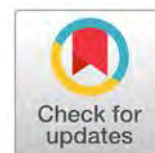
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Abstract

The Indian Sundarban, the world's largest contiguous mangrove forest has experienced significant change, attributed to human activities and natural causes. However, a component may also be due to factors commonly associated with anthropogenic, climate change, including higher air temperatures, variations in rainfall, increases in storm frequencies and intensities, and rising sea levels. The expected responses of mangroves to these drivers include changes in extent growth rates, productivity, and species composition. This paper reviews such responses and illustrates how these might appear within. In doing so, it informs countries and organizations of the potential impacts of climate change on mangrove forests and how these may be monitored.

Keywords: Climate change, Mangrove, Monitoring, Reproduction

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Introduction

Sundarban is the largest delta in the world. The total area of the present day Sundarban forests is 10,000 km², out of which 62% lies in Bangladesh and the rest 38% in Indian state of West Bengal. The estuarine land of Sundarban is the home of a substantial range of mangrove species. Some 35 species of mangroves have been recorded so far across the area (Rahman, 2013). Indian mangroves are extremely exposed to anthropogenic stresses, such as deforestation, dredging, infrastructure development, tourism business. Mangrove forests are one of the world's most jeopardised tropical ecosystem. Globally, up to 35% of the mangrove area has been lost since the 1980s (Curnick et al., 2019). Rapid climate change and sea level rise also fall among the primary reasons of continuous loss and fragmentation, which in turn creates barriers to species. The fragmentation also leads in a curtailed pollination frequency, since the mangrove species are preponderantly xenogamous i.e. cross-pollinated (Aluri, 2008). Ergo, it leads to the impediments in their secondary succession. The Indian Sundarbans, spanning approximately 10,000 km², stands as the world's largest contiguous mangrove forest. Located in the Northern Bay of Bengal, this ecosystem plays

a pivotal role in blue carbon sequestration. Not only does it provide essential ecosystem services for resident populations, but it also acts as a buffer against cyclones, safeguarding local settlements—including the densely populated cities of Kolkata and Dhaka—from their worst effects (Abhra Chanda *et al.*, 2023)

Over the last two-and-a-half centuries, the Indian Sundarbans have undergone significant changes. While the mangroves' areal extent has remained relatively stable, shifts in forest health and structure have occurred. These changes result from direct human interference, upstream development, extreme weather events, and the gradual effects of climate change. In this paper, we document these transformations and analyze their impact on the health and structure of this invaluable ecosystem. Additionally, we explore the intersection of different management strategies with local livelihoods, emphasizing the urgent need for conservation efforts.

Drivers of degradation

Tropical Cyclones: The Sundarban endures recurrent cyclones, impacting mangrove health and structure.

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Soil Erosion: Erosion threatens the stability of mangrove habitats, affecting their resilience.

Freshwater Scarcity: Reduced freshwater inflow disrupts mangrove growth and regeneration.

Sediment Flow Reduction: Inadequate sediment transport from upper river reaches affects the southern delta, where the Sundarban thrives.

Nutrient Imbalances: Nutrient deficiencies alter mangrove species composition.

Salt Stress: Elevated salinity levels induce changes in species diversity.

Human Activities: Mangrove clearing due to human interventions exacerbates degradation.

Anthropogenic Pollution: Pollution from various sources poses a significant threat.

The impact of environmental changes on mangrove reproductive processes

Salinity stress and reproductive success

Mangroves in the Sundarbans face varying salinity levels due to tidal fluctuations and freshwater influx. High salinity negatively affects reproductive success by inhibiting seed germination, reducing pollen viability, and altering flowering patterns. Some species, like *Avicennia*, exhibit halophytic adaptations to cope with salinity stress (Chowdhury *et al.* 2019)

Temperature and flowering phenology

Rising temperatures influence flowering phenology. Early flowering may lead to asynchrony with pollinators, affecting fruit set. Temperature extremes can disrupt the timing of male and female reproductive phases, impacting overall reproductive success (Chakrabarty *et al.* 2022)

Sea level rise and seed dispersal

Sea level rise affects seed dispersal mechanisms. Increased inundation may limit seedling establishment. Floating propagules (viviparous species) may disperse farther under altered tidal regimes, affecting gene flow (Van der Stocken *et al.* 2018)

Pollinator availability and climate change

Changes in pollinator behavior due to climate shifts impact mangrove reproduction. Bees, flies, and wind play crucial roles in pollination. Altered pollinator availability affects fruit set. In summary, understanding how climate change affects pollinators is crucial for mangrove conservation. Maintaining healthy pollinator populations ensures

successful reproduction and contributes to mangrove resilience (*Climate change is most prominent threat to pollinators.* 2024. *ScienceDaily*).

Anthropogenic stressors

Pollution, habitat destruction, and coastal development disrupt mangrove ecosystems. Chemical pollutants (heavy metals, pesticides) can impair reproductive processes. The coastal ecosystem is endangered due to heavy metals (HMs) contamination due to anthropogenic activities. Mangrove ecosystems faced adverse effects of HMs toxicities. Mangrove species mitigate HMs toxicities dependent on HMs type and concentration. Mangroves tolerate HMs toxicity through cell wall immobilization, complexation with biomolecules, and extracellular barriers. Mangroves Phytoremediate HMs phytotoxicity through salt glands via adaxial trichomes (Ur Rahman *et al.* 2024)

Conservation implications

Understanding these interactions is vital for mangrove conservation. Habitat restoration, maintaining freshwater inflow, and protecting breeding grounds are essential. Mangrove forests provide critical services around the globe to both human populations and the ecosystems they occupy. However, losses of mangrove habitat of more than 50% have been recorded in some parts of the world, and these losses are largely attributable to human activities. The importance of mangroves and the threats to their persistence has long been recognized, leading to actions taken locally, by national governments, and through international agreements for their protection (Romañach *et al.* 2018).

Urgent actions and research focus

Spatial Mapping: Understanding blue carbon distribution across the Sundarban is critical.

Post-Cyclone Rehabilitation: Rehabilitating cyclone-damaged trees to maintain ecosystem integrity.

Estuarine Health: Enhancing estuaries in the upper delta to support mangrove growth.

Species Diversity: Afforestation efforts to sustain diverse mangrove communities.

Erosion Mitigation: Increasing sediment flow to combat coastal erosion.

Pollution Management: Urgently addressing marine pollution (Chanda and Akhand, 2023).

Conclusion

Mangroves are complex and dynamic ecosystems that continually change in response to a wide variety of biological, chemical and physical drivers. It is therefore difficult to unambiguously attribute one single change in the forest to one or several climate-related factors. Changes in mangrove variables (primarily extent, structure, biomass, diversity, and function) may therefore be more or less pronounced depending on the relative influence of different factors and interactions between these. The main implications of a changing climate on mangroves are a. Changes in extent and distribution; mangroves are likely to extend to higher latitudes due primarily to higher temperatures and reduced frost severity or move in a landward and/or seaward direction in response to changing sediment dynamics and inundation stress (e.g., as a result of increased rainfall, changes in salinity and rising sea levels). b. Modification of structure and changing productivity; a range of environmental factors (e.g., rainfall, temperature) will be influential but cyclonic activity and storms in particular will lead to a sudden alteration of forest structure and function (e.g., photosynthesis) through mechanical damage (e.g., loss of canopy height, basal area, tree density and foliage amount). c. Changes in species composition; those tolerant of conditions such as prolonged inundation, higher or lower salinity, and high temperature will respond well and species that can recover quickly from extreme events through tree sprouts and reserve meristems are likely to dominate forests following dieback events. d. Phenological changes; temperature increases will favor some species in terms of propagule, flower, and fruit production. Phenological processes will, however, be limited under stressful conditions such as reduced temperatures, prolonged inundation, and extreme salinities. The paper has reviewed evidence of how climate-related phenomena may be manifested within remote sensing data (Asbridge *et al.* 2015).

This review delves into the intricate relationship between environmental degradation and mangroves in the Indian Sundarbans. By examining existing research and proposing actionable steps, we aim to contribute to the conservation and sustainable management of this invaluable ecosystem.

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