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Impact of Rising Sea Levels on Coastal Forest Ecosystems

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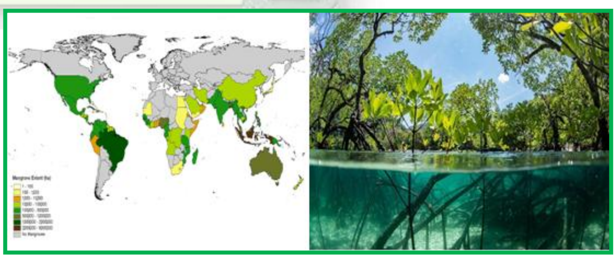
Coastal forests, especially mangrove ecosystems are threatened by saltwater intrusion in addition to storm surges and rising sea levels. The resilience and survival of mangrove forests and coastal vegetation are seriously challenged by these occurrences, which are made worse by climate change. An overview of the risks that mangrove forests and coastal ecosystems face is given in this. First of all the risk of inundation and erosion is increased by rising sea levels and storm surges, which causes habitat degradation and loss. Second, the development and dispersion of vegetation are impacted by the alteration of soil salinity levels caused by saltwater intrusion. Mangrove forests are especially susceptible because of their unique adaptations and ecological significance. In light of climate change, it is essential to recognize and mitigate these vulnerabilities for the management and protection of coastal forests. Mangrove forests and coastal ecosystems can be made more resilient to the effects of rising sea levels by implementing integrated adaptation and mitigation methods that are supported by scientific research and community involvement.

Key words: Coastal Forests, Mangrove Ecosystems, Community and Mitigation.

Introduction

Globally, rising sea levels are a serious threat to coastal ecosystems, particularly the crucial habitats of coastal forests. Ocean waters are expanding because glaciers and polar ice caps are melting at unprecedented rates due to human-induced climate change, which raises global temperatures. Sea levels have been rising alarmingly over the past few decades, a phenomenon further intensified by the thermal expansion of saltwater. The consequences extend far beyond flooding impacting flora, fauna, and the delicate balance of natural processes throughout ecosystems. Understanding the ecological dynamics between coastal forests and rising sea levels is essential for developing sustainable management and conservation measures. Coastal forests are dynamic ecosystems located at the land–sea interface and are rich in biodiversity and ecological functions. These forests act as natural buffers, shielding inland regions from storm surges, coastal erosion, and other hazards while significantly contributing to carbon sequestration through absorption and long-term storage of atmospheric carbon dioxide. Yet, as sea levels rise, coastal forests face unprecedented challenges that threaten their survival and stability[1].



Global Distribution of mangroves. (FAO : Status and Trends in Mangrove Area Extent Worldwide) (http://www.fao.org/docrep/007/j1533e/J1533E00.html)

Saltwater Intrusion and Vegetation Response

One of the most immediate impacts of sea-level rise is saltwater intrusion, the influx of saline water into freshwater systems. This disrupts soil salinity balance and affects vegetation composition and productivity. Many coastal forest tree species cannot tolerate high salinity, resulting in widespread mortality and shifts in community structure. Elevated salinity also degrades soil quality, hindering regeneration and making forests more vulnerable to other stressors such as invasive species and storms[2]. The decline of coastal forests due to rising sea levels has cascading effects on biodiversity and ecosystem services. Coastal forests support diverse flora and fauna, including migratory birds, marine species, and endemic plants. Their degradation leads to habitat loss, reduced ecosystem resilience, and declining water filtration, shoreline stabilization, and carbon storage services[3]. This not only endangers ecological integrity but also undermines the livelihoods of millions of coastal residents dependent on these ecosystems for sustenance and protection. As flooding intensifies, habitat fragmentation and isolation worsen, reducing genetic connectivity and the capacity of species to adapt to changing conditions. Fragmentation also weakens resilience to disturbances such as cyclones and disease outbreaks. The loss of connectivity between coastal forests and adjacent ecosystems diminishes the ability of natural systems to recover from shocks, making adaptation increasingly difficult. Protecting coastal forests from sea-level rise demands a multifaceted approach that integrates science, policy, and community engagement. Effective strategies include adaptive coastal land-use planning to prevent habitat loss, reforestation and habitat enhancement to restore degraded areas, and community-based management to promote stewardship. Collaboration among government agencies, NGOs, scientists, and local stakeholders is critical to safeguard these vital ecosystems and mitigate broader climate impacts[4].

Dual Threats: Rising Seas and Storm Surges

An unsettling shadow has been cast by climate change over coastal regions globally, as the combination of rising sea levels and intensifying storm surges presents dual threats of unprecedented magnitude. Extreme weather events, accelerated by anthropogenic warming, are reshaping coastlines and ecosystems. Rising sea levels, driven by greenhouse gas emissions such as carbon dioxide (CO_2), result directly from global warming linked to fossil-fuel combustion and deforestation[5]. The melting of glaciers and polar ice caps contributes to flooding of coastal areas and the gradual submergence of low-lying lands. The repercussions extend beyond shoreline erosion, encompassing saltwater encroachment, loss of freshwater resources, and the displacement of millions from vulnerable coastal communities[6]. Compounding these threats are storm surges, abnormal rises in sea level during storms, hurricanes, or typhoons. Warmer ocean temperatures enhance the intensity and frequency of such events, producing destructive surges that inundate coastlines and devastate both human and natural systems[7]. Together, rising seas and surges amplify the risks of coastal flooding and socioeconomic losses for vulnerable populations[8]. Addressing these combined hazards requires scientific understanding and innovative management. While structural defenses such as seawalls or flood barriers offer temporary protection, their environmental costs and long-term sustainability remain limited[9]. Increasingly, nature-based solutions including mangrove restoration, wetland preservation, and dune stabilization are being recognized for their dual role in enhancing resilience and providing critical habitat[10]. Mitigating the effects of climate change necessitates parallel adaptation and emission-reduction strategies. Policies that reduce greenhouse gas emissions, promote renewable energy, and encourage energy efficiency are essential[11]. Moreover, global cooperation and equitable support for vulnerable coastal communities are vital to ensure shared resilience and sustainable adaptation[12].

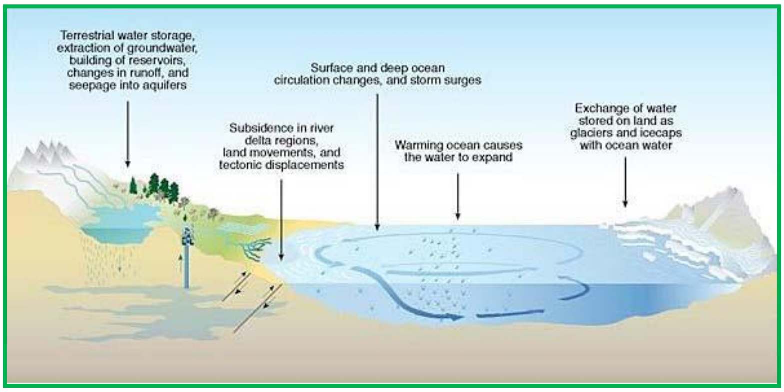
Saltwater Intrusion: Mechanisms and Impacts

Saltwater intrusion, intensified by both climate change and human activities, poses a grave threat to coastal vegetation and ecosystem dynamics[13]. It occurs through sea-level rise, storm surges, and anthropogenic pressures such as groundwater extraction and land reclamation[13].

Rising sea levels push saline water inland, contaminating freshwater aquifers and altering estuarine systems[14]. During extreme weather events, storm surges introduce large volumes of seawater into wetlands and estuaries, upsetting the balance between salt and fresh water[15]. Excessive groundwater extraction further lowers water tables, facilitating deeper saline penetration[16]. This process reshapes vegetation diversity and distribution. Many species are adapted to narrow salinity ranges; thus, intrusion allows salt-tolerant halophytes to expand while freshwater species decline[17]. Such transitions alter community composition and ecosystem function[18]. Mangroves and salt marshes already sensitive to hydrological shifts face additional stress, reducing productivity and regenerative capacity[19]. Consequently, losses in freshwater-dependent vegetation disrupt habitat functions, carbon sequestration, and shoreline stabilization[20]. Plants exposed to high salinity undergo distinct physiological adaptations. Salt-tolerant species exclude or compartmentalize salt ions, maintain osmotic balance, and regulate water uptake through biochemical mechanisms such as accumulation of glycine, betaine and proline[21,22]. Morphological adjustments reduced leaf size and extended roots also aid salt regulation[23]. However, prolonged exposure beyond tolerance limits results in tissue damage and reduced productivity[24]. Coastal vegetation underpins essential ecosystem services, supporting fisheries, carbon storage, and erosion control. Mangroves, salt marshes, and seagrass meadows serve as habitats for migratory birds and commercially valuable fish[25] while sequestering atmospheric CO_2 in biomass and sediments[26]. They stabilize shorelines, mitigating erosion and protecting human settlements from storm impacts[27]. The degradation of these vegetative buffers through saltwater intrusion therefore undermines ecological stability, economic security, and community resilience. To counteract these effects, mitigation and adaptation measures are crucial. Restoration and conservation of mangroves, salt marshes, and seagrass beds help maintain ecological integrity[28]. Sustainable groundwater management and reduced extraction can minimize intrusion[29]. Integrated coastal zone management, considering natural, climatic, and human factors, provides a holistic framework for sustainability[30]. Furthermore, international cooperation and investment in climate adaptation are vital for resilience building[31].

Vulnerability of Mangrove Forests and Coastal Ecosystems

Mangrove forests, among the most productive and valuable ecosystems, are particularly vulnerable to sea-level rise. Found in tropical and subtropical intertidal zones, mangroves support diverse species and sustain millions of people through coastal protection, fisheries, and carbon storage[2]. However, these ecosystems are increasingly endangered by climate-driven inundation, erosion, and salinity changes. Rising sea levels result in habitat submergence, land loss, and intensified saltwater intrusion, impairing mangrove growth and regeneration[32]. Coastal erosion, aggravated by higher sea levels, further accelerates mangrove degradation. As shorelines retreat, mangroves lose their ability to buffer wave energy and storm surges, leaving coastal populations exposed to extreme weather events. The deterioration of mangrove systems also diminishes their carbon sequestration potential, releasing previously stored carbon and creating feedback loops that intensify global warming[33].



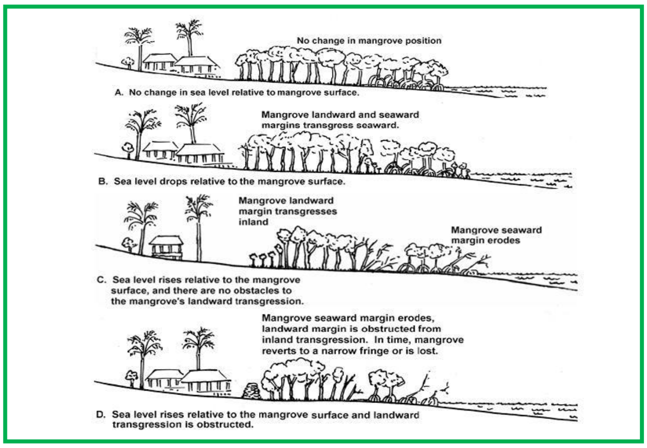
Causes of sea level rise. (UNEP)
(https://www.annualreviews.org/doi/full/10.1146/annurev-environ-101718-033302)

Impacts on Biodiversity

The vulnerability of mangroves to rising seas has major implications for biodiversity conservation. These forests harbor numerous endemic and endangered species that rely on their unique habitats for feeding and breeding. As sea levels rise, habitat loss and fragmentation disrupt ecological processes and threaten species survival[34]. Altered hydrology and salinity shifts modify species composition, enabling invasive species to spread and destabilize native communities[35].

Ecosystem Services at Risk

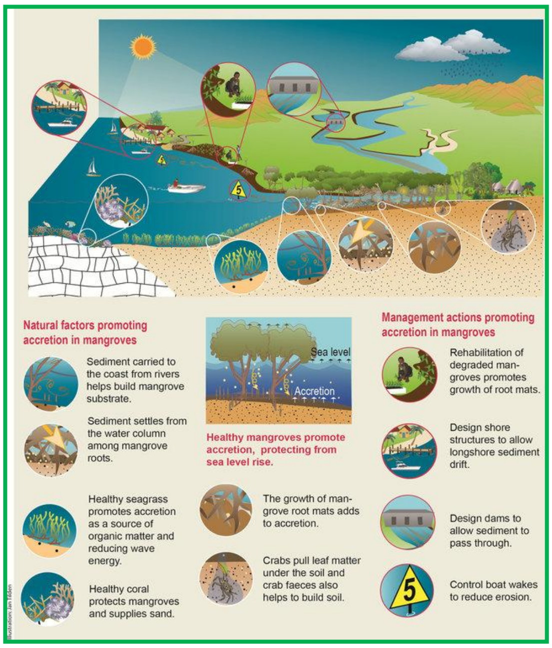
Mangroves provide essential ecosystem services such as coastal defense, carbon sequestration, and fishery support. Their dense root systems dissipate wave energy, reducing erosion and protecting coastal settlements[36]. They also store vast quantities of carbon within biomass and sediments, mitigating climate change impacts. However, as mangroves degrade under rising seas, this carbon is released, transforming them from carbon sinks into sources[37]. Declining mangrove health also affects fisheries, as nursery habitats for fish, crustaceans, and mollusks are lost, threatening food security and local economies[38].



Scenarios for generalized mangrove responses to changes in relative sea level. DOI: 10.1007/978-3-319-93284-2_9

Mitigation and Adaptation Strategies

Addressing mangrove vulnerability requires integrated conservation and management approaches. Establishing marine protected areas, enforcing sustainable management, and promoting community-based conservation strengthen resilience[39]. Incorporating ecosystem-based approaches such as using mangroves and wetlands as natural infrastructure into coastal development enhances adaptation capacity[40]. Investments in scientific research and long-term monitoring are necessary to understand mangrove responses to hydrological and climatic changes[41]. Collaborative international efforts, including knowledge sharing and coordinated restoration programs, are essential to confront the transboundary nature of sea-level rise[42].The escalating vulnerability of mangrove forests and coastal ecosystems to rising sea levels poses critical challenges to biodiversity, ecosystem functioning, and human welfare. Urgent and concerted action spanning policy, research, and grassroots implementation is needed to preserve these ecosystems. Through proactive conservation, adaptive management, and international cooperation, the resilience of mangroves and coastal forests can be strengthened, ensuring their invaluable services endure for future generations[43].



Management strategies to promote vertical accretion in mangroves (https://link.springer.com/article/10.1007/s11273-014-9397-8)

Conclusion

Mangrove and coastal forests are nature's first line of defense against the advancing impacts of climate change. Their survival is crucial not only for maintaining biodiversity but also for protecting shorelines and supporting coastal communities. As sea levels rise and salinity intrudes further inland, proactive conservation, restoration, and sustainable management become imperative. By combining scientific insight with local wisdom and collective action, we can preserve the strength and beauty of these ecosystems for generations to come.

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