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Mangrove Mortality in the Philippines: Ecological Drivers, Community Perspectives and Management Implications

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ABSTRACT

Mangrove ecosystems in the Philippines persistently decline, despite the substantial number of national and community-based rehabilitation initiatives. Despite the rehabilitation programs that have increased mangrove cover in several coastal regions, many sites continue to exhibit dieback, canopy degradation, and limited natural regeneration. Mortality patterns associated with hydrological alteration caused by aquaculture dikes, coastal infrastructure, and drainage modifications; sediment imbalance resulting from upland erosion, river modification, and localized siltation; salinity fluctuations linked to droughts, heavy rainfall, and changing freshwater inputs; and episodic disturbances induced by typhoons, storm surges, and heat extremes. These stressors impede root aeration, destabilize substrates, disrupt physiological processes, and hinder natural regeneration. Sensitive species, including *Ceriops tagal*, *Rhizophora mucronata*, and *Sonneratia alba*, exhibit insufficient establishment of juvenile cohorts in many sites, while disturbance-tolerant taxa such as *Avicennia marina* tend to dominate regenerating stands, resulting in reduced species diversity and uneven age structures. Community perceptions indicate broad awareness of mangrove ecosystem services and widespread participation in planting initiatives, yet perceived recovery may mask ecological vulnerabilities. Many restoration activities face difficulties because species are not aligned with their ecological zones, hydrological conditions are insufficiently assessed, and follow-up monitoring is inconsistent. Policy frameworks exist but are weakened by inconsistent implementation, hydrological planning, species-site matching, and long-term monitoring, which reduce restoration effectiveness. Improving mangrove resilience requires restoring tidal flow, selecting species appropriate to site conditions, strengthening monitoring systems, enhancing community ecological understanding, and adopting climate-responsive management. Coordinated ecological and institutional actions are essential to reduce mortality and support long-term ecosystem stability.

INTRODUCTION

Mangrove forests are among the most ecologically and economically valuable coastal ecosystems in the Philippines, providing critical services such as shoreline stabilization, nutrient cycling, nursery habitats for fisheries, and substantial carbon sequestration (Alongi, 2012; Primavera & Esteban, 2008). Historically, the country supported more than 500,000 hectares of mangroves; however, extensive conversion for aquaculture, timber extraction, and coastal settlement has reduced national cover by over 50% during the past century (Long *et al.*, 2014). Although recent restoration initiatives, including the National Greening Program and community-based planting efforts, have contributed to measurable increases in mangrove extent, gains in area do not necessarily translate into improvements in ecological condition, functionality, or resilience (Abino *et al.*, 2014).

Beyond their ecological functions, mangroves play a vital role in sustaining coastal communities by supporting fisheries, protecting infrastructure, and contributing to emerging ecotourism economies. Their continued degradation, therefore, poses both environmental and socio-economic risks. As emphasized by Manalo (2023), the preservation of mangrove ecosystems is essential not only for maintaining ecological balance but also for ensuring the availability of sustainable resources and community development.

Despite ongoing restoration efforts, increasing evidence indicates that mangrove mortality persists across multiple regions of the Philippines. This mortality is driven by interacting ecological stressors, including hydrological alteration, sediment imbalance, salinity fluctuations, rising temperatures, and intensified typhoon disturbances (Salmo, 2021; Lovelock *et al.*, 2017). These factors are further compounded by anthropogenic pressures such as aquaculture expansion, coastal development, pollution, and illegal harvesting, creating chronic conditions that limit regeneration and reduce species diversity (Primavera, 2006; Richards & Friess, 2016).

Local-scale studies from General Santos City reflect these national patterns, characterized by low species evenness, dominance of disturbance-tolerant *Avicennia marina*, and limited recruitment of more sensitive species such as *Ceriops tagal*, *Rhizophora mucronata*, and *Sonneratia alba*. Notably, community perceptions often emphasize visible increases in mangrove cover, while underlying structural degradation and ecological imbalance remain insufficiently recognized. This disconnect highlights

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the need for more integrated approaches that combine scientific assessment with community awareness.

Given these intersecting pressures, there is a critical need to synthesize current scientific evidence on mangrove mortality in the Philippines. This review paper aims to: (1) examine the ecological drivers of mangrove mortality in the Philippines, with a focus on hydrological changes, sediment disruptions, and climate impacts; (2) assess community perceptions and their influence on mangrove restoration efforts, highlighting the disconnect between local observations and scientific assessments; and (3) evaluate the effectiveness of current mangrove conservation strategies, including policy frameworks, species-site matching, and the integration of climate adaptation measures. By addressing these objectives, this review provides an in-depth analysis of the factors contributing to mangrove mortality and offers recommendations for improving conservation efforts and management practices.

LITERATURE REVIEW

Global and Regional Context of Mangrove Mortality

Recent research over the past decade indicates that mangrove mortality is an increasingly significant global concern, driven by the interaction of climatic extremes, sea-level rise, sediment dynamics, and anthropogenic pressures. Large-scale dieback events in northwestern Australia, associated with prolonged drought and elevated temperatures, demonstrate the high sensitivity of mangrove systems to hydrological stress and thermal anomalies (Duke *et al.*, 2017). Comparable patterns have been observed in the Mekong Delta, where altered freshwater inflows and coastal erosion have contributed to extensive stand degradation (Lovelock *et al.*, 2017). Collectively, these findings highlight the increasing influence of climate-driven stressors, which are projected to intensify under future warming scenarios.

Within Southeast Asia, mangrove loss continues to be strongly shaped by anthropogenic activities. Historical conversion for aquaculture remains a dominant driver of regional decline (Richards & Friess, 2016), while ongoing pressures, including sedimentation changes, pollution, and urban expansion, further exacerbate ecosystem vulnerability. Recent assessments emphasize that, despite a deceleration in deforestation rates, stand-level mortality and forest thinning remain underdetected in national monitoring frameworks (Hamilton & Casey, 2016). This distinction is critical, as mortality processes often precede observable forest loss and may serve as early indicators of long-term ecosystem instability.

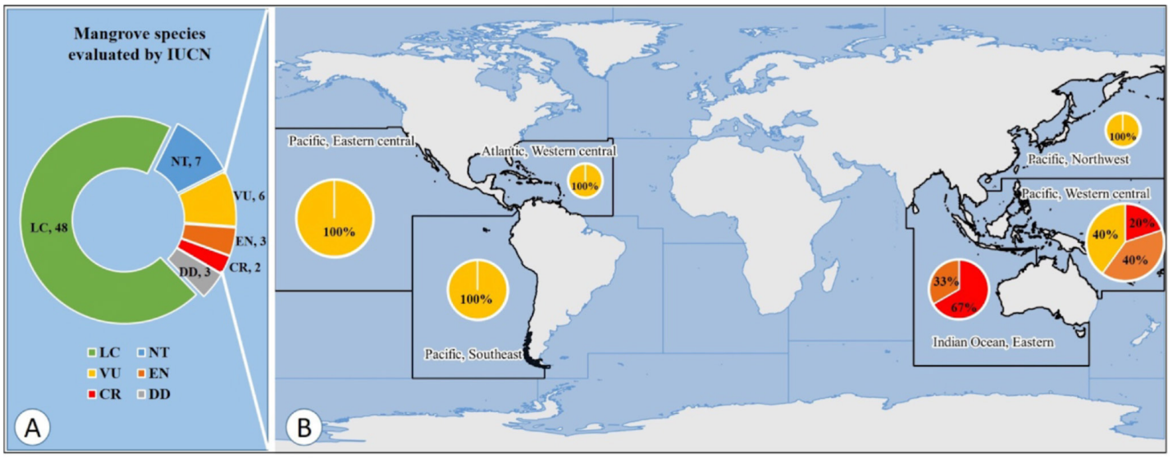

Figure 1: Global and regional patterns of mangrove mortality, including dieback events in northern Australia and Southeast Asia, illustrate the increasing influence of climate-driven stressors (Duke *et al.*, 2017; Lovelock *et al.*, 2017).

Mangrove Mortality in the Philippines

Mangrove mortality remains widespread in the Philippines despite sustained national and community-based rehabilitation efforts. Historical analyses attribute substantial declines in mangrove cover to aquaculture expansion during the 1970s to 1990s (Primavera, 2006). Although recent restoration initiatives, particularly under the National Greening Program, have contributed to increases in overall mangrove extent, stand-level assessments continue to report persistent mortality. These patterns are primarily associated with hydrological alterations, mismatches between species and site conditions, and unstable sediment substrates (Abino *et al.*, 2014).

Spatial assessments further identify mortality hotspots across Manila Bay, Palawan, Bohol, Leyte, Cebu, Sarangani Bay, and Davao Gulf. These areas are consistently linked to environmental stressors, including sediment burial and coastal erosion, tidal flow obstruction resulting in water stagnation, and salinity variability driven by altered freshwater inputs (Salmo, 2021). Local-scale evidence from General Santos City reinforces these regional patterns, indicating limited regeneration of disturbance-sensitive species, low species evenness, and the dominance of *Avicennia marina*. Such structural imbalances reflect reduced ecosystem complexity and suggest declining long-term resilience.

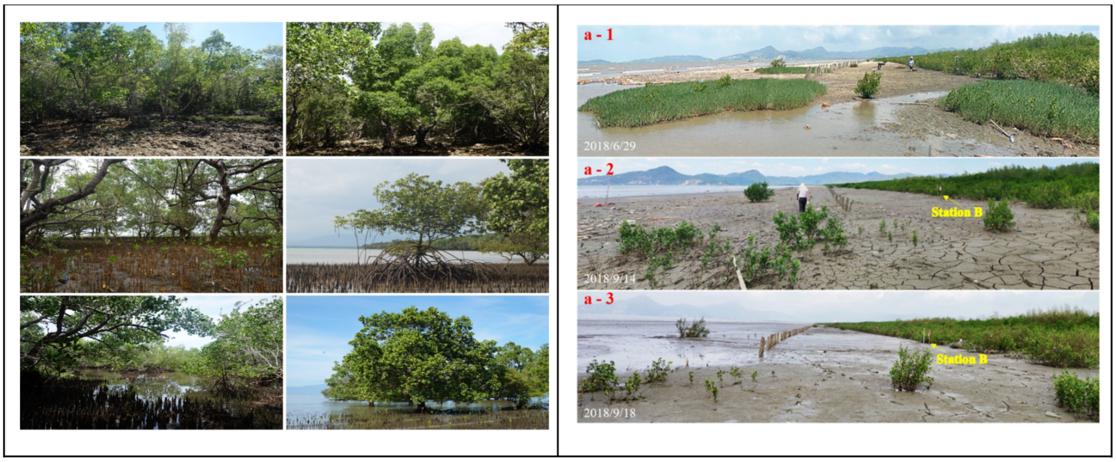

Figure 2: Side-by-side examples of healthy and degraded mangrove stands in the Philippines, illustrating mortality symptoms such as sediment burial, root exposure, canopy thinning, and poor regeneration (Abino *et al.*, 2014; Salmo, 2021; Zhang *et al.*, 2022; Agduma & Cao, 2023).

Ecological Drivers of Mangrove Mortality

Hydrological alteration is widely recognized as a primary driver of mangrove mortality. Obstruction of tidal exchange, commonly caused by blocked creeks, abandoned aquaculture dikes, and coastal infrastructure, restricts water circulation, leading to stagnant and hypoxic conditions that impair root respiration and promote sulfide toxicity (Krauss *et al.*, 2009). Sedimentation imbalance represents another critical driver, operating through both excessive burial and erosion. Burial of pneumatophores limits oxygen diffusion, increasing physiological stress and susceptibility to mortality, whereas erosion destabilizes substrates and exposes root systems to mechanical damage (Abino *et al.*, 2014).

Climatic stressors further interact with hydrological and sedimentary disturbances, amplifying their ecological impacts. Evidence from other tropical deltaic landscapes further shows that rainfall variability, land-cover change, and population growth interact to intensify environmental pressure on coastal ecosystems, highlighting the need to consider climate and human-driven land-use changes in assessing mangrove vulnerability (Akinrinwoye *et al.*, 2023). Extreme heat events, prolonged drought, and salinity anomalies, particularly during El Niño–Southern Oscillation phases, contribute to canopy stress, reduced photosynthetic efficiency, and propagule failure (Lovelock *et al.*, 2017). In addition, typhoon disturbances generate both immediate structural damage and delayed mortality through prolonged inundation and debris accumulation (Salmo, 2021). Species-specific responses are also evident. *Avicennia marina* exhibits relatively high tolerance to fluctuating salinity and inundation regimes, whereas *Ceriops tagal* and *Sonneratia alba* show reduced persistence under disturbed conditions. These differential responses contribute to shifts in species composition, often resulting in simplified forest structure and diminished ecosystem resilience.

Anthropogenic Drivers of Mangrove Mortality

Anthropogenic activities continue to exacerbate ecological vulnerabilities and accelerate mangrove mortality. Aquaculture expansion has created a persistent legacy of hydrological fragmentation, resulting in localized dieback and limited regeneration capacity in previously converted sites (Primavera, 2006). Coastal reclamation further intensifies these impacts by altering sediment transport dynamics, compacting substrates, and restricting the landward migration of mangrove zones. These changes increase exposure to prolonged inundation and salinity extremes, thereby reducing ecosystem adaptability under rising sea levels (Richards & Friess, 2016).

Pollution represents an additional and increasingly significant stressor. The accumulation of plastic debris and agricultural runoff alters soil chemistry, disrupts microbial processes, and impairs root function. Empirical evidence indicates that polluted environments are associated with reduced microbial activity and elevated seedling mortality rates (Goldberg *et al.*, 2020). Although illegal cutting has declined due to strengthened community-based regulation, it persists in several coastal barangays, leading to the removal of mature reproductive trees and a consequent reduction in propagule supply.

Local-scale evidence from General Santos City reinforces these patterns, with pollution and urban encroachment identified as the most prominent threats by coastal communities. Collectively, these anthropogenic pressures interact with existing ecological stressors, compounding system degradation and further constraining the natural recovery and resilience of mangrove ecosystems.

Community-Level Perspectives and Socioecological Dynamics

Recent studies highlight the importance of integrating community perceptions into mangrove management, recognizing that coastal residents often possess valuable experiential and ecological knowledge. However, gaps persist between local perceptions and scientific assessments of forest condition (Walters, 2000). Communities commonly attribute observed mangrove degradation to a combination of anthropogenic and natural drivers, including urban expansion, population growth, mangrove harvesting, aquaculture activities, and

Figure 3: Anthropogenic sources of mangrove mortality in the Philippines include aquaculture dikes, coastal reclamation, and pollution accumulation, which disrupt hydrology and soil quality (Primavera, 2006; Goldberg *et al.*, 2020).

destructive fishing practices, alongside extreme climatic events (Mohamed *et al.*, 2026). While these perceptions reflect an awareness of multiple stressors, they may not fully capture underlying ecological processes that influence long-term forest stability.

Evidence from General Santos City illustrates this disconnect. Local residents demonstrate high awareness of mangrove benefits and actively participate in planting initiatives; however, visible indicators such as seedling abundance are often interpreted as signs of ecological recovery. This contrasts with scientific findings that indicate species imbalance, dominance of disturbance-tolerant *Avicennia marina*, and limited recruitment of more sensitive species. Such discrepancies suggest that surface-level observations may obscure deeper structural and functional degradation within mangrove ecosystems. Community participation remains a critical component of mangrove conservation, as local stakeholders play a central role in resource stewardship and ecosystem protection (Manalo, 2023). However, misaligned perceptions can lead to suboptimal management practices, including planting in unsuitable sites, insufficient monitoring, and the continuation of interventions that may inadvertently increase mortality. Addressing these challenges requires the integration of scientifically grounded environmental education, participatory monitoring, and knowledge co-production. Bridging the gap between local understanding and ecological science is essential to ensure that community-based initiatives contribute effectively to long-term mangrove resilience and sustainability.

Management Implications and Policy Analysis

The Philippines possesses one of the most extensive

Figure 4: Community participation in mangrove planting activities in the Philippines, highlighting the role of local stewardship and the need for perception-aligned ecological education (Walters, 2000).

policy frameworks for mangrove conservation in Southeast Asia, including the Revised Forestry Code of the Philippines, the Philippine Fisheries Code, and the National Integrated Protected Areas System Act. Despite this comprehensive legal foundation, implementation gaps continue to constrain effectiveness. A persistent limitation lies in restoration practices that favor *Rhizophora* monocultures, frequently established in ecologically unsuitable environments such as mudflats and seagrass beds. These practices often result in low survival rates due to mismatches between species requirements and site conditions (Primavera & Esteban, 2008). In contrast, hydrology-based restoration approaches such as breaching abandoned fishpond dikes, reopening tidal creeks, and re-establishing natural water exchange have demonstrated significantly higher success and long-term stability (Walton *et al*., 2007). Similarly, community-based ecological mangrove rehabilitation emphasizes that successful restoration should not rely on planting alone but should integrate hydrological assessment, natural regeneration, site suitability, local governance, and sustained community participation (Brown *et al*., 2014). This approach is particularly relevant to Philippine mangrove restoration, where planting-based interventions often fail when hydrological conditions, species–site matching, and long-term monitoring are not adequately addressed.

Projected climate change impacts further underscore the need for adaptive and forward-looking governance. Sea-level rise will necessitate the landward migration of mangrove ecosystems; however, ongoing coastal development and infrastructure expansion continue to restrict these migration pathways (Hamilton & Casey, 2016). Consequently, effective policy responses must move beyond static protection measures and incorporate dynamic, ecosystem-based management strategies. Integrating ecological science, climate projections, and community-based governance mechanisms is critical to enhancing restoration outcomes, strengthening resilience, and ensuring the long-term sustainability of mangrove ecosystems.

MATERIALS AND METHODS

This review employed a structured narrative synthesis to examine mangrove mortality in the Philippines, focusing on ecological drivers, anthropogenic pressures, climate-related disturbances, community perspectives, and management implications. The study was based entirely on secondary data obtained from peer-reviewed journal articles, scientific book chapters, conference papers, and institutional reports relevant to mangrove degradation, regeneration, restoration, and conservation. Literature sources were retrieved from academic databases and publisher repositories, including Google Scholar, ScienceDirect, SpringerLink, Taylor & Francis Online, and other peer-reviewed journal platforms. Official reports from government and institutional sources, such as the Department of Environment and Natural Resources, PAGASA, IPCC, FAO/NACA, and SEAFDEC, were also considered to strengthen the policy and management context of the review. Philippines-based studies and locally relevant evidence, including findings from General Santos City and comparable tropical mangrove systems, were prioritized to ensure contextual relevance.

The selection of literature followed predefined inclusion and exclusion criteria. Studies were included if they addressed at least one of the following: mangrove mortality, forest degradation, regeneration failure, restoration outcomes, hydrological alteration, sediment imbalance, salinity stress, typhoon impacts, climate-related disturbances, aquaculture expansion, coastal development, pollution, community participation, or mangrove management. Studies were excluded if they were not directly related to mangrove ecosystems, lacked a clear methodological or empirical basis, focused mainly on unrelated coastal habitats, or provided insufficient information for qualitative synthesis.

The filtering process was conducted in three stages. First, titles and abstracts were screened to remove duplicate and irrelevant records. Second, the full texts of potentially relevant studies were reviewed to determine their direct contribution to the objectives of the review. Third, the retained literature was organized thematically according to ecological drivers, anthropogenic pressures, climate-related stressors, community-level perspectives, restoration practices, and policy implications. A total of 33 sources were retained and considered in the final analysis. These consisted of peer-reviewed articles, technical reports, policy-related documents, and locally relevant studies cited in the manuscript. Because the reviewed materials varied in research design, geographic scope, indicators, and analytical methods, a statistical meta-analysis was not conducted. Instead, the study used thematic synthesis to identify recurring patterns, evidence gaps, and management implications related to mangrove mortality in the Philippines.

RESULTS AND DISCUSSION

The analysis of the literature reveals several significant factors contributing to mangrove mortality in the Philippines. Hydrological alterations are identified as the most prominent ecological driver of mangrove decline. Disruptions in tidal exchange, caused by aquaculture dikes and coastal infrastructure, significantly impair mangrove regeneration. These changes restrict the flow of water, which is necessary for nutrient cycling and seedling establishment. Without proper tidal flow, mangrove ecosystems are exposed to hypoxic conditions that impede root respiration, a process crucial for regeneration. This finding aligns with Krauss *et al.* (2009) and Primavera & Esteban), who demonstrated that the obstruction of tidal exchange leads to severe degradation in mangrove forests. Additionally, sedimentation imbalances, including excessive burial of roots and coastal erosion, destabilize the substrate and hinder seedling establishment, which is essential for the survival of mangrove ecosystems (Abino *et al.*, 2014).

Climate-related disturbances also contribute significantly to mangrove mortality. Salinity fluctuations, extreme temperature events, and typhoon impacts exacerbate stress on mangrove ecosystems, leading to canopy degradation and seedling mortality. These climate-induced stressors are consistent with findings from Duke *et al.* (2017) and Lovelock *et al.* (2017), who found that extreme weather events, such as typhoons, reduce the regenerative capacity of mangrove ecosystems, causing damage to canopy structure and reducing seedling survival. As climate change continues to increase the intensity of such disturbances, mangrove ecosystems are becoming more vulnerable to long-term degradation.

On the anthropogenic side, aquaculture expansion and coastal reclamation were found to be persistent threats to mangrove ecosystems. These activities significantly alter hydrological patterns by obstructing natural water flow, further limiting the ability of mangroves to recover and adapt to environmental changes. The review also highlighted the ongoing issue of pollution from agricultural runoff and plastic debris, which affects soil chemistry and disrupts the microbial processes needed for healthy mangrove growth (Goldberg *et al.*, 2020).

Despite the widespread community participation in mangrove restoration, a disconnect exists between local perceptions and scientific assessments of mangrove health. Many communities interpret the visible increase in mangrove cover as a sign of successful restoration, despite underlying issues such as species imbalance and poor regeneration. *Avicennia marina*, a more disturbance-tolerant species, is often the dominant species in regenerating mangrove stands, while more sensitive species like *Ceriops tagal* and *Sonneratia alba* show limited recruitment. This reflects ecological degradation, despite the perceived success of planting efforts (Walters, 2000; Abino *et al.*, 2014).

In conclusion, this review underscores the complex interplay of ecological, climatic, and anthropogenic stressors in driving mangrove mortality. Hydrological alterations, including disruptions to tidal exchange and sedimentation imbalances, continue to be the most significant contributors to mangrove mortality. The effects of climate change, particularly extreme weather events, further exacerbate the vulnerability of mangrove ecosystems. Human activities, such as aquaculture and coastal reclamation, contribute to ongoing degradation by disrupting natural processes that support mangrove regeneration. Restoration efforts should prioritize hydrology-based strategies to restore natural tidal flow, species-site matching to ensure appropriate species selection, and community-based education to align local efforts with scientific restoration practices. By addressing these multifaceted stressors, mangrove ecosystems in the Philippines can be better protected, ensuring their long-term resilience.

A. Natural Regeneration

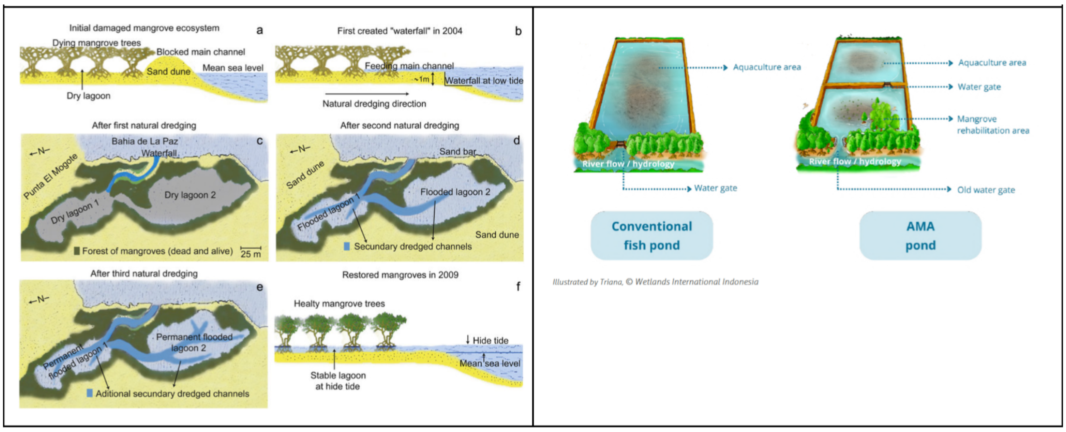

Figure 5: Hydrological restoration approaches used in mangrove rehabilitation, including dike breaching and tidal channel reconnection, improve sediment exchange, water flow, and oxygenation necessary for seedling establishment (Bashan *et al.*, 2013; Krauss *et al.*, 2009; Primavera & Esteban, 2008).

B. Species-Site Matching (Zonation)

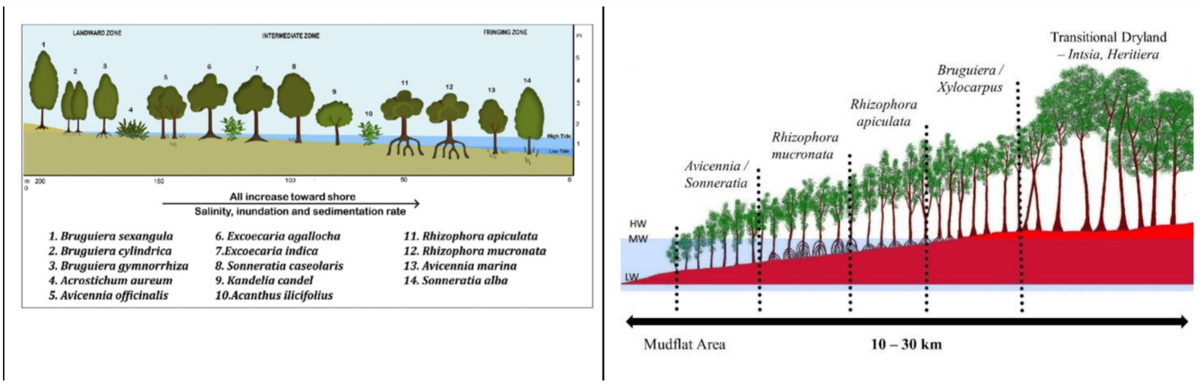

Figure 6: Mangrove zonation patterns showing natural distribution of key species such as *Avicennia, Sonneratia*, and *Rhizophora* across salinity and hydrodynamic gradients, supporting ecologically appropriate species-site matching in restoration planning. (Sreelekshmi *et al.*, 2018; Hashim & Shahruzzaman, 2017; Walton *et al.*, 2006).

C. Natural Regeneration

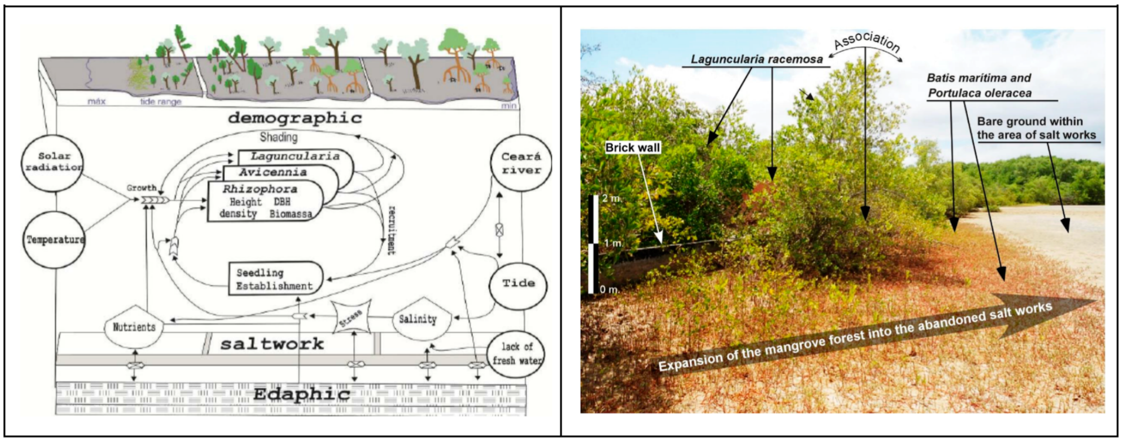

Figure 7: Natural regeneration in hydrologically functional mangrove zones demonstrates spontaneous seedling establishment and self-organization that often outperform artificial planting in survival and ecological alignment (Chazdon & Guariguata, 2016; Abino *et al.*, 2014; Reis-Neto *et al.*, 2019).

D. Monitoring System

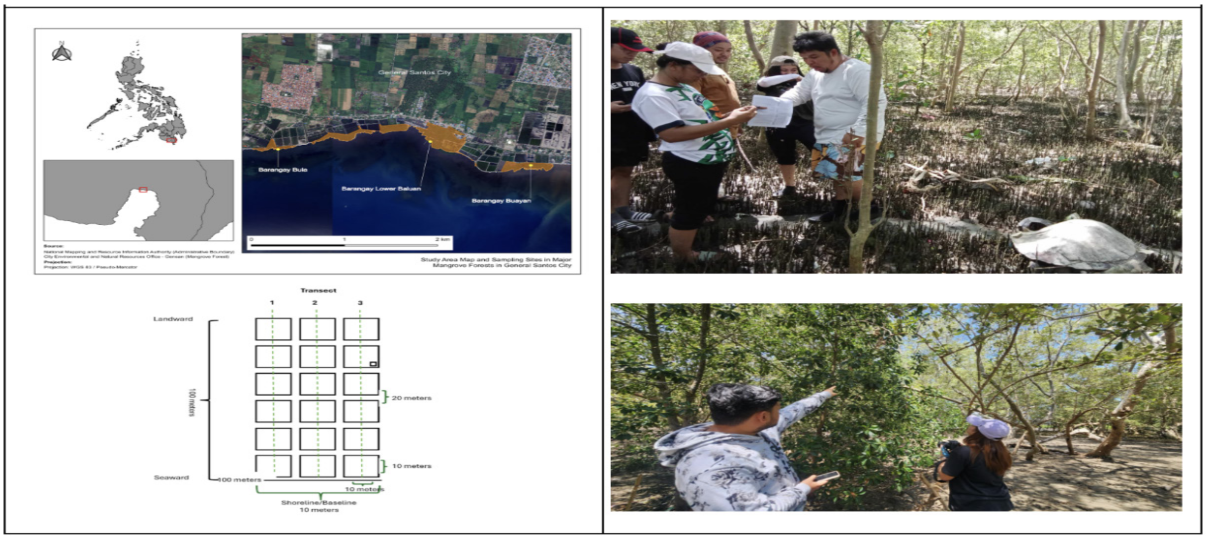

Figure 8: Monitoring tools used in mangrove assessment include drone-based imaging, GIS mapping, and on-site structural surveys. These approaches enable long-term evaluation of structure, health, and mortality trends (Friess *et al.*, 2019; Hamilton & Casey, 2016).

E. Community Participation in Conservation

Figure 9: Community participation in mangrove rehabilitation activities in the Philippines, emphasizing the role of local stewardship and collective action in sustaining restoration outcomes (Walters, 2000).

CONCLUSION

The evidence synthesized in this review demonstrates that mangrove mortality in the Philippines is driven by interacting ecological, climatic, and anthropogenic stressors that reduce forest resilience despite restoration efforts. Major findings identify hydrological alteration from aquaculture dikes, coastal infrastructure, and drainage modification as the dominant driver because it restricts tidal exchange, creates hypoxic and sulfide-rich sediments, and limits seedling establishment. Sediment burial, erosion, salinity fluctuations, extreme heat, and typhoon disturbances further intensify canopy decline, root stress, and regeneration failure. Local evidence from General Santos City reflects these patterns through the dominance of disturbance-tolerant *Avicennia marina*, limited recruitment of sensitive species, and a mismatch between community-perceived recovery and actual ecological condition. To improve resilience, restoration should first restore hydrological function by reopening tidal channels, breaching or removing flow obstructions, and improving water circulation before planting. Species selection should follow natural zonation, site suitability, and ecological tolerance instead of monoculture planting. Long-term monitoring, climate-responsive planning, stronger inter-agency coordination, and community education on ecological indicators are recommended to reduce mortality, improve survival, and support sustainable mangrove management. These actions are essential to ensure that reported gains in mangrove cover translate into functional, diverse, and resilient coastal ecosystems.

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