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Degradation of Mangrove Ecosystems in Banyuasin Regency, South Sumatra: Extent of Damage, Causes, and Ecological Impacts

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Abstract: This study aims to examine the scale of damage, identify the contributing factors, and analyze the resulting ecological impacts. The research employed a qualitative descriptive approach through field observations, interviews with coastal communities, and a literature review. Observations were conducted to assess the biophysical condition of mangroves, including vegetation density, stand structure, species composition, and indicators of degradation. Interviews were used to gather information on mangrove utilization activities, socio-economic pressures, and community perceptions of environmental change. The literature review supported the interpretation of field findings within the context of regional and global mangrove dynamics. The results indicate that mangrove degradation in Banyuasin is driven by a complex interaction between anthropogenic factors—particularly land conversion, resource exploitation, and coastal development—and natural factors such as abrasion, sedimentation, and tidal flooding. The identified ecological impacts include a decline in coastal protection functions, reduced habitat quality for coastal biota, and decreased carbon storage capacity. The conclusion of this study emphasizes the need for an integrated coastal management strategy that incorporates ecologically appropriate rehabilitation, strengthened governance, and community participation in order to sustainably enhance the resilience of mangrove ecosystems.
Keywords: Mangrove degradation; coastal ecosystem; anthropogenic pressure; ecological impacts

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INTRODUCTION

Mangrove ecosystems constitute one of the most important coastal ecosystems, playing strategic ecological, social, and economic roles. Ecologically, mangroves function as natural barriers that protect coastlines from erosion, seawater intrusion, and extreme waves, while also serving as critical habitats for various species of fish, crustaceans, and other aquatic organisms. In addition, mangroves are recognized as highly effective absorbers and reservoirs of blue carbon, possessing a substantial capacity to store carbon both in aboveground biomass and within sedimentary soils. This function positions mangroves as a crucial component in global climate change mitigation efforts (Alongi, 2014; Melki & Isnaini, 2014).

From a socio-economic perspective, mangrove ecosystems contribute directly to the sustainability of coastal community livelihoods through capture fisheries and aquaculture, the utilization of non-timber forest products, and the development of environmental services such as ecotourism and coastal protection. Therefore, mangroves not only function as ecological buffers but also serve as fundamental pillars supporting the socio-economic resilience of coastal communities. However, over the past several decades, mangrove ecosystems in Indonesia have faced serious pressures resulting from anthropogenic activities and changes in coastal environmental dynamics, which have triggered widespread and systematic degradation (Friess et al., 2019; Kurniawansyah et al., 2023).

At the national level, Indonesia possesses the largest mangrove area in the world, covering approximately 3.36 million hectares according to data from the Ministry of Environment and Forestry (KLHK, 2023). Despite this substantial resource potential, a considerable portion of these mangrove areas has experienced varying degrees of degradation, ranging from minor ecological disturbance to significant loss of forest cover. In South Sumatra Province, the eastern coastal region—including Banyuasin Regency—represents one of the mangrove areas that plays a vital role in maintaining the stability of coastal ecosystems in eastern Sumatra (Theresia et al., 2016). Mangroves in this region function as buffers for estuarine systems, controllers of erosion and coastal abrasion, and primary habitats for various economically valuable aquatic species (Alongi, 2014; Ilmu et al., 2019).

However, several studies have reported a decline in both the quality and extent of mangrove forests in Banyuasin Regency as a result of land-use conversion for aquaculture ponds, agriculture, settlements, and coastal infrastructure development (Ilmu et al., 2019; Reflis, 2025). Furthermore, logging activities, hydrological alterations, uncontrolled sedimentation, and increasing coastal development pressures have accelerated the degradation process (Friess et al., 2019; Kurniawansyah et al., 2023). This degradation has directly affected the reduction of coastal protection functions and increased the risk of coastal abrasion, decreased carbon storage capacity, and disrupted the habitat and productivity of aquatic biota (Alongi, 2014). These ecological impacts ultimately have socio-economic implications, particularly in reducing the welfare of coastal communities that depend heavily on mangrove resources (Theresia et al., 2016; Sarno et al., 2024).

Although several studies have examined mangrove conditions in South Sumatra, most previous research remains partial in scope. Some studies have focused on vegetation structure and species composition, while others have emphasized changes in mangrove cover or socio-economic impacts separately. Comprehensive studies that integrate quantitative analysis of degradation levels, identification of the main drivers of degradation, and evaluation of ecological impacts within a single analytical framework at the scale of Banyuasin Regency remain relatively limited. This condition indicates the existence of a research gap in providing integrated information that can support the formulation of evidence-based and regionally contextualized mangrove management strategies.

Therefore, this study proposes an integrated analytical approach that combines the identification of the levels and spatial patterns of mangrove degradation, the evaluation of the primary causal factors, and the assessment of ecological impacts within a framework of sustainable coastal management in Banyuasin Regency. Specifically, this study aims to (1) analyze the level and spatial distribution of mangrove ecosystem degradation, (2) identify the main driving factors that trigger degradation, and (3) evaluate the resulting ecological impacts as a basis for developing adaptive, evidence-based, and sustainable mangrove management and restoration strategies.

METHOD

This study employed a qualitative descriptive approach with a qualitative case study design. This design was selected because the research focused on an in-depth examination of the phenomenon of mangrove ecosystem degradation within the specific coastal context of Banyuasin Regency, South Sumatra Province. The case study approach enabled a comprehensive exploration of the degradation conditions, causal factors, and ecological impacts through in-depth interviews and a literature review.

The research was conducted in the coastal areas of Banyuasin Regency, which are characterized by extensive mangrove ecosystems, aquaculture ponds, and coastal settlements. Administratively, the study focused on several coastal villages that maintain direct interactions with mangrove forests and coastal resource utilization activities, such as capture fisheries and aquaculture farming. The region is characterized by significant anthropogenic pressures, including land-use conversion, mangrove logging, and coastal aquaculture activities, all of which potentially influence the ecological condition of mangrove ecosystems.

Primary data were collected through semi-structured interviews with 10 informants selected using a purposive sampling technique. The informants consisted of two coastal community members, two fishermen, two aquaculture pond managers, two community leaders, and two village officials, all of whom were considered to possess relevant knowledge and experience regarding the condition of mangrove ecosystems. Interviews were conducted in March 2024, with each session lasting approximately 30–60 minutes. The interviews focused on gathering information regarding changes in mangrove conditions, forms of mangrove resource utilization, human activity pressures, perceptions of environmental degradation, and the ecological and socio-economic impacts experienced by the community. This interview approach was intended to capture empirical experiences, local knowledge, and the dynamics of community interactions with the mangrove ecosystem.

In addition to interviews, the study also employed field observations to obtain a direct overview of the physical condition of the mangrove ecosystem. Observations were conducted using a non-participatory approach, documenting mangrove vegetation characteristics, indications of degradation (such as logging, land conversion, and coastal abrasion), and resource utilization activities around the coastal area. The observational findings served as supporting data to strengthen the interview results.

Secondary data were obtained through a literature review of national and international scientific journals, reference books, and institutional reports from organizations such as the Ministry of Environment and Forestry (KLHK), Peatland and Mangrove Restoration Agency (BRGM), Geospatial Information Agency (BIG), Meteorology, Climatology, and Geophysics Agency (BMKG), FAO, UNEP, and IPCC. The literature review focused on the ecological functions of mangroves, patterns and mechanisms of degradation, causal factors of ecosystem damage, ecological and socio-economic impacts, and strategies for rehabilitation and sustainable management.

Data analysis was conducted using a descriptive qualitative approach with an interpretative framework. Data obtained from interviews and observations were analyzed to describe the current condition of the mangrove ecosystem and the forms of degradation identified. Subsequently, empirical findings were compared and synthesized with previous research to explain the relationships between anthropogenic pressures, coastal environmental dynamics, and the responses of mangrove ecosystems. An integrative approach was employed to strengthen the validity of the interpretation by ensuring consistency between field evidence and theoretical foundations.

RESULTS AND DISCUSSION

Research conducted in the coastal area of Banyuasin Regency, South Sumatra Province, showed that mangrove ecosystem degradation was influenced by a complex interaction among anthropogenic pressures, coastal environmental dynamics, and community socio-economic factors. These findings indicated that mangrove degradation occurred gradually and cumulatively as a result of the combined effects of land-use change, natural resource exploitation, and coastal and climatic dynamics (Alongi et al., 2021).

Scale and Level of Mangrove Degradation in Banyuasin

Field research in the coastal area of Banyuasin Regency showed that mangrove ecosystem degradation identified through interviews and field observations was consistent with the condition of mangrove degradation at the scale of South Sumatra Province. According to Pandji, the total mangrove area in South Sumatra reached 345,990 hectares, with the largest distribution found in Ogan Komering Ilir Regency and Banyuasin Regency. Of this total area, approximately 18.23% was categorized as critical, covering 565 hectares, while 62.5 hectares were classified as very critical.

These findings reinforced the field observations in Banyuasin, where some mangrove areas exhibited signs of degradation, including reduced vegetation density, stand fragmentation, and the emergence of open areas. Furthermore, interviews with 10 informants are presented in Table 1.

Table 1. Indications of mangrove degradation based on informant perceptions (n = 10)

Degradation Indicator	Number of Informants	Percentage (%)
Decline in mangrove cover	8	80
Increased coastal abrasion	7	70
Conversion into aquaculture ponds	6	60
Decline in fishery catches	6	60
Mangrove cutting	5	50

Based on the perceptions of the 10 informants, the most dominant indication of mangrove degradation was the decline in mangrove cover (80%), followed by increased coastal abrasion (70%). In addition, conversion into aquaculture ponds and declining fishery catches were each reported by 60% of informants, while mangrove cutting was reported by 50%. These data showed that mangrove degradation was perceived to have both ecological and socio-economic impacts. This was acknowledged by a fisher during the interview process, who stated that, "Mangroves are no longer as dense as they used to be. When large waves come, the coast erodes more quickly."

Field observations also identified the presence of tree stumps from previous cutting, active and inactive pond canals, and shoreline changes at several points along the Banyuasin coast. These conditions indicated that mangrove degradation was not only structural in nature but also directly affected coastal stability. Unlike global mangrove degradation, which is often dominated by large-scale industrialization, mangrove degradation in Banyuasin was fragmented and driven by local activities, particularly traditional aquaculture and pressures from coastal development.

Causes of Mangrove Degradation

Mangrove degradation in Banyuasin was dominated by anthropogenic factors. Informants emphasized that mangrove degradation in South Sumatra was triggered by illegal encroachment for pond construction and port expansion. These findings were consistent with the interview results, in which 60% of informants identified mangrove conversion into aquaculture ponds as the main cause of degradation. This was also acknowledged by a community leader during the interview process, who stated that, "Mangroves were cleared for ponds because of economic needs, but the impacts are now being felt."

In addition, field observations found changes in water management and hydrological flow resulting from pond canal construction, which accelerated mangrove vegetation degradation and increased vulnerability to coastal abrasion. The drivers of degradation in Banyuasin were closely linked to the community's economic dependence on fisheries and aquaculture, meaning that ecological pressure was rooted in local socio-economic dynamics rather than solely in large-scale industrial exploitation.

Based on field observations, land-cover change analysis, and interviews with coastal communities in Banyuasin Regency, this study found that mangrove ecosystem degradation resulted from the complex interaction between anthropogenic pressures and natural factors, as reported in the recent literature on global mangrove dynamics (Hamilton & Casey, 2021; Friess et al., 2022). The factors causing mangrove ecosystem degradation are described below:

1. Anthropogenic factors (mangrove land conversion)

Interpretation of field conditions indicated that mangrove land had been converted into agricultural land and aquaculture ponds, as reflected by declining mangrove stands and increasing open land in locations with easy access to water transportation. This pattern was consistent with the results of mangrove cover change mapping in Southeast Asia, which identified land-use conversion as the primary cause of mangrove loss (Richards & Friess, 2020).

The conversion of mangrove land into ponds and agricultural areas was the dominant factor causing degradation, as it not only reduced total cover but also caused habitat fragmentation and disrupted ecological functions such as coastal protection and carbon storage (Mcleod et al., 2020; Friess et al., 2022). In the context of coastal ecosystems, extensive land-use change reduced the capacity of mangroves to provide essential ecosystem services (Hamilton et al., 2021). Because of its permanent nature, land conversion also slowed the natural regeneration of mangroves, which depends on stable hydrological and sedimentary patterns (Seto et al., 2021). The imbalance between economic needs and ecosystem sustainability remains a critical issue in coastal area management in developing countries (Barbier, 2016).

2. Exploitation and encroachment

Field findings recorded mangrove cutting at various scales to meet the demand for firewood and local construction materials, as well as land encroachment practices in the absence of clear spatial planning regulations. This exploitation contributed to declining vegetation density, which in turn slowed the process of natural succession (Alongi et al., 2021; Lovelock et al., 2021).

Continued selective cutting, even at a small scale, can disrupt stand structure and reduce ecosystem resilience to hydrological disturbance and environmental change (Hamilton & Friess, 2021). In the long term, exploitation pressure increases coastal vulnerability to abrasion and accelerates widespread mangrove degradation (Friess et al., 2022).

3. Infrastructure development

In areas adjacent to coastal development zones—including around Tanjung Api-Api—a decline in mangrove vegetation density was observed alongside increasing development activity and economic mobility. Coastal infrastructure development can affect hydrological characteristics, sediment dynamics, and salinity, which ultimately have negative impacts on the growth and distribution of mangrove vegetation (Lovelock et al., 2021; Friess et al., 2022).

Global studies on the impacts of coastal development have shown that changes in water flow, land reclamation, and road or port construction alter sediment and tidal patterns, thereby inhibiting mangrove regeneration processes (Hamilton et al., 2021). This is consistent with the field findings in Banyuasin, where development pressure had both direct and indirect impacts on mangrove ecosystem structure.

4. Community socio-economic pressure

Interviews with coastal communities revealed that most residents remained highly dependent on mangrove resources for their livelihoods, including wood harvesting, pond land clearing, and the collection of coastal fauna for household consumption. This dependence reflected the vital role of mangroves as a source of local ecosystem services, but also indicated continuous anthropogenic pressure in the absence of viable economic alternatives (Seto et al., 2021; Friess et al., 2022).

Community-based conservation approaches are therefore crucial in addressing this pressure. Adaptive strategies such as silvofisheries (the integration of fish farming and mangrove vegetation), mangrove ecotourism, and participatory rehabilitation have been identified in international studies as effective solutions for balancing economic and ecological objectives (Richards & Friess, 2020; Hamilton & Casey, 2021).

5. Natural factors

Observations along the Banyuasin coast showed coastal landscape dynamics characterized by shoreline shifts, localized abrasion, and sedimentation in estuarine areas, reflecting active natural processes in the land–sea transition zone (Woodroffe, 2018; Lovelock et al., 2021). These changes in the coastal landscape were influenced by the interaction of ocean currents, tides, and river sediment supply, all of which jointly affected mangrove habitat structure (Woodroffe, 2018). Coastal abrasion can erode the seaward mangrove zone, while excessive sedimentation disrupts root systems and oxygen exchange, both of which are essential for vegetation growth (Alongi et al., 2021; Lovelock et al., 2021).

The periodic occurrence of tidal flooding, especially during maximum high tides, indicated changes in relative sea level and coastal oceanographic dynamics (BMKG, 2024). Prolonged tidal inundation can increase salinity stress and reduce mangrove vegetation productivity, particularly when the rate of sea-level rise exceeds the adaptive and sediment accretion capacity of the ecosystem (IPCC, 2022; Lovelock et al., 2021).

6. Stand structure and ecological characteristics

At several locations, mangrove stands were found to be in declining physiological condition, as indicated by the dominance of old trees and low natural regeneration. This condition suggested a reduced ecosystem resilience to both anthropogenic and natural disturbances (Walters et al., 2008; Alongi et al., 2021). Ecological characteristics such as stand age and regeneration capacity play an important role in mangrove resistance to hydrological change, extreme salinity, and other environmental disturbances. Stands dominated by old trees with limited regeneration indicate lower adaptive capacity, thereby increasing the risk of vegetation mortality and accelerated degradation (Friess et al., 2022; UNEP, 2020).

Impacts of Mangrove Forest Degradation

Mangroves serve strategic ecological functions as coastal buffers, nutrient providers, and habitats for marine biota. Pandji emphasized that mangrove ecosystems are among the primary producers supporting marine fisheries. In addition, mangroves store exceptionally high carbon reserves, reaching 891.70 tons of carbon per hectare, which is nearly equivalent to the carbon storage capacity of peatland ecosystems.

The South Sumatra Marine and Fisheries Agency stated that mangrove degradation directly affects the decline in fishery potential. Data showed that in 2020, the utilization of marine aquatic commodities in South Sumatra reached 48,186 tons, while marine catches were only around 44,311 tons per year. This imbalance has encouraged fishers from South Sumatra to fish as far as the Natuna waters. These findings are in line with the field interview results, in which 60% of informants stated that fish catches had declined in recent years.

Mangrove forest degradation in the coastal area of Banyuasin Regency has generated various environmental impacts, particularly by disrupting the balance of the coastal ecosystem. Mangrove degradation caused by anthropogenic pressure has direct implications for declining ecological functions, reduced physical coastal stability, and the sustainability of coastal biological resources, as described below:

1. Decline in ecological functions

The decline in mangrove ecological functions in the coastal area of Banyuasin Regency is a logical consequence of reduced vegetation cover and density caused by land conversion, resource exploitation, and coastal dynamic pressures. Degradation of mangrove stand structure directly reduces the ecosystem's capacity to attenuate wave energy, stabilize sediments, and protect the shoreline from hydrodynamic disturbance (Alongi, 2015; Barbier et al., 2011). Recent studies have confirmed that reduced complexity of mangrove roots and canopies is associated with greater coastal vulnerability to erosion and geomorphological disturbance (Friess et al., 2022).

In addition to their coastal protection function, mangrove degradation has significant effects on the coastal carbon cycle. Mangroves are among the most efficient blue carbon ecosystems; therefore, mangrove degradation has the potential to increase carbon emissions through the release of carbon stocks from biomass and sediments (Donato et al., 2011; Lovelock et al., 2021). From a climate change perspective, mangrove loss weakens the natural mitigation capacity of coastal zones against rising greenhouse gas concentrations (IPCC, 2021).

The decline in mangrove habitat quality also affects its ecological role as a nursery ground, feeding ground, and shelter for various species of fish, crustaceans, and waterbirds. Disturbance to habitat structure reduces biodiversity and the productivity of coastal fisheries that depend on the connectivity of the mangrove–estuary–sea ecosystem (Nagelkerken et al., 2008; Friess et al., 2022).

2. Coastal abrasion and tidal flood risk

The reduction in mangrove vegetation increases coastal vulnerability to abrasion due to the loss of natural shoreline protection. The complex mangrove root system functions as both a sediment trap and a wave-energy buffer; damage to this system accelerates erosion rates and substrate instability (Krauss et al., 2009; Gedan et al., 2011). Global empirical evidence shows that coastal areas experiencing mangrove degradation undergo higher abrasion rates than areas with stable mangrove cover (Friess et al., 2022).

On the eastern coast of South Sumatra, mangrove degradation is associated with increasing frequency and intensity of tidal flooding and seawater intrusion. This phenomenon is influenced by the interaction of relative sea-level rise, local land subsidence, and changes in coastal hydrodynamics (Ward et al., 2016; IPCC, 2021). Prolonged tidal inundation not only damages mangrove vegetation but also disrupts infrastructure, settlements, and the economic activities of coastal communities (Lovelock et al., 2021).

3. Socio-economic impacts

Mangrove degradation has significant socio-economic implications, particularly for coastal communities that depend heavily on ecosystem services. Declining mangrove habitat quality contributes to reduced stocks of fish, shrimp, and crabs, thereby lowering the productivity of capture fisheries and aquaculture (Mumby et al., 2004; FAO, 2007). Recent studies have confirmed that mangrove degradation is correlated with reduced household income among fishers and increased local economic vulnerability (Barbier, 2016; Friess et al., 2022).

Community economic dependence on mangrove resources creates a negative feedback loop, in which declining productivity drives intensified exploitation of the remaining resources. In the long term, this condition has the potential to further worsen ecosystem degradation while increasing social risks, such as land-use conflicts and livelihood instability (Adger et al., 2005; Hamilton & Casey, 2021).

Restoration Efforts, Local Wisdom, and Challenges

Various mangrove conservation and rehabilitation initiatives have been implemented in the coastal area of Banyuasin Regency in response to ecosystem degradation driven by anthropogenic pressures and coastal environmental dynamics. Rehabilitation programs generally include replanting, the development of mangrove nurseries/seedlings, and the protection of areas experiencing abrasion and declining vegetation density (KLHK, 2023; BRGM, 2022). These efforts are aimed at restoring the ecological functions of mangroves as coastal protectors, habitats for coastal biota, and blue carbon reservoirs that play an important role in climate change mitigation (Alongi, 2015; Lovelock et al., 2021).

In addition to formal technical approaches, the social-ecological dimension expressed through the local wisdom practices of Banyuasin coastal communities has shown a significant contribution to maintaining ecosystem sustainability. Global studies have emphasized that community-based management can improve the success of mangrove restoration by strengthening social legitimacy, local compliance, and maintenance sustainability (Armitage et al., 2009; Berkes, 2012). In several coastal villages, communities have traditionally applied selective mangrove use practices, such as harvesting non-timber products without damaging the main stands, which ecologically helps maintain vegetation structure and regeneration (FAO, 2020; Datta et al., 2012).

Customary values, social norms, and local informal rules function as control mechanisms against overexploitation. Prohibitions on cutting in certain zones considered crucial for coastal protection and fish spawning habitats reflect a form of social adaptation to coastal ecological risk (Berkes, 2012). Recent empirical evidence shows that integrating local knowledge with scientific restoration approaches can enhance ecosystem resilience while strengthening the socio-economic resilience of coastal communities (Friess et al., 2022; Romañach et al., 2023).

Local wisdom is also reflected in mutual cooperation practices for mangrove planting and coastal area maintenance. Collective community participation strengthens the sense of ownership, which has been shown to influence mangrove seedling survival rates and the long-term success of restoration (Armitage et al., 2009; Bayraktarov et al., 2020). In addition, mangrove-based economic diversification—such as the development of processed products, ecotourism, and silvofisheries systems—has become an adaptive strategy capable of reducing pressure for land conversion and mangrove wood cutting (Barbier, 2016; Hamilton & Friess, 2018).

However, the effectiveness of integrating formal rehabilitation programs with local practices still faces several structural and technical constraints. Limited funding, weak post-rehabilitation assistance, and the lack of long-term monitoring can reduce restoration success (Lewis, 2005; Bayraktarov et al., 2020). In addition, mismatches between planted mangrove species and local hydrological and substrate conditions often result in low vegetation survival rates (Flores-de-Santiago et al., 2017; Friess et al., 2022).

Socio-economic challenges remain a key factor in the sustainability of rehabilitation efforts. Community dependence on coastal resources, combined with limited alternative livelihoods, has the potential to drive intensive mangrove use (Adger et al., 2005; Barbier, 2016). At the same time, social change, economic modernization, and shifts in cultural values may weaken local wisdom practices that previously functioned as instruments of ecological control (Berkes, 2012; Romañach et al., 2023).

Accordingly, the mangrove restoration approach in Banyuasin requires an integrated strategy that combines ecological interventions, strengthening of local institutions, and sustainable economic development. Synergy among government policy, scientific support, and community participation is a primary prerequisite for improving the long-term effectiveness of mangrove ecosystem recovery (Friess et al., 2022; IPCC, 2021).

CONCLUSION

This study concludes that the degradation of mangrove ecosystems along the coastal area of Banyuasin Regency is a multidimensional phenomenon driven by anthropogenic pressures, environmental dynamics, and socio-economic factors. The degradation is not only indicated by the reduction in mangrove cover area but also by decreased vegetation density, habitat fragmentation, and weakened stand structure, all of which reduce ecosystem resilience. Land conversion, resource exploitation, and infrastructure development constitute the primary drivers, further exacerbated by coastal abrasion, sedimentation, and tidal flooding. These impacts include the decline of coastal protection functions, disruption of the carbon cycle, degradation of habitats for marine and coastal biota, and increased economic vulnerability of coastal communities. Therefore, adaptive and evidence-based integrated coastal management is required, strengthening governance and encouraging community participation to ensure the long-term sustainability of mangrove ecosystems.

RECOMMENDATION

Based on the findings of the study on mangrove ecosystem degradation in the coastal region of Banyuasin Regency, South Sumatra, future research and management efforts should strengthen integrated coastal management that balances ecological, social, and economic aspects while controlling the conversion of mangrove land. Rehabilitation initiatives should be based on local biophysical suitability to ensure effectiveness and long-term sustainability, accompanied by strengthened governance and integrated regulatory enforcement between central and regional authorities. Increasing community participation through education and the development of environmentally sustainable livelihoods is also essential. In addition, technology-based monitoring and further studies on blue carbon, biodiversity, and coastal resilience to climate change should be expanded through multi-stakeholder collaboration.

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