



The role of community capacity in shaping responses to mangrove ecosystem degradation

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ABSTRACT

Background: Previous studies have examined mangrove degradation from both biophysical and socio-economic perspectives; however, only a limited number have investigated how community capacity influences the types of responses that emerge in response to ecosystem degradation. This issue has become increasingly relevant as mangrove planting is no longer entirely feasible in some ecological settings. This study aims to analyze the role of community capacity in shaping responses to mangrove ecosystem degradation and its implications for environmental sustainability in the coastal area of Demak Regency. **Methods:** The research employs a qualitative approach using a case-study design based on secondary data. Data were collected from scientific journal articles, government reports, policy documents, and publications from relevant institutions. Data analysis employed a social-ecological systems approach incorporating adaptive capacity theory, ecosystem services, sustainability transformation, and community-based natural resource management frameworks. **Findings:** The findings indicate that mangrove ecosystem degradation has triggered a range of community responses, from repeated symbolic planting activities to more adaptive restoration efforts. These variations are influenced by differences in community capacity, particularly in terms of local institutions, social learning, and the ability to coordinate with external actors. **Conclusion:** The study concludes that community capacity plays a crucial role in determining whether responses to mangrove degradation are adaptive and sustainable or remain limited to short-term activities. Strengthening community capacity is therefore essential for developing more context-specific and sustainable responses to mangrove degradation. **Novelty/Originality of this article:** The novelty of this study lies in positioning community capacity as a determining factor in shaping responses to mangrove ecosystem degradation, rather than merely as a supporting factor for rehabilitation success, especially in contexts where ecological limitations restrict mangrove planting efforts.

KEYWORDS: community capacity; Demak Coast; human resource development; mangrove degradation; social-ecological systems.

1. Introduction

Mangrove ecosystems are one of the coastal systems with high ecological, economic, and social value (Nurhati & Murdiyarso, 2022). Ecologically, mangroves play a role in protecting coastal areas from the impacts of climate change, such as sea-level rise, erosion, and increased wave energy. Additionally, mangroves support biodiversity and maintain the connectivity of other coastal ecosystems, such as seagrass beds and coral reefs, through hydrological and biogeochemical processes (Arifanti et al., 2025). From a socio-economic perspective, mangroves provide various direct benefits to communities, including as a source of fisheries and non-timber forest products.

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However, pressure on mangrove ecosystems continues to rise due to human activities. Since the 1970s, development policies promoting the exploitation of coastal resources, particularly through the expansion of aquaculture ponds, have led to the loss of approximately 800,000 hectares of mangroves in Indonesia over the past three decades (Ilman et al., 2016). This situation indicates that changes in the mangrove biophysical system do not occur in isolation but are driven by socio-economic dynamics that encourage intensive resource use (Pratiwi, 2025). This is clearly reflected in Demak Regency, which faces continuous pressure from the conversion of coastal land. The increase in pond area during the 1990–2000 period was inversely proportional to the decline in mangrove vegetation area, while mangrove biodiversity levels in some regions, such as Sayung Subdistrict, were classified as low (Munasikhah & Wijayati, 2021; Alifiansyah et al., 2024). Community dependence on the aquaculture, fisheries, and agriculture sectors further intensifies pressure on mangrove ecosystems, while also highlighting the close interconnection between social and ecological systems in coastal areas. This situation indicates that mangrove degradation must be understood as part of a more complex system involving dynamic interactions between humans and the environment.

In this context, the socio-ecological systems approach views ecosystems and communities as a single, mutually interacting, dynamic, and adaptive unit (Portorreal et al., 2024; Refulio-Coronado et al., 2021). Interactions between biophysical factors, such as ocean waves, currents, and tidal dynamics, and human activities shape patterns of both vulnerability and resilience in coastal areas. The impacts of these interactions are not merely ecological but also directly influence the socioeconomic conditions of local communities. In Sungai Nibung Village, West Kalimantan, the contribution of mangroves to capture fisheries is estimated to reach approximately Rp2 billion per year, while the coastal protection function in Pangkah Kulon and Wetan Villages, East Java, is valued at up to Rp45.16 billion per year. From a climate regulation perspective, mangroves also hold economic value through carbon sequestration, estimated to range from Rp7.4 billion to Rp45.2 billion per year across various regions. The magnitude of these values indicates that mangrove degradation not only impacts the environment but also has the potential to result in the loss of significant economic benefits for communities.

Within the framework of a socio-ecological system, adaptive capacity serves as a key element bridging the relationship between social and ecological components (Cinner et al., 2021). This capacity reflects a community's ability to understand changes, access information, organize collective actions, and manage resources sustainably. In a coastal context, adaptive capacity is crucial to communities' ability to respond to environmental pressures, such as erosion, tidal flooding, and declines in fisheries and aquaculture productivity. Thus, adaptive capacity serves as the primary mechanism determining whether socio-ecological interactions will lead to continued degradation or, conversely, to recovery and enhanced resilience (Refulio-Coronado et al., 2012).

From a socio-ecological systems perspective, interactions between biophysical and social factors are not one-directional but form feedback loops that can amplify either the vulnerability or resilience of coastal areas, depending on how the social system responds to occurring changes (Portorreal et al., 2024; Refulio-Coronado et al., 2021). In this context, a community's adaptive capacity reflects not only the ability of individuals to adapt but also the collective capacity to organize joint actions, access external knowledge networks, and build local institutions capable of responding to environmental pressures in a sustainable manner. In the context of mangrove management, this capacity is largely determined by the level of trust among residents, the strength of social capital, and the presence of local groups capable of acting as collective organizers and liaisons with external stakeholders. Thus, a community's adaptive capacity is not merely a static variable but a dynamic process that continues to evolve alongside changes in ecological conditions, economic pressures, and available institutional support.

Furthermore, the concept of ecosystem services provides a framework for understanding the consequences of changes within these systems on human well-being. Mangroves provide various services, both direct, such as fisheries yields and indirect such

as coastal protection and carbon sequestration (Arifanti et al., 2025). Changes in the biophysical conditions of mangroves will directly impact the availability of these services, which ultimately affect the well-being of coastal communities. However, adaptive capacity does not stand alone; it is influenced by governance structures, power relations, and institutional dynamics. Therefore, a sustainability transformation perspective is needed to explain the importance of more fundamental changes in resource management systems, changes that encompass not only technical interventions like mangrove rehabilitation but also shifts in value systems, decision-making patterns, and the distribution of access to and control over resources (Armitage et al., 2021; Blythe et al., 2020).

In this context, the community-based management approach is understood as a concrete manifestation of adaptive capacity in practice. The effectiveness of this approach is highly determined by the community's capacity in the planning, implementation, and evaluation processes of management (Wally, 2026). However, in practice, community participation tends to remain limited to technical aspects, such as rehabilitation or replanting activities, and does not yet fully encompass strategic decision-making. This situation indicates that the community's capacity is not yet optimal in influencing the overall direction of coastal resource management.

The coastal area of Demak Regency serves as an important and strategic empirical context for examining this issue. Academically, Demak represents a case where mangrove degradation occurs concurrently with the emergence of various community-based rehabilitation initiatives, thereby offering rich analytical opportunities to observe how variations in community capacity influence the effectiveness of responses. From a policy perspective, Demak is also relevant as it is one of the priority areas in the national mangrove rehabilitation program; however, its implementation still faces various structural challenges directly related to the capacity of local communities. Thus, an in-depth study of the interaction between community capacity and mangrove ecological conditions in Demak Regency can provide both conceptual contributions and more context-specific, evidence-based policy recommendations, particularly for ongoing and future coastal rehabilitation programs in areas with similar socio-ecological characteristics.

Although various studies have examined mangrove degradation from both biophysical and ecosystem service valuation perspectives, research that integrally links the dynamics of socio-ecological systems with community capacity to respond to degradation remains relatively limited, particularly in local contexts such as Demak Regency, Central Java Province. This region is known as one of the coastal areas experiencing significant environmental pressures due to erosion, shoreline changes, and the conversion of mangrove lands into fish ponds. These conditions not only affect the structure of the coastal ecosystem but also have a direct impact on the socioeconomic conditions of communities dependent on coastal resources.

Most existing studies tend to focus on the ecological condition of mangroves or the economic benefits of their ecosystem services, without thoroughly analyzing how community capacity influences variations in community responses to environmental pressures. However, community capacity plays a crucial role in determining how communities understand environmental changes, organize collective action, and develop adaptation strategies. In this study, community capacity is operationally defined to include adaptive capacity to environmental and economic pressures, local institutional capacity to organize collective action, and access to knowledge, information, and resources.

Furthermore, community-based management approaches are often narrowly understood as merely technical forms of participation, without exploring the community's role in planning, decision-making, and evaluation processes. This limitation indicates a gap in understanding how the interaction between mangrove biophysical conditions, ecosystem services, and community capacity collectively shapes the direction of management toward sustainability. Therefore, this study aims to address this gap by integrating a socio-ecological systems framework, community capacity, and the dynamics of community-based management within the local coastal context of Demak Regency.

Based on this, the objective of this study is to analyze the role of community capacity in shaping community responses to mangrove ecosystem degradation within a socio-ecological systems framework in the coastal area of Demak Regency. Specifically, this study aims to: identify the dynamics of mangrove ecosystem degradation and environmental pressures occurring in the coastal area of Demak Regency; analyze the dimensions of community capacity that influence the community's ability to respond to changes in ecosystem conditions; and examine the interaction between mangrove biophysical conditions and community capacity in shaping various forms of community responses to environmental degradation. Thus, this study is expected to contribute to the development of a more integrative, contextual, and community-based approach to mangrove management in addressing the challenges of coastal ecosystem degradation.

2. Methods

2.1 Study area and data collection

Demak Regency is located on the coast of Java Island, with a coastline of 102 km (Demak Regency Government, 2024). Geographically, Demak Regency is situated at coordinates 6°43'26"–7°09'43" S and 110°27'58"–110°48'47" E (Figure 1). The total area of Demak Regency is recorded at 99,531 ha, with the majority of the area consisting of rice fields (57.47%) and the remainder comprising gardens, buildings, and fish ponds (42.53%). Based on consolidated data (Demak Regency Population and Civil Registration Office, 2023), the population of Demak Regency in 2023 was 1,246,059 people.

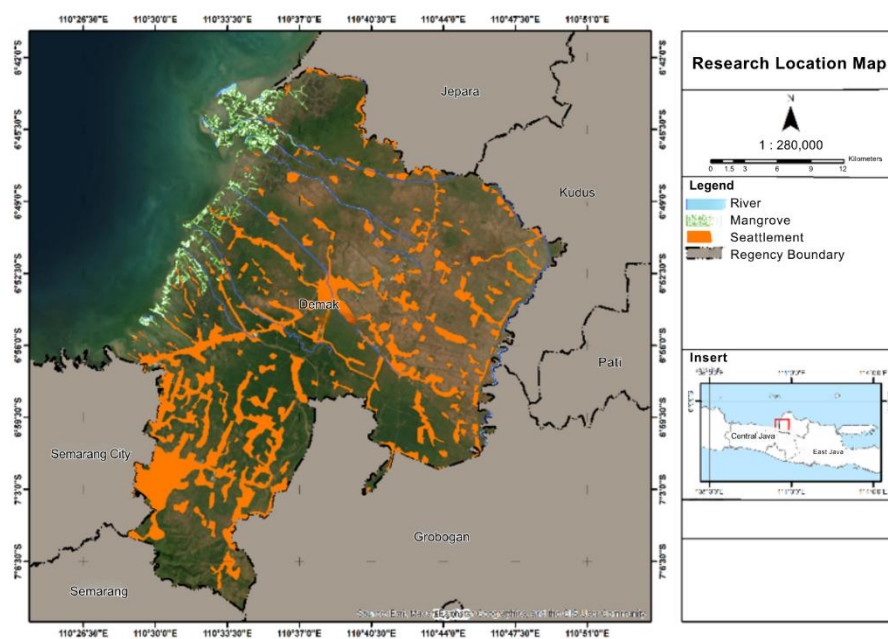


Fig. 1. Research location map

The data used to identify the condition of the mangrove ecosystem in this study were collected from various relevant secondary sources, one of which is the Ministry of Environment and Forestry/*Kementerian Lingkungan Hidup dan Kehutanan Republik Indonesia* (KLHK). Data from KLHK were utilized to obtain spatial information regarding changes in the extent and condition of mangrove cover, both at the national and regional scales. This information was generally obtained from satellite imagery such as Landsat 8 (30 m resolution) and Sentinel-2 (10 m) which was subsequently processed through remote sensing analysis to identify the distribution and density of mangroves as indicators of the ecosystem's biophysical condition.

To complement this analysis, scientific articles were utilized to examine the condition of mangrove ecosystems in greater depth through a vegetation analysis approach focused on Demak Regency. This analysis includes the Importance Value Index, which is a composite parameter of species density, frequency, and dominance. Through this approach, mangrove conditions are assessed not only based on their area but also on the vegetation structure and the ecological roles of each constituent species, thereby providing a more comprehensive picture of ecosystem quality.

Furthermore, scientific articles are utilized to describe the current conditions in Demak Regency, particularly regarding the impacts of mangrove ecosystem degradation. These impacts include changes in the coastline and an increase in tidal flooding incidents, which also reflect the level of coastal vulnerability and the potential losses experienced by the community. Analysis of shoreline changes and tidal flooding is generally conducted using Geographic Information System (GIS)-based data to generate spatial information regarding shoreline shifts and the distribution of areas affected by inundation due to sea-level rise (Ilhami et al., 2024). The data used in this analysis are derived from satellite imagery integrated with oceanographic and environmental parameters, such as tides, wave height, currents, geomorphology, and topography. Furthermore, to understand the social dimensions of mangrove ecosystem degradation, this study also utilizes reports from non-governmental organizations and scientific articles as secondary data sources. This data is used to complement field information and various empirical findings regarding environmental pressures in coastal areas, particularly in describing community characteristics and community capacity in Demak Regency.

The social conditions examined include demographic aspects and community perceptions of mangrove degradation. Demographically, the parameters used include age, education level, occupation, and income level, which play a role in determining the community's response and adaptive capacity in facing environmental changes. Additionally, community perceptions of mangrove degradation are classified to assess the level of environmental understanding and awareness among coastal communities. Through the integration of these biophysical, ecological, and social data, this study can provide a more comprehensive picture of the dynamics of mangrove ecosystem degradation and its implications for environmental conditions and the lives of coastal communities in Demak Regency.

2.2 Data methods

This study employs a qualitative approach grounded in literature review to understand the dynamics of mangrove ecosystem degradation and coastal community responses within a socio-ecological framework. The qualitative approach was chosen because this study aims to interpret and synthesize existing scientific findings regarding the relationship between mangrove biophysical conditions, ecosystem services, and community capacity to respond to environmental changes. This approach not only describes ecological conditions but also explains how social factors influence how communities respond to environmental changes.

This study employs a literature-based case analysis design focused on the coastal area of Demak Regency, Central Java Province. This design was chosen to conduct an in-depth examination of mangrove degradation and coastal community responses by utilizing various previously published sources of information. Demak Regency was selected as the case context because it is a coastal area experiencing significant environmental pressures, particularly in the form of coastal erosion, shoreline changes, and the conversion of mangrove land into fish ponds. Additionally, the various community-based mangrove rehabilitation initiatives emerging in this region make Demak Regency a relevant case for analyzing the relationship between environmental pressures and community capacity to respond to ecosystem degradation.

The literature used in this study was obtained from journal articles indexed in Google Scholar, Scopus, and Web of Science, as well as relevant reports from government and non-governmental organizations. The literature was selected based on the following criteria:

published between 2000 and 2026, with priority given to publications from the last ten years; thematically relevant to the topics of mangrove degradation, community capacity, and coastal community responses; and focused on the Indonesian region, specifically the coast of Demak Regency.

The literature search was conducted using the following primary keywords and their combinations: “mangrove degradation”, “community capacity”, “social-ecological systems”, “adaptive capacity”, “coastal community responses”, “mangrove rehabilitation”, “community-based natural resource management”, and “Demak coast”. Additional exclusion criteria applied were: sources not peer-reviewed or lacking institutional authority (for reports and policy documents); and literature focused on mangrove ecology without incorporating a social or governance dimension. Sources published after 2024 were considered on a case-by-case basis when they provided highly relevant empirical data on the Demak study area not available from earlier publications.

Community capacity in this study is understood as the ability of communities to respond to changes in mangrove ecosystem conditions, as reflected through the dimensions of local knowledge, the existence of community institutions, the strength of social capital, and access to economic resources. This capacity is viewed as a key mediating variable in the relationship between mangrove ecosystem degradation and various forms of community-level responses, such as mangrove rehabilitation, the development of alternative economic activities, and changes in coastal resource utilization practices.

The literature-based qualitative approach used in this study has strong methodological justification within the context of socio-ecological research. First, the phenomena under study are multidimensional and involve complex interactions between biophysical and social systems that are difficult to adequately capture through quantitative data alone. Second, the social-ecological systems framework underpinning the analysis is inherently interpretive, requiring an understanding of meaning, context, and relationships between variables, rather than merely measuring their magnitude. Third, in the context of Demak Regency, the availability of comprehensive and up-to-date primary data remains limited; thus, synthesizing existing literature from various sources serves as a realistic and productive strategy for generating a more comprehensive understanding. The literature selection process was conducted in stages: beginning with an initial search using thematic keywords across three indexed databases (Google Scholar, Scopus, Web of Science), followed by screening based on thematic and geographical relevance, and culminating in a final selection that considered the methodological quality and the recency of the data presented in each source.

2.3 Data analysis

The analysis in this study was conducted using a thematic analysis approach, which involves grouping the main findings from various literature sources based on themes relevant to the research focus. This approach allows researchers to systematically identify patterns of relationships among various findings from previous studies. Within this analytical framework, mangrove ecosystem degradation is understood as a factor triggering pressures within the coastal socio-ecological system, while community capacity plays a role in determining how communities respond to these pressures.

The analysis process was conducted in stages. First, the collected literature was classified and coded into three main themes: the condition and extent of mangrove ecosystem degradation in Demak Regency; the dimensions of coastal community capacity; and the forms of community responses to environmental pressures. Second, findings from the coded literature were analyzed to identify patterns of relationships among variables, including consistency and contradictions among the findings. Third, the analysis results were synthesized to produce a comprehensive understanding of the dynamics of the coastal socio-ecological system in Demak Regency.

To ensure the validity of the analysis, this study employed source triangulation by comparing findings from various types of literature, including journal articles, government

reports, and field studies. Coding consistency was also maintained through periodic re-checking of the established thematic categories. Public responses emerging from the analysis results were then further examined to understand their implications for the dynamics of mangrove management at the local level, particularly in the form of community-based management practices that have the potential to drive a transformation toward more sustainable mangrove ecosystem management

3. Results and Discussion

The research results were synthesized by integrating ecological land-cover data from satellite imagery analysis conducted by Graha (2018) with social data drawn from community perception surveys, participation assessments, and institutional mapping reported by Handayani (2021) and Hastuti (2025) in coastal villages of Demak Regency. The rate of change in mangrove land cover, dimensions of community capacity, and the interactions between them were examined at three scales of analysis: temporal (2000–2015), spatial (subdistrict level), and comparative (Demak, Indramayu, and Pohuwato). All land cover change values presented in Subsections 1(a) and 1(b) are derived from remote sensing analysis by Graha (2018), processed using GIS-based spatial analysis. Community capacity indices are derived from structured survey data reported by Handayani (2021) and Hastuti & Mussadun (2025). This integrated analytical framework ensures that the research results are transparent, reproducible, and aligned with a socio-ecological systems research approach.

3.1 Dynamics of mangrove degradation and environmental pressures

3.1.1 Analysis of mangrove land cover change

Analysis of satellite imagery from 2000–2015 reveals a persistent and significant net loss of mangrove cover in the coastal areas of Demak Regency, with an overall rate of change of -3.49 ha/year. In all three sub-observation periods, the dominant conversion trajectory was the conversion of mangrove land into fish ponds, with areas of 191.99 ha (2000–2003), 343.63 ha (2003–2009), and 149.04 ha (2009–2015), resulting in a cumulative total of 684.66 ha over 15 years. These figures indicate that the expansion of fish ponds has consistently been the single largest driver of mangrove loss during each observation period (Figure 2).

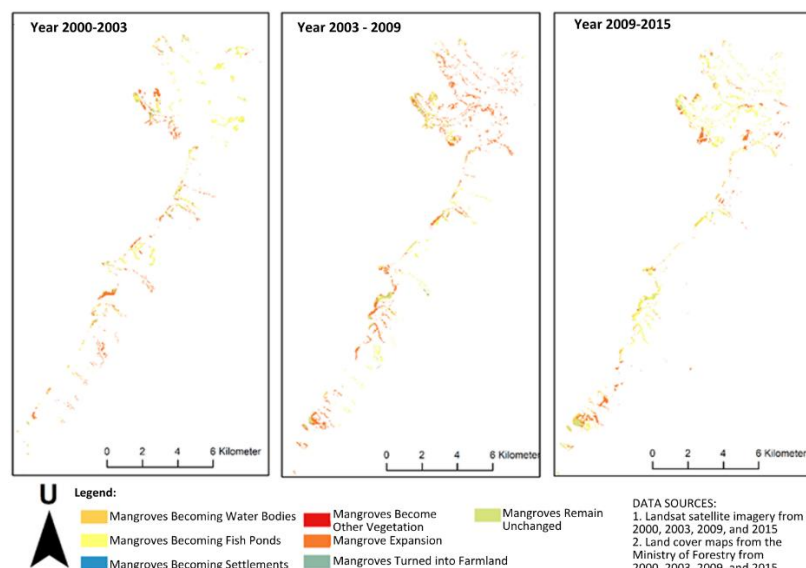


Fig. 2. Map of changes in mangrove land cover in Demak Regency, 2000–2015 (Graha, 2018)

A significant exception to this degradation trend occurred during the 2003–2009 sub-period, during which the net mangrove area increased by 183.42 ha. This recovery was driven by the conversion of 325.80 ha of non-mangrove land into mangroves, indicating active rehabilitation efforts facilitated by external programs as well as natural regeneration processes. The area of mangroves that remained unchanged in each sub-period was 42.44 ha (2000–2003), 135.05 ha (2003–2009), and 25.93 ha (2009–2015). The progressive decline in stable mangrove area between 2009 and 2015, where the area of mangroves that remained unchanged (25.93 ha) was smaller than the area experiencing land cover change, confirms a deteriorating ecological trajectory during the most recent period (Figure 3).

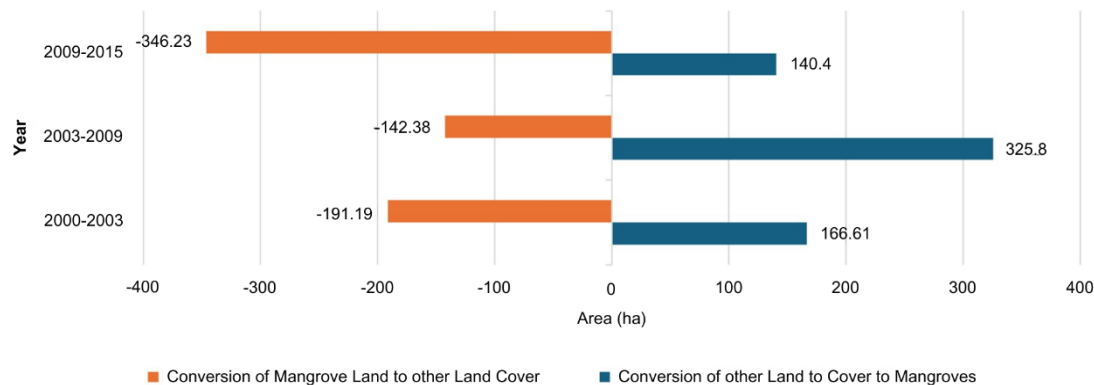


Fig. 3. Summary of mangrove land cover changes in Demak Regency, 2000–2015 (Graha, 2018)

Land cover change trends in Demak generally align with findings in other coastal areas of Java. The dominance of mangrove conversion into aquaculture ponds reflects patterns documented in the coastal regions of Indramayu and Brebes, where short-term economic incentives from brackish water aquaculture consistently outweigh ecosystem conservation considerations (Kusmana, 2017). However, the temporary recovery observed between 2003 and 2009 distinguishes Demak as a location where community-based rehabilitation produced measurable, albeit still fragile, ecological effects, a characteristic explored further in relation to community capacity in 3(a).

3.1.2 Distribution of tidal flooding

Spatial analysis of tidal flood inundation distribution indicates that the progressive loss of mangrove cover is directly linked to the expansion of flood-prone areas along the coast of Demak Regency (Figure 3). Mangrove ecosystems perform a well-documented wave attenuation function through their root architecture and above-ground biomass, which dissipates tidal energy and traps sediment (Risheharan et al., 2025). Consequently, the loss of mangrove vegetation due to conversion into aquaculture ponds reduces natural coastal protection, creating a positive feedback loop in which the degraded shoreline becomes increasingly vulnerable to further inundation. This flooding, in turn, disrupts pond productivity through sedimentation, excessive waterlogging, and delays in harvest cycles, ultimately reducing the economic benefits that originally motivated the mangrove conversion itself (Dewi et al., 2023).

This ecological cascade is consistent with the broader literature on coastal socio-ecological systems. Barbier et al. (2011) demonstrated that the loss of mangroves in Southeast Asian deltas significantly amplifies the impact of storm surges on nearby human settlements and aquaculture infrastructure. In the context of Demak, the convergence of anthropogenic pressures and hydrodynamic vulnerabilities creates a layered risk environment that community responses must navigate. The ecological conditions outlined above are therefore the primary environmental stressors driving the social responses analyzed in the following sections.

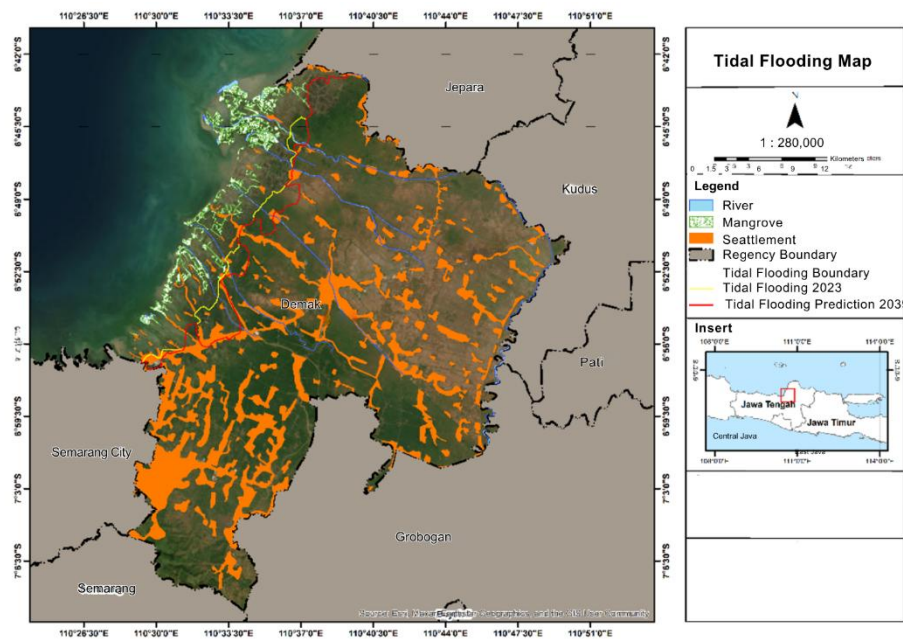


Fig. 4. Spatial distribution of tidal flooding in Demak Regency (Ilhami et al., 2024)

3.1.3 Community structure and mangrove health index

A field-based assessment of mangrove community structure along the coast of Demak Regency (Setiyawati, 2023) identified three species: *Avicennia marina*, *Rhizophora mucronata*, and *Thespesia populnea*. Tree density ranged from 1,533 to 3,200 individuals/ha across all observation stations. The Diversity Index (H') and Evenness Index (J') fell into the low category at all three stations, with high dominance values indicating a structurally simplified canopy. The average canopy cover of $76.2 \pm 4.37\%$ falls into the dense category; however, the average mangrove health index of $47.7 \pm 9.98\%$ places this ecosystem in the moderate category.

A health index value of 47.7% indicates an ecosystem under active stress, yet it still maintains sufficient structural integrity for recovery under improved management conditions. The combination of high canopy cover but low species diversity is consistent with a successional community dominated by early colonizing species such as *A. marina*, which is known to be tolerant of disturbed and waterlogged substrates. These structural characteristics have direct implications for ecosystem function: while dense, monospecific stands may provide wave attenuation, their lower resilience to environmental disturbances, including disease outbreaks and salinity fluctuations, makes them more vulnerable compared to structurally diverse stands (Feller et al., 2010). The spatial coexistence of moderate health indices, expanding flood zones, and persistent pressure for pond conversion defines the biophysical foundation upon which community capacity must be assessed. The following section examines how coastal communities in Demak Regency perceive and respond to this ecological context.

It should be noted that a health index value of 47.7% with a dominance of *Avicennia marina* has important implications for applicable restoration strategies. Ecologically, the success of mangrove planting is highly dependent on the hydrodynamic conditions of the site, particularly wave height, currents, and tidal dynamics, which determine whether propagules can take root and develop without being carried away by currents before a root system is established (Choudhary et al., 2024). In some coastal segments of Demak experiencing intense erosion, high hydrodynamic conditions often lead to ecological failure in direct planting efforts without prior construction of wave-attenuation structures such as permeable dams or hybrid engineering. This fact underscores the importance of community capacity not only to carry out planting but also to assess the ecological conditions of the site

and select intervention methods aligned with the specific biophysical constraints of each area. In other words, the effectiveness of community responses to mangrove degradation is determined not only by willingness and participation but also by the ability to adaptively interpret and respond to ecological signals (Gumilar, 2012).

3.2 Dimensions of community capacity

3.2.1 Ecological knowledge and perceptions

Survey data from coastal communities in Sayung Subdistrict (Handayani, 2021) indicate that the majority of respondents demonstrated a high level of ecological awareness regarding mangrove ecosystem services (Figure 3). Most respondents agreed or strongly agreed that mangroves function as wave breakers, windbreaks, sediment traps, oxygen producers, barriers against seawater intrusion, and water quality regulators. This perception profile reflects a community that has developed functional ecological knowledge through direct experience facing coastal hazards, rather than solely through formal education or outreach programs.

Table 1. Community perception towards mangrove ecosystem in Demak Regency

Aspect / Survey Item	Key Finding (Response Distribution)	Implication for Community Capacity
Mangroves buffer currents and waves	Scale 4–5 = 90% (strongly agree); only 3% disagree	Coastal physical protection function is very well understood by the community
Mangroves resist strong winds and storms	Scale 4–5 = 81%; 8% disagree	Strong perception of climatic protection; supports conservation motivation
Mangroves function as sediment traps	Scale 4–5 = 84%; 3% disagree	Understanding of geomorphological function is fairly high
Mangroves produce oxygen	Scale 4–5 = 93%; no respondents disagree (0)	Basic ecological function is uniformly understood across all community members
Mangroves prevent saltwater intrusion	Scale 4–5 = 66%; scale 3 = 34%	Understanding of hydrogeological function is adequate; highly relevant to tidal flooding context in Demak
Mangroves as water quality regulators	Scale 4–5 = 66%; 5% disagree	Awareness of water filtration function supports ecosystem services-based management
Mangroves as spawning habitat for marine organisms	Scale 4–5 = 95%; no respondents disagree	Mangrove–fisheries linkage is very strongly understood → foundation for conservation motivation
Mangroves as a food source for marine biota	Scale 4–5 = 94%; no respondents disagree	Ecological value as a coastal food chain is highly perceived by the community
Mangrove fruit as food and beverage ingredients	Scale 4–5 = 95%; no respondents disagree	Food potential is widely acknowledged; notable contrast with low actual utilisation (Table 7.4 No.14)
Mangrove wood as firewood	Scale 4–5 = 60%; 11% disagree	Timber value is recognised but not dominant; consistent with low actual exploitation rates
Mangrove wood as construction material	Scale 1–2 = 42% disagree; scale 3–5 = 58%	Ambivalence over construction timber value; requires education on structural degradation from exploitation

Mangrove leaves as livestock feed	Scale 4–5 = 71%; 5% disagree	Agroforestry benefits of mangroves are well known; potential alternative livelihood pathway
Mangrove forest for aquaculture pond development	Scale 1–2 = 43%; scale 3–5 = 58% — high polarisation	Ambivalent perception towards pond conversion → reflects the economy–ecology dilemma in Demak
Potential of mangroves as ecotourism destination	Scale 4–5 = 94%; very high	Very strong awareness of ecotourism potential; gap between perception and actual economic realisation
Potential of mangroves for scientific research	Scale 4–5 = 87%; no respondents disagree	Community is open to research collaboration; positive social capital for academic partnership programs

Survey data collected from 38 respondents in the coastal communities of Demak Regency reveal a consistently high level of ecological awareness regarding mangrove ecosystem functions. The overwhelming majority of respondents demonstrated strong agreement with statements related to the physical protective functions of mangroves, including wave and current buffering (90% scale 4–5), wind resistance (81%), and sediment trapping (84%), indicating that direct exposure to coastal hazards such as erosion and tidal flooding has effectively shaped experiential ecological knowledge within the community. Ecological functions were perceived with even greater consensus, particularly the role of mangroves as spawning habitat for marine biota (95%) and as a food source for coastal organisms (94%), reflecting the community's direct livelihood dependence on mangrove-associated fisheries. Notably, the potential of mangroves as an ecotourism destination was also widely acknowledged (94%), yet this perception has not translated into tangible economic benefits for most households, as evidenced by the low actual utilisation reported in the participation data. A degree of ambivalence was observed specifically regarding the use of mangrove forest for aquaculture pond expansion, where responses were polarised (scale 1–2: 43%; scale 3–5: 58%), indicating that the economy–ecology dilemma remains unresolved within the community's value system. Overall, the perception data suggest that the cognitive dimension of community capacity, that is, the ability to recognise and articulate the ecological and economic value of mangroves, is well established, providing a strong foundation upon which behavioural and institutional responses can be further developed.

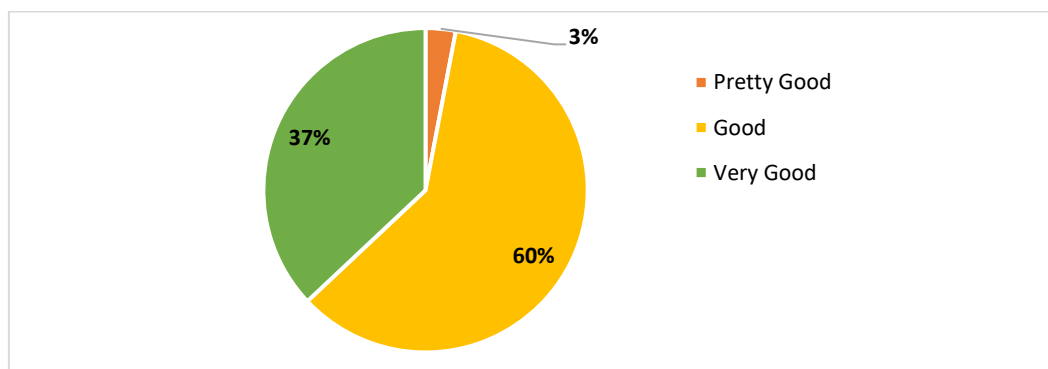


Fig. 5. Community perceptions of mangrove ecosystems in Sayung Subdistrict, Demak Regency (Handayani, 2021)

The formation of ecological knowledge through lived experience under environmental pressure, a process known as experiential social learning, has been extensively documented among coastal communities facing chronic environmental change (Armitage et al., 2008). In Demak, the intensification of tidal flooding and coastal erosion over the past two decades has served as a sustained forcing mechanism, gradually increasing the community's

awareness of the protective functions of mangrove cover. This finding aligns with Mann-Kendall trend observations from comparable contexts, where increasing environmental pressure correlates with increased community ecological literacy, even in the absence of formal conservation programs (Kasim et al., 2022). Critically, high levels of ecological knowledge do not automatically translate into conservation behavior. Survey responses indicate that some communities still hold perceptions shaped by historical land-use patterns, in which mangrove areas are traditionally viewed as land suitable for conversion. The coexistence of these two perception profiles within the same community reflects the adaptive tension discussed further in 3(a).

3.2.2 Participation and collective action

An assessment of community participation in mangrove management (Handayani, 2021) placed the overall level of participation in the high category across all measured dimensions: decision-making, activity implementation, and monitoring (Figure 5). In the decision-making domain, community members actively attended planning meetings and contributed their opinions, driven by their self-identification as primary knowledge holders regarding coastal ecosystems. In the implementation domain, community members, particularly those organized through local mangrove groups, actively participated in planting activities, seedling provision, and the designation of planting zones.

Table 2. Community participation towards mangrove ecosystem in Demak Regency

Aspect / Survey Item	Key Finding (Response Distribution)	Implication for Community Capacity
Community deliberation meetings for mangrove management planning	Majority frequently participate (scale 4–5: ~87%); only 3% never attended	High engagement in planning processes; supports the legitimacy of management programs
Active attendance at mangrove management meetings	76% responded scale 4–5 (always/frequently involved)	Local institutional capacity is active in internal coordination
Involvement in formulating activity plans	More even distribution (8% never); scale 3–5 dominant (81%)	Substantive planning participation is adequate, though not yet uniform across members
Involvement in management decision-making	Scale 4–5 reaches 74%; only 8% never involved	Community actively engages in decision forums; strengthens social capital
Providing suggestions and opinions on management	Scale 3–5 dominant (90%); score 1 only 5%	Community voices are accommodated, supporting adaptive management
Attendance at management activity implementation	Scale 4–5: 61%; 3% never; relatively high overall	Community mobilisation in program implementation is fairly effective
Mangrove seedling nursery activities	Scale 3 (sometimes) = 29% highest; scale 4–5 = 24%; 9% never	Participation in nursery activities needs strengthening; opportunity for technical capacity building
Mangrove planting activities	Scale 4–5 reaches 61%; no respondents answered never (0)	Participation in planting is very high; reflects strong ecological commitment of the community
Mangrove maintenance along the coastal area	Scale 4–5 = 68%; 3% never	Post-planting maintenance is fairly consistent; supports long-term ecological sustainability
Use of mangrove area for aquaculture ponds	Scale 1 (never) = 55% highest; only 23% scale 4–5	Most respondents do not use mangroves for ponds → relatively low pond conversion pressure
Selling mangrove seedlings	Scale 1 = 68% never sold seedlings	Economic potential of seedling production remains untapped; opportunity for silvofishery development

Benefits derived from mangrove ecotourism	Scale 1 = 50%; only 29% experienced tourism benefits (scale 4–5)	Ecotourism has not developed equitably; conservation-based economic access remains limited
Benefits from capture fisheries around mangroves	Scale 4–5 = 69%; 16% never	High fisheries dependence → mangrove ecosystem valued as critical fish habitat
Use of mangrove fruit as food ingredients	Scale 1 = 45%; only 24% utilise (scale 4–5)	Mangrove-based food diversification is suboptimal; potential for product development
Use of mangrove wood for construction materials	Scale 1 = 66% never used mangrove wood	Low timber exploitation pressure → reduces structural degradation of mangrove stands
Attendance at programme evaluation meetings	Relatively even distribution (13–29%); no single dominant response	Participation in evaluation remains weak; need to strengthen participatory monitoring mechanisms
Providing feedback at evaluation meetings	Scale 3–5 dominates (87%); no respondents answered never (0)	Active community feedback supports adaptive learning within the management cycle

(Handayani, 2021)

Assessment of community participation across four dimensions, decision-making, implementation, utilisation, and evaluation, reveals a pattern of relatively high engagement in governance and implementation activities, alongside persistent gaps in economic access and monitoring involvement. In the decision-making dimension, participation levels were consistently high, with 74–87% of respondents regularly attending planning meetings, contributing to activity formulation, and providing input into management decisions, indicating that local deliberative institutions are functioning and that community voices are substantively incorporated into the management process. Participation in implementation activities, particularly mangrove planting (scale 4–5: 61%; 0% never) and coastal maintenance (68%), was similarly strong, suggesting effective community mobilisation for field-level conservation work. However, participation in nursery activities (scale 4–5: 24%) and programme evaluation meetings (no single dominant response across scales) was comparatively weaker, pointing to uneven engagement across the full management cycle (Aulia et al, 2023). In the utilisation dimension, the data reveal a significant disconnect between resource use and economic benefit: while most respondents do not convert mangrove areas into ponds (55% never) or exploit timber (66% never), they also largely do not benefit from conservation-linked livelihoods such as seedling sales (68% never) or ecotourism (50% never). This gap between restrained exploitation and limited alternative income reflects the structural economic constraint identified throughout this study, namely, that community capacity to participate in conservation is constrained not by unwillingness, but by the absence of viable economic incentives tied to ecosystem stewardship.

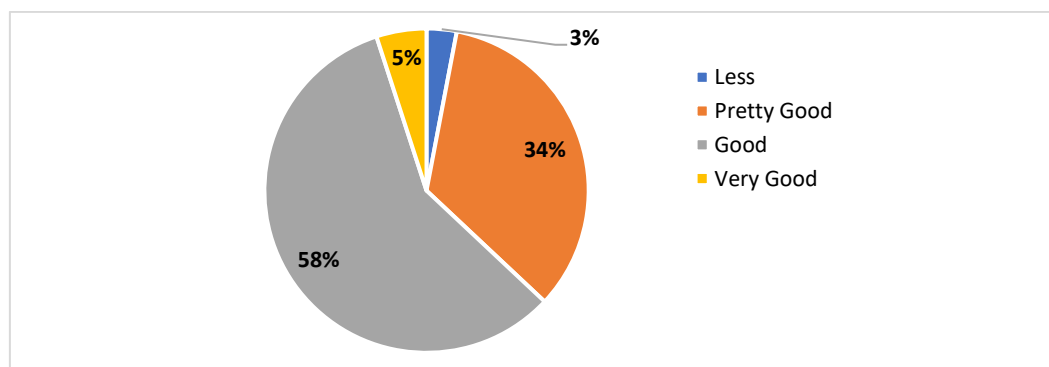


Fig. 6. Levels of community participation in mangrove ecosystem management (Handayani, 2021)

The organizational structure of local groups such as the Bahari Mangrove Group is a crucial institutional asset. These groups function as governance intermediaries, coordinating collective action among community members while serving as interlocutors for external actors, including government agencies, NGOs, and research institutions (Hastuti & Mussadun, 2025). This dual role, as internal organizers and external liaisons, is theoretically consistent with the concept of bridging organizations within the framework of adaptive governance, which emphasizes the importance of multi-scale institutional linkages for effective resource management (Folke et al., 2005).

Nevertheless, coordination challenges persist. Institutional fragmentation across government agencies, unclear jurisdictional boundaries over coastal lands, and an inadequate post-planting monitoring system collectively undermine the operational effectiveness of local groups. These structural weaknesses mean that even high levels of participation do not necessarily translate into sustainable ecological outcomes, unless supported by coherent multi-stakeholder governance arrangements.

3.2.3 Integration and economic constraints

Economic data indicates that mangrove-based livelihood activities in Demak remain spatially concentrated and of marginal economic value to most coastal households. Mangrove seedling propagation and processing of mangrove-derived products are limited to specific villages, while surrounding communities do not derive tangible economic benefits from conservation efforts. The ecotourism potential in some mangrove areas has not been systematically developed, so its contribution to household income diversification remains low (Hastuti & Mussadun, 2025).

This economic marginalization creates a structural dilemma: households lacking alternative income sources face strong incentives to maintain or expand aquaculture activities, even when they possess sufficient ecological knowledge to understand the long-term costs of mangrove conversion. Economic calculations, in which immediate income from aquaculture outweighs diffuse and delayed conservation benefits, partly explain why mangrove degradation continues even during periods of high community awareness and active rehabilitation programs.

3.3 Interactions between biophysical conditions and human capacity

3.3.1 Dynamics of environmental pressures and social learning

The relationship between mangrove biophysical conditions and community capacity is neither linear nor unidirectional. Analysis of temporal trends over the 2000–2015 period indicates that periods of intensified environmental pressure, particularly the documented expansion of tidal flood inundation after 2009, coincided with observable shifts in community perceptions and organization. This pattern suggests that ecological degradation functions as a forcing mechanism for social learning, gradually transforming the community's view of mangrove lands from a convertible resource into protective infrastructure. This two-way dynamic is further supported by post-program trajectories in areas where rehabilitation has been completed: communities that experienced successful mangrove restoration reported increased inter-household trust, enhanced group cohesion within local management organizations, and more regular engagement with government partners. Conversely, short-term or discontinued programs were associated with declining collective motivation and eroding institutional trust, a pattern consistent with the adaptive governance literature documenting the sensitivity of community-based systems to program continuity (Ostrom, 2009).

Given the overall patterns described, it can be asserted that effective and sustainable mangrove management in the coastal areas of Demak Regency requires an approach that goes beyond the paradigm of physical rehabilitation alone. A fundamental reorientation is needed in how conservation programs are designed and evaluated: shifting from an

approach focused on physical outputs to one that prioritizes community capacity-building as the primary objective, with ecological outcomes as a natural consequence. This paradigm shift, although requiring more time and investment in the short term, has the potential to yield far more sustainable impacts in the long term because it builds the social foundation necessary for coastal communities to continue responding adaptively to ecological changes, even without relying on temporary external interventions. Overall, the findings of this study expand the theoretical framework of the socio-ecological system (SES) in two directions. First, these findings confirm that community capacity is not merely a background variable but an active mediating mechanism that determines the form, direction, and sustainability of community responses to ecosystem degradation. This shifts the analytical focus from the question of whether communities respond to how and under what structural conditions their responses become ecologically effective.

Second, these findings challenge the implicit assumption in sustainability transition theory that providing information and raising awareness are sufficient to trigger behavioral change. Repeated mangrove planting programs documented in several subdistricts, which yielded measurable short-term ecological recovery but failed to prevent further degradation, illustrate the distinction between transitional interventions and transformative outcomes. Transformative change, in which community practices shift at the level of decision-making norms, power distribution, and institutional legitimacy, requires the simultaneous strengthening of these three dimensions of capacity in proportion to the specific structural conditions of each community context.

The SES framework thus reveals a set of interdependent feedback loops that cannot be adequately understood by examining each subsystem in isolation. Mangrove land cover degradation) reduces coastal protection, expanding tidal flood inundation and lowering mangrove health indices. These biophysical stressors, in turn, simultaneously erode and stimulate community capacity: they reduce the ecological knowledge base upon which adaptive responses depend, strain the institutional cohesion of community groups through increased livelihood pressure, and heighten the economic dilemma between short-term aquaculture revenue and long-term conservation investment). Conversely, when community capacity across all three dimensions operates synergistically, as evidenced by the temporary recovery in mangrove cover during 2003–2009 linked to active rehabilitation programs, the social system can generate a positive feedback loop that supports ecological recovery. This bidirectional, multi-scale interaction is the defining characteristic of a social-ecological system and underscores why interventions targeting any single factor are insufficient to produce durable sustainability outcomes.

3.4 Recommendation

At the program level, community capacity building must be designed in an integrated manner to address all three dimensions adaptive, institutional, and economic access, simultaneously rather than in sequence or isolation. Concretely, this means that any mangrove rehabilitation program should include: a pre-program community capacity diagnostic to identify which dimensions are weakest in a given village context; at least one full growing cycle (minimum three years) of post-planting accompaniment by trained facilitators who support local groups in monitoring, adaptive management, and conflict resolution; and the development of at least one mangrove-based economic alternative per village, such as silvofishery, propagule propagation for sale, or community-managed ecotourism, that provides tangible income tied to mangrove health within 18 months of program onset. Programs that cannot commit to all three components should explicitly acknowledge this limitation in their design documentation and set expectations accordingly (Susanto, 2020).

At the monitoring and research level, future studies should move beyond the 2015 satellite data baseline used in this study by commissioning updated mangrove cover mapping using Sentinel-2 or equivalent imagery for the 2016–2025 period in Demak Regency. Community capacity assessment tools should be expanded to include behavioral

observation protocols, not merely perception surveys, by incorporating participatory monitoring sessions and institutional performance scorecards co-developed with local mangrove groups. A longitudinal panel design, tracking the same villages at 3-year intervals over at least a decade, would allow researchers to test causality between capacity-building interventions and ecological outcomes rather than relying on cross-sectional inference alone.

At the policy level, the Demak Regency Government and the Ministry of Environment and Forestry should institute a mandatory pre-intervention community capacity mapping process before approving any new mangrove rehabilitation funding in the region. This mapping should assess all three capacity dimensions using standardized instruments and should directly inform the design of interventions. Additionally, benefit-sharing mechanisms from mangrove-based carbon credit schemes and ecotourism revenue should be restructured to prioritize households in the highest-vulnerability subdistricts, particularly those in the central and southern coastal zones where aquaculture pressure is greatest, ensuring that conservation generates economically meaningful returns for those most likely to convert mangrove land for short-term income. Without these structural changes at the program, monitoring, and policy levels, community capacity will remain a latent resource rather than an active driver of sustainable mangrove management.

4. Conclusions

Findings indicate that mangrove ecosystems in the coastal areas of Demak Regency have experienced significant and consistent degradation pressures during the 2000–2015 period. The rate of change in mangrove cover was recorded at -3.49 ha/year, with land conversion into fish ponds serving as the primary driver during each observation period. This conversion was driven by strong economic pressures at the household level; the need for short-term income led to mangrove land being viewed as more valuable when converted into productive fish ponds, particularly given the limited alternative livelihood options available to coastal communities. Although there was a recovery trend from 2003 to 2009, indicating efforts at rehabilitation or natural regeneration, this recovery was largely driven by planting programs facilitated by external parties and the growing collective awareness of the community after directly experiencing the increasingly severe impacts of coastal erosion and tidal flooding, rather than solely due to structural changes in land-use policies. This positive trend did not persist in subsequent periods. This ecological pressure is exacerbated by the expanding inundation from tidal flooding, which increasingly threatens both mangrove areas and community aquaculture ponds. With an average mangrove health index of 47.7%, the condition of the mangrove ecosystem in Demak falls into the “moderate” category, indicating an ecosystem under pressure but not yet fully degraded and still possessing the potential for recovery.

A community’s capacity to respond to ecological pressures is not singular. This capacity comprises three interrelated dimensions: adaptive capacity, institutional capacity, and access to resources. In Demak Regency, the community demonstrates a relatively high level of ecological understanding, shaped by direct experiences with coastal erosion and tidal flooding, as well as active participation in mangrove management activities. Local groups such as “Mangrove Bahari” play a crucial role as institutional drivers and as a bridge between the community and external stakeholders. However, mangrove-based economic access has not developed evenly, so some community members still face a dilemma between short-term economic needs and long-term conservation commitments. A comparison with Indramayu and Pohuwato underscores that no single dimension is more important than the others. Indramayu has a structured formal institutional framework but weak community participation, while Pohuwato possesses sufficient environmental knowledge but faces more dominant economic pressures. Both cases demonstrate that effective community capacity can only emerge when all three dimensions operate synergistically. A weakness in just one dimension is sufficient to hinder the overall adaptive response.

The relationship between the biophysical condition of mangroves and community capacity is not one-directional but rather dynamically interdependent. Ecological pressures such as erosion and tidal flooding not only damage the ecosystem but also trigger social learning processes that gradually shift the community's perspective on mangroves from land to be converted into a resource that must be preserved. However, it must be emphasized that changes in community behavior regarding mangrove conservation are a long-term process. This emerging awareness still requires consistent economic and institutional support to truly transform into sustainable conservation actions. When such support is available and community capacity operates synergistically, more proactive adaptive responses can emerge. Conversely, when institutional frameworks are weak or economic pressures are too great, even communities with high levels of knowledge tend to be unable to translate awareness into concrete action. Thus, community capacity is not merely a supporting variable in mangrove management, but a determining factor that shapes how communities respond to environmental pressures, whether resulting in adaptive and transformative responses, or leading to stagnation. The novelty of this research lies in the assertion that community capacity is not merely a supporting factor for conservation but a factor that directly determines the quality and sustainability of community responses to ecological pressures, a perspective that has not received adequate attention in previous mangrove management research.

The findings of this study also have important implications for the development of a more integrative science of coastal management. Within the context of sustainability science, this study underscores that interventions focused solely on biophysical aspects, such as mangrove planting without concurrent community capacity-building, tend to yield short-term, unsustainable impacts. Conversely, programs that simultaneously integrate the strengthening of all three dimensions of capacity, adaptive capacity through enhanced ecological knowledge, institutional capacity through the strengthening of local community organizations, and resource access capacity through the development of mangrove-based economic alternatives, have greater potential to generate changes that endure beyond the program period. Therefore, future evaluations of mangrove rehabilitation programs need to move beyond physical indicators such as the number of seedlings planted and the area restored, toward indicators that reflect tangible community capacity building, including the self-reliance of local groups, the diversification of coastal residents' livelihoods, and increased community involvement in decision-making regarding coastal resource management.

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Author Contribution

The author was solely responsible for the conceptualization, methodology, data collection, data analysis, interpretation of results, drafting of the manuscript, critical revision of the content, and approval of the final version of the manuscript.

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During the preparation of this work, the authors used Grammarly to assist in improving grammar, clarity, and academic tone of the manuscript. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

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