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Mangrove ecosystem dynamics: a case study in maintaining coastal resilience to climate change

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ABSTRACT: The degradation of mangrove ecosystems due to climate change pressures and anthropogenic activities has reduced the natural protective capacity of coastal areas. This study aims to analyze the dynamics of mangrove ecosystems in maintaining coastal resilience to climate change through a case study approach. The research employed a mixed-methods design, integrating mangrove vegetation analysis, environmental parameters, spatial imagery, and social data collected through community interviews. The results indicate that the structure of the mangrove ecosystem remains relatively stable with a dominance of adaptive species, but experiences pressure in areas with high human activity. Spatial analysis reveals a decline in mangrove cover in several areas, although there has been an increase in community-based rehabilitation zones. Significant findings show that the interaction between environmental factors, anthropogenic pressures, and community participation directly influences the resilience of coastal ecosystems. Therefore, integrated and adaptive mangrove management is key to strengthening coastal resilience to climate change.

Kata Kunci : mangrove ecosystem, coastal resilience, climate change, ecological dynami

I. INTRODUCTION

Mangrove ecosystems are one of the most important components of coastal systems, functioning as natural buffers against various environmental pressures. Mangroves are known for their ability to reduce wave energy, prevent coastal erosion, and enhance shoreline stability (Arief et al., 2023). In addition, these ecosystems play a significant role in blue carbon storage, contributing to global climate change mitigation (Husain et al., 2025). In this context, the presence of mangroves is crucial for maintaining both ecological balance and the socio-economic well-being of coastal communities.

In recent decades, climate change has exerted significant pressure on coastal ecosystems, including mangroves. Sea-level rise, increased storm frequency, and changes in precipitation patterns have affected the structure and function of mangrove ecosystems (Saputra et al., 2025). These impacts have led to a decline in both the extent and quality of mangroves in various regions worldwide. This condition indicates that mangrove ecosystems are increasingly vulnerable to global environmental changes (Zebua et al., 2025).

On the other hand, anthropogenic activities such as land conversion for aquaculture, settlements, and industrial purposes have accelerated mangrove degradation. Studies indicate that more than one-third of the world's mangroves have been lost over the past five decades (Rembah et al., 2025). This loss not only affects ecological aspects but also reduces the natural capacity for coastal disaster protection. Therefore, mangrove degradation has become a critical issue that requires serious scientific attention and appropriate policy responses (Ziraluo, 2025).

Ideally, mangrove ecosystems are expected to function optimally as coastal protectors and providers of ecosystem services. However, field conditions reveal a gap between this ideal state and the current reality. Many mangrove areas have experienced structural degradation, reducing

their adaptive capacity to climate change (Kurnia & Gusri, 2025). This gap highlights the need for a more comprehensive scientific approach to understanding mangrove ecosystem dynamics.

Previous studies have extensively examined the role of mangroves in climate change mitigation and coastal protection. However, most studies tend to focus on static aspects such as coverage area and carbon stocks without fully exploring ecosystem dynamics. Furthermore, the methodological approaches used are often limited to quantitative analysis without integrating socio-ecological data. These limitations result in an incomplete understanding of the complex interactions within mangrove ecosystems (Waruwu et al., 2023).

Moreover, there is a research gap in case study contexts that integrate local factors with the global dynamics of climate change. Many studies are conducted at a macro scale, which may not adequately represent specific local or community-level conditions. In fact, mangrove ecosystem characteristics are strongly influenced by local geographic, social, and economic contexts (Ersan et al., 2022). Therefore, a case study approach is essential to produce findings that are more contextual and applicable.

Based on the above discussion, it is important to examine mangrove ecosystem dynamics more deeply in the context of coastal resilience to climate change. The main research question that arises is how the dynamics of mangrove ecosystem structure and function contribute to coastal resilience in a specific study area. Additionally, how the interaction between ecological and anthropogenic factors influences the adaptive capacity of mangroves to climate change remains a key concern. This study is expected to contribute scientifically to the development of sustainable and evidence-based mangrove management strategies.

II. METHODS

This study was designed using a qualitative approach with a case study strategy to gain an in-depth understanding of mangrove ecosystem dynamics in maintaining coastal resilience to climate change. This approach was selected because it enables a holistic exploration of phenomena through interacting social, ecological, and contextual perspectives.

The research site was purposively selected in the Lafau–Lahewa coastal area, which has an active mangrove ecosystem and is subject to pressures from environmental changes and human activities. The site selection considered distinctive socio-ecological characteristics to provide a contextual representation of mangrove dynamics at the local level.

Data collection was conducted through field observations, in-depth interviews, and documentation. Observations were carried out to directly understand the condition of the mangrove ecosystem, including vegetation distribution patterns, environmental conditions, and forms of interaction between humans and the ecosystem. In-depth interviews were conducted in a semi-structured manner with key informants such as fishermen, community leaders, and local government officials. These interviews aimed to explore perceptions, experiences, and local practices in mangrove management and adaptation to environmental changes.

In addition, documentation in the form of archives, government reports, and scientific publications was used as supporting data to enrich the research context. These data helped in understanding changes in the mangrove ecosystem from historical and policy perspectives.

Data analysis was conducted using thematic analysis techniques. The process began with the transcription of interview data, followed by coding to identify key themes emerging from the data. These themes were then analyzed to identify patterns of relationships among environmental factors, anthropogenic activities, and the role of communities in maintaining coastal resilience.

To ensure data validity, this study employed source and method triangulation techniques. Interview data were compared with observation and documentation results to ensure consistency of findings. In addition, member checking was conducted with informants to ensure that the researcher's interpretations aligned with their experiences and perspectives.

III. RESULTS AND DISCUSSION

The mangrove ecosystem along the Lafau–Lahewa Coast demonstrates dynamics that reflect a balance between natural resilience and external pressures. Field observations indicate that the vegetation structure is still capable of maintaining its ecological function as a coastal protector. The presence of adaptive mangrove species suggests that this system has resilience capacity in response to environmental changes (Yang et al., 2023). However, anthropogenic pressures remain a factor that gradually influences ecosystem stability (Barrera-Bello et al., 2025).

The dominance of certain mangrove species within the study area indicates adaptive mechanisms to dynamic environmental conditions. Species such as *Rhizophora sp.* and *Avicennia sp.* are ecologically known for their high tolerance to salinity and tidal inundation. This condition supports the theory that key species play an important role in maintaining ecosystem balance (Kalaivnai, 2025). Therefore, the presence of dominant species reflects not only environmental conditions but also the natural adaptive strategies of the mangrove ecosystem.

From a qualitative perspective, ecosystem stability is not only assessed through vegetation composition but also through the relationships among ecosystem components. Interactions among vegetation, soil, and water form an interdependent and adaptive system. These findings align with the concept of ecosystems as complex systems capable of responding to change through internal mechanisms (Mohanty et al., 2024). Therefore, the observed dynamics should be understood as a continuous process rather than a static condition.

Human activities represent one of the main factors influencing changes in the mangrove ecosystem. Activities such as land conversion into aquaculture ponds and settlements have altered the natural structure of coastal areas. The impacts of these activities are evident not only in physical changes but also in the decline of mangrove ecological functions. This condition is consistent with findings that global mangrove degradation is closely associated with human activities (Fadli et al., 2025).

Nevertheless, the results also reveal efforts toward ecosystem recovery through community-based rehabilitation. Community participation in mangrove planting activities has had a positive impact on ecosystem conditions. This involvement reflects a collective awareness of the importance of mangroves for coastal life. This finding is consistent with studies emphasizing the significant role of communities in mangrove conservation (Windayati et al., 2025).

Community perceptions of mangroves indicate a fairly strong understanding of their ecological functions. Local communities recognize mangroves as natural barriers against coastal erosion and sea waves. In addition, mangroves are viewed as economic resources through fisheries and related products. However, there is a gap between understanding and practice, as economic needs often drive exploitation (Ersan et al., 2022).

These dynamics indicate that coastal resilience is determined not only by ecological factors but also by socio-economic factors. The interaction between humans and the environment creates a complex socio-ecological system. In this context, coastal resilience is the result of a balance between utilization and conservation. Therefore, management approaches must simultaneously consider both aspects.

Environmental factors also play a crucial role in determining mangrove ecosystem conditions. Variations in water and soil conditions influence the distribution and growth of mangrove vegetation. Local communities observe environmental changes as part of their daily experiences. This local knowledge becomes an important source of information in understanding ecosystem dynamics (Agusrinal et al., 2025).

Conceptually, the dynamics of the mangrove ecosystem in this study can be framed into three main components:

- Environmental factors: water, soil, and climate conditions
- Anthropogenic pressures: land conversion and resource exploitation
- Conservation interventions: rehabilitation and community participation

These three components interact and form a system that determines coastal resilience to climate change.

Table 1. Relationships among these components

Main Component	Qualitative Description	Implications for Coastal Resilience
Environmental Factors	Natural conditions influencing mangrove growth and distribution	Determine natural adaptive capacity
Anthropogenic Pressures	Human activities that alter ecosystem structure	Reduce protective functions
Conservation Interventions	Community-based rehabilitation and management efforts	Enhance ecosystem recovery

Table 1 shows that coastal resilience is the result of dynamic interactions among these components.

From a theoretical perspective, the findings reinforce the view that mangrove ecosystems are adaptive systems with the capacity to respond to environmental changes. However, this capacity is not absolute and depends on the intensity of pressures faced. When pressures exceed adaptive capacity, ecosystem degradation occurs. This highlights the importance of maintaining a balance between natural factors and human activities (Oliveira et al., 2025).

In addition, this study demonstrates that community-based approaches have significant potential in mangrove conservation. Community involvement not only improves rehabilitation success but also strengthens a sense of ownership toward the ecosystem. This approach aligns with community-based management concepts that emphasize active participation in environmental stewardship. Therefore, this strategy can serve as a model for sustainable coastal management.

However, there are limitations in the implementation of mangrove management at the local level. These limitations are related to economic, institutional, and policy aspects that do not fully support conservation efforts. This condition indicates that mangrove management requires synergy among multiple stakeholders. Therefore, collaboration among government, communities, and academics is essential to strengthen coastal resilience.

Overall, the results and discussion demonstrate that mangrove ecosystem dynamics reflect complex interactions between ecological and social factors. Coastal resilience is determined not only by the presence of mangroves but also by the quality of management and community participation. These findings contribute to the development of adaptive and sustainable mangrove management strategies. Thus, the qualitative approach provides a deeper understanding of mangrove ecosystem dynamics in the context of climate change.

IV. CONCLUSION

This study concludes that the mangrove ecosystem in the Lafau–Lahewa coastal area exhibits adaptive dynamics shaped by the interaction of environmental factors, anthropogenic pressures, and community-based conservation efforts, where the ecosystem still maintains its ecological functions but remains vulnerable to gradual degradation caused by human activities. Coastal resilience is therefore not only determined by ecological conditions but also by the capacity and participation of local communities in sustainable management practices. Based on these findings, it is recommended to strengthen community-based mangrove management through continuous education and capacity building, enhance policy enforcement related to coastal land use, and promote collaboration among government, communities, and academic institutions, while future research should focus on long-term and interdisciplinary studies to better understand and support sustainable mangrove ecosystem management in the context of climate change.

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