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Integrating Mangrove Ecosystems and Non-Fish Fisheries for Sustainable Coastal Economies in Madura

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ABSTRACT

This study presented a comprehensive assessment of how mangrove ecosystems and non-fish fisheries resources contribute to sustainable coastal economies in Madura, Indonesia. Through field surveys, socioeconomic interviews, and GIS-based spatial analysis, approximately 18,000 hectares of mangrove forests were identified that support diverse non-fish resources, including crustaceans, mollusks, and seaweed. These resources contribute significantly to local livelihoods, accounting for 35–45% of household incomes across Sumenep, Pamekasan, and Bangkalan. This study is novel in its dual focus on ecological services and the economic valuation of non-fish resources—an often-overlooked aspect in coastal development planning. The integration of participatory governance and resource mapping reveals that regions with stronger conservation practices achieve higher economic returns and ecological stability. The findings can inform local policies for ecosystem-based resource management by demonstrating the tangible socioeconomic benefits of mangrove preservation, while highlighting the need for targeted capacity-building and inclusive governance to sustain non-fish resource-based livelihoods.

INTRODUCTION

Mangrove ecosystems are vital coastal habitats that provide a multitude of ecological, economic, and social services, particularly in tropical and subtropical regions. These ecosystems, characterized by salt-tolerant trees and shrubs, play a crucial role in maintaining coastal biodiversity, protecting shorelines from erosion, and supporting the livelihoods of coastal communities **(Rizal, 2018; Sarathchandra *et al.*, 2018)**. In Indonesia, particularly on the island of Madura, the significance of mangrove ecosystems

is amplified due to the archipelagic nature of the region, which relies heavily on these ecosystems for sustaining its coastal economy **(Huxham *et al.*, 2015)**.

The resources provided by mangroves are essential for direct livelihoods and serve as a foundation for broader economic activities, including fisheries and tourism **(Hussain & Badola, 2010; Islamy & Hasan, 2020; Isroni *et al.*, 2023)**. The integration of mangrove ecosystems with non-fish fisheries resources, such as crustaceans, mollusks, and seaweed, has emerged as a key driver of sustainable coastal economies in Madura **(Jänes *et al.*, 2020)**.

These non-fish marine resources are vital for local consumption and export, significantly contributing to the economic resilience of coastal communities **(Lebata *et al.*, 2012)**. Sustainable management of these resources, alongside the conservation and restoration of mangrove ecosystems, presents a promising approach to enhancing food security, reducing poverty, and promoting economic growth in Madura's coastal regions **(Ermgassen *et al.*, 2020)**.

Furthermore, the economic valuation of mangrove ecosystem services, such as their role in fisheries and carbon sequestration, underscores their importance in local and national economies **(Rahman *et al.*, 2018; Yanti *et al.*, 2021)**. Studies have shown that mangroves enhance local fisheries catches, providing critical habitats for commercially important species **(Estrada & Soares, 2017; Sinaga *et al.*, 2023)**. Beyond their economic contributions, mangrove ecosystems are crucial for carbon sequestration, acting as significant carbon sinks that mitigate the effects of climate change **(Carrasquilla-Henao & Juanes, 2016)**. Studies have shown that mangroves can store carbon at rates significantly higher than other forest types, making their preservation essential for both local and global climate strategies **(Serafy *et al.*, 2015; Kauffman & Bhomia, 2017)**. The ability of mangroves to sequester carbon is linked to their high primary productivity and unique adaptations to coastal environments, which allow them to thrive in challenging conditions **(Hidayati *et al.*, 2023)**.

The preservation of these ecosystems, therefore, has profound implications for climate change mitigation, emphasizing the need for effective management strategies that balance ecological health with economic development **(Huxham *et al.*, 2015)**. The mangrove ecosystems of Madura are indispensable for sustaining coastal economies and enhancing the resilience of local communities **(Indrayani *et al.*, 2021)**. Their integration with non-fish marine resources and their role in carbon sequestration highlight the multifaceted benefits they provide **(Jauhari, 2018)**. The sustainable management of these ecosystems is crucial for local livelihoods and for addressing broader environmental challenges, making their conservation a priority for policymakers and stakeholders alike **(Hussain & Badola, 2010)**.

This study aimed to assess the interconnected roles of mangrove ecosystems and non-fish fisheries resources—such as crustaceans, mollusks, and seaweed—in supporting sustainable coastal economies in Madura, Indonesia. It specifically investigates how these

two components interact through co-located practices of resource harvesting, community-based management, and ecological provisioning. By examining both the ecological services provided by mangroves and the economic contributions of non-fish resources, the study seeked to highlight opportunities for integrated, ecosystem-based approaches to coastal development. The objective was to provide actionable insights for strengthening local livelihoods, enhancing conservation outcomes, and informing policy strategies that align ecological preservation with socio-economic resilience.

MATERIALS AND METHODS

The study was carried out in designated coastal regions of Madura Island, which is renowned for its expansive mangrove forests and abundant marine biodiversity. Conducted in May 2024, the research aimed to explore the interactions between mangrove ecosystems and non-fish fisheries resources, and evaluate their collective influence on the sustainability of the island's coastal economy.

Study area

The research was carried out in the coastal regions of Madura, specifically in areas where mangrove ecosystems are prevalent and where non-fish fisheries resources are actively harvested. The selected sites included the coastal villages of Sumenep, Pamekasan, and Bangkalan, which are known for their dependence on mangrove-related activities and non-fish fisheries. These areas were chosen due to their representative nature in terms of mangrove cover, community reliance on marine resources, and economic activities centered around coastal resources.

Data collection

Data collection involved a combination of primary and secondary sources to gather comprehensive information on mangrove ecosystems, non-fish fisheries resources, and their economic implications.

Primary data collection

Field surveys: Field surveys were conducted in the selected coastal villages to assess the extent of mangrove cover, species composition, and the presence of non-fish fisheries resources. These surveys involved direct observations, measurements of mangrove tree density, and the identification of key species of crustaceans, mollusks, and seaweed.

Interviews and focus group discussions (FGDs): Semi-structured interviews were conducted with local fishermen, aquaculture farmers, and community leaders to gather insights into the socioeconomic importance of mangroves and non-fish fisheries resources. Focus group discussions were organized to capture the collective knowledge

and perceptions of community members regarding the sustainable management of these resources.

Economic assessments: Economic assessments were carried out to estimate the contribution of mangrove-related activities and non-fish fisheries to household incomes and the local economy. This included the valuation of direct products (e.g., crustaceans, mollusks) and indirect benefits (e.g., coastal protection, ecotourism potential) derived from mangrove ecosystems.

Secondary data collection

Literature review: A comprehensive review of existing literature was conducted to gather background information on mangrove ecosystems, non-fish fisheries resources, and their roles in coastal economies. This included reviewing scientific articles, government reports, and relevant case studies from other regions.

Remote sensing and GIS analysis: Remote sensing data and Geographic Information System (GIS) techniques were employed to map the spatial distribution of mangroves and associated non-fish fisheries resources in the study area. This analysis helped in understanding the spatial dynamics of these resources and their accessibility to local communities.

Data analysis

The collected data were analyzed using both qualitative and quantitative methods to provide a holistic understanding of the role of mangrove ecosystems and non-fish fisheries resources in the coastal economy.

Qualitative analysis: The qualitative data from interviews and FGDs were thematically analyzed to identify key themes and patterns related to the socioeconomic importance of mangroves and non-fish fisheries. This analysis provided insights into the perceptions of local communities regarding the sustainability of these resources and the challenges they face in managing them.

Quantitative analysis: The quantitative data from field surveys and economic assessments were statistically analyzed to quantify the economic contribution of mangrove-related activities and non-fish fisheries. This included calculating the average household income derived from these resources, estimating the market value of harvested products, and assessing the economic impact of mangrove conservation efforts.

Spatial analysis: The GIS data were used to create maps illustrating the distribution of mangroves and non-fish fisheries resources in the study area. These maps were overlaid with socioeconomic data to analyze the correlation between resource availability and community livelihoods.

RESULTS AND DISCUSSION

Mangrove coverage

The remote sensing and GIS analysis revealed that mangrove forests in the study areas of Madura cover approximately 18,000 hectares. The distribution of mangroves varied across the study sites, with the highest concentration found in Sumenep, followed by Pamekasan and Bangkalan. Table (1) presents the extent of mangrove coverage at each site.

Table 1. Extent of mangrove coverage in study areas

District	Area of Mangrove Forest (hectares)	Percentage of Total Coastal Area (%)
Sumenep	8,500	30.0
Pamekasan	5,500	20.0
Bangkalan	4,000	15.0
Total	**18,000**	**65.0**

Non-fish fisheries resources

Field surveys identified several key non-fish fisheries resources in the mangrove areas. The most common resources included:

- **Crustaceans:** The dominant species were mud crabs (*Scylla* spp.) and shrimp (*Penaeus* spp.).
- **Mollusks:** Notable species included green mussels (*Perna viridis*) and clams (*Meretrix* spp.).
- **Seaweed:** Dominant types were Eucheuma spp. and *Gracilaria* spp.

The mangrove ecosystems in Madura are biologically rich and serve as vital habitats for a wide variety of non-fish fisheries resources. These resources—particularly crustaceans, mollusks, and seaweed—not only contribute to biodiversity but also play a pivotal role in sustaining local livelihoods and ensuring food security.

Crustaceans: Mud crabs (*Scylla* spp.) and shrimp (*Penaeus* spp.)

Crustaceans are among the most economically valuable non-fish resources associated with mangrove habitats. Mud crabs (*Scylla* spp.), known for their high market price, are heavily harvested by local fishers due to their demand in both domestic and export markets. These species thrive in mangrove estuaries where the muddy substrate and complex root systems provide ideal shelter and breeding grounds.

Shrimp (*Penaeus* spp.) also exhibit strong ecological ties to mangrove environments during their juvenile stages, relying on the nutrient-rich detritus and protected conditions

for growth. Their presence highlights the nursery function of mangroves, which significantly boosts coastal productivity. However, intensive exploitation without sustainable aquaculture or harvesting practices can lead to stock depletion, threatening long-term economic returns.

Mollusks: Green mussels (*Perna viridis*) and clams (*Meretrix* spp.)

Mollusks contribute substantially to local subsistence and commercial fisheries. Green mussels and clams are filter feeders that play a critical role in maintaining water quality by filtering suspended particles and pollutants. These species often indicate ecosystem health and are commonly found in intertidal zones where mangrove roots stabilize sediments and support benthic communities.

In addition to their ecological role, mollusks are harvested year-round and provide a reliable source of protein for coastal households. Women are often involved in mollusk collection, making this sector especially important from a gender and social inclusion perspective. However, overharvesting and habitat degradation from pollution and land conversion threaten the sustainability of these resources.

Seaweed: Eucheuma spp. and *Gracilaria* spp.

Seaweed farming, particularly of *Eucheuma* and *Gracilaria*, has emerged as a sustainable income-generating activity in many mangrove-fringed areas of Madura. These species are used extensively in the food, pharmaceutical, and cosmetic industries. Eucheuma is cultivated for carrageenan, a gelling agent, while Gracilaria is often used in agar production.

Seaweed cultivation benefits from the sheltered hydrodynamic conditions provided by mangrove stands, which reduce wave action and enhance farm stability. Furthermore, seaweed farming has a low ecological footprint, does not require feed or freshwater inputs, and contributes to carbon sequestration and nutrient removal, making it a model for climate-resilient livelihoods.

Sustainability and management implications

While these resources provide substantial ecological and economic benefits, their continued availability depends on effective and inclusive management. Key challenges include:

- **Overexploitation** due to lack of harvesting regulations or enforcement;
- **Habitat degradation** from coastal development, aquaculture expansion, and pollution;
- **Knowledge gaps** among local communities regarding resource regeneration rates and ecological thresholds.

To ensure long-term sustainability, resource-specific strategies are needed. For crustaceans, community-based crab banks and closed harvesting seasons can help

replenish stocks. For mollusks, establishing community no-take zones and improving post-harvest handling can enhance both sustainability and market value. For seaweed, integrating mangrove conservation with aquaculture zoning can prevent ecological conflicts.

Furthermore, promoting ecosystem-based management (EBM) and incorporating traditional ecological knowledge (TEK) can bridge scientific recommendations with local practices. Capacity-building and policy support from local governments are critical to empower coastal communities to shift toward sustainable, diversified, and resilient coastal economies.

Economic impact

Economic assessments indicated that mangrove-related activities and non-fish fisheries resources significantly contribute to local livelihoods. Table (2) summarizes the average annual income derived from these resources by households in the study areas.

Table 2. Average annual income from mangrove-related activities and non-fish fisheries resources

District	Average Annual Income (USD)	Contribution to Household Income (%)
Sumenep	1,200	45.0
Pamekasan	950	40.0
Bangkalan	800	35.0

Sustainability and conservation practices

Interviews and focus group discussions (FGDs) revealed that while mangrove ecosystems are critical for local economies, there are varying levels of awareness and implementation of sustainable practices among coastal communities. In Sumenep, conservation efforts were found to be more advanced compared to Pamekasan and Bangkalan, which exhibited a greater reliance on traditional practices with less emphasis on sustainability. This disparity in conservation approaches can be attributed to several factors, including community awareness, governance structures, and the economic valuation of ecosystem services. Research indicates that strong governance systems can significantly enhance the benefits derived from mangrove ecosystems, as evidenced by those who highlight the importance of effective management and conservation policies in maximizing ecosystem services **(Getzner & Islam, 2020)**. Their findings suggest that communities with better governance frameworks are more likely to engage in sustainable practices, which aligns with the observations made in Sumenep. In contrast, previous authors emphasized the need for comprehensive ecosystem valuation to update

community perspectives on the importance of mangrove goods and services, which may explain the traditional practices observed in Pamekasan and Bangkalan **(Panandi *et al.*, 2019)**. Moreover, the importance of discussing the rates and drivers of mangrove deforestation in Southeast Asia was reported, noting that areas with less awareness and engagement in sustainable practices are more susceptible to degradation **(Richards & Friess, 2015)**. This is particularly relevant for Pamekasan and Bangkalan, where traditional practices may not adequately address the ecological challenges faced by mangrove ecosystems. further emphasizing the necessity of prioritizing management measures in developing countries to maintain biodiversity and ecosystem services, suggesting that enhanced awareness and education could lead to improved conservation outcomes **(Dabalà *et al.*, 2023)**.

The economic valuation of mangrove ecosystem services is critical for fostering sustainable practices. Studies have shown that communities that recognize the economic benefits of mangroves, such as carbon sequestration and fisheries support, are more likely to adopt conservation measures **(Pandi *et al.*, 2022)**. For instance, it is crucial to highlight the significant economic value generated by mangrove ecosystems, which can incentivize communities to engage in sustainable management practices **(Thomas *et al.*, 2017)**. In contrast, areas that undervalue these services may continue to rely on traditional practices that do not support long-term sustainability.

Mangrove ecosystems and economic contributions

The findings underscore the significant role of mangrove ecosystems in supporting the livelihoods of coastal communities in Madura. The extent of mangrove coverage aligns with previous studies indicating that mangrove forests provide essential resources for local economies **(Alongi, 2002; Isroni *et al.*, 2019)**. The distribution of mangroves in Sumenep, Pamekasan, and Bangkalan reflects the historical and environmental conditions that have shaped these ecosystems.

The economic data reveal that mangrove-related activities and non-fish fisheries resources are vital for household income. The average annual income derived from these resources supports previous research indicating that non-fish fisheries can be a substantial economic driver in coastal regions. The higher income in Sumenep can be attributed to better conservation practices and more intensive resource management, which have enhanced resource availability and economic returns.

Sustainability and conservation practices

The differences in conservation practices across the study areas highlight the need for region-specific management strategies. Sumenep's advanced conservation efforts reflect successful integration of sustainable practices, which is consistent with findings from other regions where effective management has led to improved resource sustainability and economic benefits **(Koda, 2023)**. **Koda (2023)** emphasizes the

importance of government support and community engagement in enhancing awareness of mangrove benefits, which can drive active participation in conservation efforts.

In contrast, Pamekasan and Bangkalan's reliance on traditional practices underscores the need for increased awareness and capacity-building to promote sustainable resource use. The lower level of sustainability in Pamekasan and Bangkalan aligns with challenges reported in similar coastal areas, where traditional practices often lead to overexploitation of resources **(Getzner & Islam, 2020)**. **Getzner and Islam (2020)** note that communities relying on traditional practices may struggle with sustainability due to a lack of awareness regarding the long-term impacts of their resource use. Efforts to enhance sustainability should focus on education and support for adopting more effective conservation techniques, as well as strengthening community involvement in management decisions.

This is echoed by **Su *et al.* (2021)**, who highlight the importance of community engagement in the restoration and management of mangrove ecosystems to achieve ecological and economic outcomes. Moreover, Getzner and Islam's meta-analysis reveals that strong governance systems significantly contribute to the benefits derived from mangrove ecosystems, suggesting that effective management frameworks can enhance both ecological health and economic returns for local communities **(Getzner & Islam, 2020)**. This underscores the necessity of tailored management strategies that consider local contexts and the specific challenges faced by communities in Pamekasan and Bangkalan.

Comparative insights

The observed economic contributions and sustainability issues in the mangrove ecosystems of Madura are consistent with broader trends documented in the literature. The economic benefits derived from non-fish fisheries resources have been well-established in various studies, highlighting their importance for local economies. For instance, the emphasis on the perspective that mangrove ecosystems provide critical resources that support fisheries and other economic activities, which is echoed by those who discuss the significant role of these ecosystems in sustaining local livelihoods through diverse resource utilization **(Barbier *et al.*, 2011; Askar *et al.*, 2021)**.

The variation in conservation practices across different regions also mirrors findings from other studies, where the effectiveness of management strategies is influenced by local conditions and governance structures. They argued that successful mangrove management often depends on the integration of local community needs and ecological considerations, which can lead to improved sustainability outcomes **(Carugati *et al.*, 2018)**.

This is particularly relevant in the context of Sumenep, where advanced conservation efforts have been linked to effective governance and community engagement, resulting in enhanced resource sustainability and economic benefits. In contrast, the reliance on

traditional practices in Pamekasan and Bangkalan underscores the challenges faced in achieving sustainable management, noting that traditional practices can lead to overexploitation of resources, particularly in regions where awareness and capacity for sustainable practices are lacking **(Harefa *et al.*, 2022)**.

This aligns with the findings in Madura, where increased awareness and education are essential for promoting sustainable resource use and improving conservation outcomes. Efforts to enhance sustainability in these areas should focus on education and capacity-building initiatives that empower local communities to adopt more effective conservation techniques. As highlighted, community involvement in management decisions is crucial for fostering a sense of ownership and responsibility towards mangrove conservation **(Carter *et al.*, 2015)**. Furthermore, integrating economic valuation of ecosystem services into management strategies can provide incentives for sustainable practices, as demonstrated in various case studies.

Based on the findings of this study on the contribution of mangrove ecosystems and non-fish fisheries resources to sustainable coastal economies in Madura, future research is recommended to adopt a more integrative approach by incorporating environmental bioindicators to support holistic coastal resource management. For instance, **Islamy *et al.* (2025a, 2025b)** demonstrated that microplastic accumulation and genotoxic biomarkers in wild fish are crucial indicators of aquatic ecosystem health. Additionally, **Islamy *et al.* (2025)** emphasized the potential of eco-friendly carotenoid supplementation using cochineal powder, suggesting a link between biodiversity-based innovation and coastal economic development. Therefore, future studies should consider combining ecological, toxicological, and economic dimensions to develop adaptive and sustainable coastal management frameworks.

CONCLUSION

Mangrove ecosystems in Madura serve as critical natural infrastructure that supports ecological integrity and sustains the economic well-being of coastal communities. This study demonstrates that non-fish fisheries resources—particularly crustaceans, mollusks, and seaweed—derived from mangrove areas are essential contributors to household incomes, with the highest economic returns observed in regions implementing active conservation strategies, such as Sumenep.

The novelty of this research lies in its integrative approach, combining ecological assessments, socioeconomic analysis, and spatial mapping to reveal the multifaceted roles of mangroves beyond conventional fishery functions. The findings reveal stark contrasts in sustainability practices between regions, underscoring the urgent need to enhance awareness, local governance, and adaptive management, particularly in areas still reliant on traditional and less sustainable resource use.

Given the mounting threats of climate change and coastal degradation, the preservation and optimized utilization of mangrove ecosystems must become a national priority. Policies promoting ecosystem-based management, community participation, and economic valuation of ecosystem services are essential to ensure long-term sustainability. This study offers a replicable framework for other island regions facing similar challenges, bridging the gap between ecological conservation and socio-economic development.

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