

A POLICY AND INNOVATION FRAMEWORK FOR SUSTAINABLE MANGROVE ECOSYSTEM MANAGEMENT THROUGH SMART AQUACULTURE AND ECOTOURISM

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Abstract— Mangrove ecosystem degradation has increasingly threatened coastal sustainability, particularly in developing countries such as Indonesia. Despite various conservation efforts, existing approaches often lack integration between ecological preservation, economic value creation, and policy-oriented frameworks. This study aims to develop a policy and innovation framework for sustainable mangrove ecosystem management through the integration of smart aquaculture and ecotourism. This research employs a mixed-method approach, combining vegetation analysis, spatial analysis using the Normalized Difference Vegetation Index (NDVI), multi-criteria analysis for ecotourism suitability, and AWOT (AHP–SWOT) for strategic formulation. The study was conducted in the Kalimireng coastal area, Gresik, Indonesia, which represents a critical mangrove ecosystem under environmental pressure. The findings reveal that integrating smart aquaculture with mangrove ecotourism enhances both ecological resilience and economic productivity. The proposed model supports sustainable resource utilization by optimizing the balance between conservation and aquaculture activities while creating alternative income sources for local communities. Furthermore, the framework demonstrates strong alignment with sustainable development goals, particularly SDG 14 (Life Below Water), and highlights the potential for scalable policy implementation in coastal areas. This study contributes to the literature by offering an integrated policy and business-oriented model that bridges environmental sustainability with economic value creation, providing actionable insights for policymakers, industry stakeholders, and coastal communities.

Keywords— Mangrove ecosystem, smart aquaculture, ecotourism, policy framework, sustainable coastal development, economic value creation

1. INTRODUCTION

Mangrove ecosystems play a crucial role in supporting coastal sustainability by providing ecological, economic, and social benefits. These ecosystems function as natural coastal protection, biodiversity habitats, and sources of livelihood for local communities. In Indonesia, mangrove areas are particularly important due to their contribution to fisheries, aquaculture, and coastal economic activities. However, increasing environmental degradation caused by land conversion, industrial expansion, and unsustainable resource utilization has significantly threatened the sustainability of mangrove ecosystems. The Kalimireng coastal area in Gresik, East Java, represents one of the remaining mangrove ecosystems that has experienced substantial degradation. Approximately 100 hectares of mangrove areas have been converted for industrial and settlement purposes, resulting in environmental issues such as coastal flooding and declining ecosystem services. Although various conservation initiatives have been implemented, most approaches remain fragmented and lack integration between ecological preservation, economic utilization, and policy frameworks. Recent studies have highlighted the importance of integrating environmental conservation with economic value creation to achieve sustainable coastal management (Bengen et al., 2023; Dahuri et al., 1996). One promising approach is the implementation of smart aquaculture (silvofishery), which integrates aquaculture practices with mangrove conservation. This approach is designed to achieve dual objectives:

economically, it enhances aquaculture productivity by rehabilitating degraded ponds, while ecologically, it supports mangrove restoration through proportional planting within aquaculture areas (Clough & Johnston, 2000; Rahmad Royan, n.d.).

The smart aquaculture model is considered an effective alternative for balancing environmental sustainability and economic utilization in coastal regions. By integrating mangrove ecosystems into aquaculture systems, this approach promotes a balanced ecosystem in which nutrient availability supports the growth of cultivated species. This balance is achieved through natural ecological processes, particularly the decomposition of mangrove litter, which provides essential nutrients such as nitrogen, phosphorus, and potassium. Furthermore, this system reflects a supply–demand equilibrium within aquaculture environments, where ecological functions directly contribute to production efficiency. In addition to aquaculture, mangrove-based ecotourism offers significant potential as an alternative source of income for coastal communities while promoting environmental awareness and conservation (Ellison, 2008). The integration of smart aquaculture and ecotourism therefore represents a promising pathway toward sustainable coastal development that simultaneously addresses ecological preservation and economic growth. Despite these potentials, there remains a significant gap in developing an integrated framework that connects smart aquaculture and ecotourism within a policy and business-oriented perspective. Existing studies tend to focus on ecological or technical aspects, with limited attention to how these approaches can be translated into scalable policy models and sustainable business strategies.

Therefore, this study aims to develop an integrated policy and innovation framework for sustainable mangrove ecosystem management through the combination of smart aquaculture and ecotourism. Specifically, the research seeks to assess the ecological and economic potential of mangrove ecosystems, evaluate the feasibility of smart aquaculture and mangrove-based ecotourism, and formulate strategic recommendations for sustainable coastal development. The novelty of this study lies in the integration of ecological and economic perspectives within a unified management framework, bridging environmental sustainability with value creation and policy-oriented strategies.

2. LITERATURE REVIEW

2.1. Ecological and Sustainable Coastal Management

Mangrove ecosystems play a vital role in supporting coastal sustainability through their ecological, economic, and social functions. Ecologically, mangroves act as natural coastal barriers that protect shorelines from erosion and provide habitats for diverse marine organisms. They also contribute to nutrient cycling and maintain ecological balance in coastal environments. From a socio-economic perspective, mangrove ecosystems support fisheries, aquaculture, and other coastal-based livelihoods, while also enhancing community welfare through income generation and human development. Sustainable mangrove management requires an integrated approach that considers sectoral, ecological, and interdisciplinary aspects. This includes the integration of land and marine ecosystems, coordination among stakeholders, and the involvement of multiple disciplines to ensure balanced resource utilization. Such an approach allows economic benefits to be achieved while maintaining ecological sustainability for future generations (Bengen et al., 2023).

One of the most effective approaches in sustainable coastal management is smart aquaculture (silvofishery), which integrates aquaculture practices with mangrove conservation. This model is designed to achieve dual objectives by enhancing aquaculture productivity while simultaneously supporting mangrove restoration. Mangroves contribute to aquaculture systems through litter decomposition, which releases essential nutrients such as nitrogen, phosphorus, and potassium, thereby improving soil and water quality. In addition, mangroves function as natural biofilters that help reduce pollutants and maintain water quality. The integration of mangroves into aquaculture systems creates a balanced ecosystem in which ecological processes directly support production efficiency. This reflects a natural supply–demand equilibrium, where nutrient availability meets the needs of aquaculture species. As a result, smart aquaculture represents a sustainable and environmentally friendly model for optimizing coastal resource utilization (Dahuri et al., 1996).

2.2. Economic Value and Policy Perspective

In addition to ecological functions, mangrove ecosystems also offer significant economic value, particularly through the development of mangrove-based ecotourism. Ecotourism emphasizes environmental conservation while providing alternative income sources for coastal communities. It enhances environmental

awareness, promotes conservation efforts, and supports local economic development without compromising ecosystem integrity. The success of ecotourism development depends on active stakeholder participation, including local communities, government institutions, and private sectors. When properly managed, ecotourism can generate economic benefits while preserving natural ecosystems, making it a strategic approach to sustainable coastal development (Rönnbäck & Primavera, 2000).

Despite the recognized benefits of smart aquaculture and ecotourism, their integration within a unified framework remains limited. Many existing approaches treat ecological conservation, aquaculture development, and tourism activities separately, resulting in fragmented management strategies. From a policy and business perspective, there is a growing need to develop integrated models that connect environmental sustainability with economic value creation. The integration of smart aquaculture and mangrove ecotourism offers a holistic solution that aligns ecological preservation with economic and policy objectives. This approach not only enhances ecosystem resilience but also supports sustainable economic development and community empowerment. Therefore, the development of a policy and innovation framework that integrates these elements is essential for achieving sustainable mangrove ecosystem management (Yulianda & Atmadipoera, 2019).

3. METHODS

This study employs a mixed-method approach that integrates ecological assessment, spatial analysis, and policy-oriented evaluation to develop a comprehensive framework for sustainable mangrove ecosystem management. The research was conducted from January to December 2022 in the coastal area of Kalimireng Village, Manyar District, Gresik Regency, East Java, Indonesia. This location was selected due to its representative characteristics of mangrove ecosystems and its potential for aquaculture and coastal economic development. Primary data were collected through field observations, including mangrove vegetation assessment and general ecological condition analysis, as well as surveys of local community characteristics. Secondary data were obtained from previous studies, institutional reports, and relevant literature to support ecological, economic, and policy analysis.

The study examines both ecological and socio-economic aspects. Ecological assessment focuses on mangrove vegetation characteristics, ecosystem functions, and their role in supporting aquaculture systems. Socio-economic aspects include ecosystem service values, aquaculture productivity, and community characteristics such as income, education level, and occupation. Spatial analysis using the Normalized Difference Vegetation Index (NDVI) was applied to support the assessment of mangrove distribution and coverage. In addition, a multi-criteria approach was used to evaluate the suitability of ecotourism development, while strategic analysis was conducted using AWOT (AHP–SWOT) to formulate policy recommendations. Overall, this methodological framework integrates ecological, economic, and policy dimensions to support the development of a sustainable and scalable model for mangrove ecosystem management through smart aquaculture and ecotourism.

4. RESULTS AND DISCUSSION

4.1. Mangrove Ecosystem Condition and Ecological Potential

The results indicate that the mangrove ecosystem in the Kalimireng coastal area remains relatively diverse despite experiencing environmental degradation. The findings are derived from qualitative and semi-quantitative analysis of ecological conditions and socio-economic factors. Based on field identification, several dominant mangrove species were found, including *Avicennia marina*, *Rhizophora mucronata*, *Rhizophora apiculata*, *Bruguiera cylindrica*, *Excoecaria agallocha*, *Sonneratia alba*, and *Bruguiera gymnorhiza*. These species play an important role in maintaining ecological balance, supporting biodiversity, and stabilizing coastal environments.

Table 1. Dominant Mangrove Species Identified in Kalimireng Coastal Area

Species Name	Ecological Role
<i>Avicennia marina</i>	Pioneer species, shoreline stabilization
<i>Rhizophora mucronata</i>	Sediment trapping, habitat provider
<i>Rhizophora apiculata</i>	Coastal protection, nursery ground
<i>Bruguiera cylindrica</i>	Soil stabilization
<i>Excoecaria agallocha</i>	Supporting biodiversity
<i>Sonneratia alba</i>	Coastal buffering
<i>Bruguiera gymnorhiza</i>	Nutrient Cycling

Table 1 presents the dominant mangrove species and their ecological roles in the study area. The ecological functions of mangroves are closely linked to aquaculture productivity. The decomposition of mangrove litter contributes to nutrient availability, particularly nitrogen, phosphorus, and potassium, which are essential for supporting aquatic organisms. In addition, mangroves act as natural biofilters that improve water quality and reduce environmental pollution in aquaculture systems. However, land conversion for industrial and settlement purposes has reduced mangrove coverage in the study area, leading to environmental issues such as coastal flooding and declining ecosystem services. This highlights the urgency of implementing integrated management strategies that restore ecological functions while maintaining economic productivity.

4.2. Feasibility of Smart Aquaculture and Ecotourism Development

The findings show that the implementation of smart aquaculture (silvofishery) has strong potential to improve both ecological and economic outcomes. By applying proportional ratios between mangrove areas and aquaculture ponds, this system creates a balanced ecosystem that enhances nutrient cycling and water quality. As a result, aquaculture productivity can be improved while minimizing environmental degradation. From an economic perspective, smart aquaculture reduces dependency on external inputs by utilizing natural ecosystem services. This contributes to cost efficiency and promotes sustainable aquaculture practices. Furthermore, the adoption of polyculture systems within smart aquaculture allows for more efficient resource utilization, as different species can coexist and optimize the use of available nutrients.

In addition to aquaculture, mangrove-based ecotourism provides a promising opportunity for diversifying local economic activities. The unique biodiversity and natural landscape of mangrove ecosystems offer attractive features for tourism, education, and research. Ecotourism activities generate additional income for local communities while promoting environmental awareness and conservation efforts. The integration of smart aquaculture and ecotourism creates a synergistic model that supports both environmental sustainability and economic development. This approach enables coastal communities to benefit from multiple income sources while preserving ecosystem integrity.

4.3. Integrated Policy and Business Model for Sustainable Coastal Management

The results highlight the importance of integrating ecological conservation with economic value creation through a policy-oriented framework. The combination of smart aquaculture and mangrove ecotourism represents a holistic approach that aligns environmental, economic, and social objectives.

Table 2. Integrated Model of Smart Aquaculture and Mangrove Ecotourism

Aspect	Smart Aquaculture	Ecotourism	Expected Outcome
Ecology	Mangrove conservation, nutrient cycle	Ecosystem preservation	Improved ecosystem resilience
Economy	Aquaculture productivity	Tourism-based income	Increased community
Social	Local participation	Environmental education	Community empowerment
Sustainability	Balanced ecosystem	Low-impact tourism	Sustainable coastal development

Table 2 presents the integrated model of smart aquaculture and mangrove ecotourism. From a policy perspective, the integration of these approaches provides a foundation for developing sustainable coastal management strategies. The model demonstrates that mangrove ecosystems can be managed not only as conservation areas but also as productive assets that generate economic value. From a business perspective, this integrated approach opens opportunities for innovation in coastal-based industries, including sustainable aquaculture production and eco-friendly tourism services. The model supports value creation by combining environmental sustainability with economic productivity. Furthermore, stakeholder collaboration is essential for successful implementation. Government institutions, local communities, and private sector actors must work together to develop regulatory frameworks, provide incentives, and ensure long-term sustainability. Overall, the integration of smart aquaculture and mangrove ecotourism offers a practical and scalable solution for addressing environmental degradation while enhancing economic resilience in coastal areas. This approach provides a strong foundation for policy development and sustainable coastal management.

5. CONCLUSIONS

This study demonstrates that mangrove ecosystem management can be effectively enhanced through the integration of smart aquaculture and mangrove-based ecotourism within a policy and innovation framework. The findings indicate that mangrove ecosystems in the Kalimireng coastal area possess significant ecological and economic potential, despite experiencing environmental degradation due to land conversion and unsustainable practices. The implementation of smart aquaculture supports ecological sustainability by improving nutrient cycling, water quality, and overall ecosystem balance, while simultaneously enhancing aquaculture productivity. In parallel, mangrove-based ecotourism provides alternative income opportunities for local communities and promotes environmental awareness, contributing to both economic development and conservation efforts. The integration of these two approaches creates a synergistic model that aligns ecological preservation with economic value creation. From a policy perspective, this study highlights the importance of developing integrated and scalable frameworks that connect environmental management with economic and social objectives. The proposed model offers practical insights for policymakers, stakeholders, and coastal communities in designing sustainable coastal development strategies. This study contributes to the literature by bridging ecological and economic perspectives within a unified management framework, emphasizing the role of innovation and policy in achieving sustainable mangrove ecosystem management. Future research is recommended to incorporate quantitative analysis and broader geographic applications to further validate and expand the proposed framework.

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