



## Mangrove Conservation and Social-Ecological Resilience in a Community-Based Coastal Landscape of Indonesia

Agung Ardiyansah<sup>1</sup>, Ghanishta Seburrun<sup>2</sup>, Shannon M Lambert<sup>3</sup>

<sup>1</sup>Department of Fishery Agrobusiness, University of Brawijaya, East Java, Indonesia

<sup>2</sup>Department of Conservation Biology, University of Mauritius, Moca, Mauritius

<sup>3</sup>Fish Wildlife and Conservation Biology, Colorado State University, Colorado, United States

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### ABSTRACT

**Purpose of the study:** This study aims to examine the evolution of community-based mangrove conservation in Wringinputih Village, Indonesia, from the implementation of the Cofish Project to the present. It also aims to develop a social-ecological framework for future mangrove management that supports ecosystem restoration, biodiversity conservation, coastal landscape resilience, and sustainable community livelihoods.

**Methodology:** This study employed a qualitative case study approach. Data were collected through field observations, in-depth interviews, document analysis, and source triangulation. Informants included village authorities, fisheries officers, Perhutani representatives, fisher groups, and aquaculture farmers. Environmental measurements utilized a pH meter, thermometer, hand refractometer, GPS, and digital camera. Data were analyzed using the Miles and Huberman interactive model.

**Main Findings:** Mangrove conservation in Wringinputih Village evolved from ecosystem degradation caused by aquaculture expansion toward a community-based restoration model supported by multi-stakeholder collaboration. Continuous rehabilitation activities increased mangrove cover, improved habitat quality, enhanced biodiversity conservation, strengthened coastal protection functions, and supported fisheries resources. The proposed social-ecological framework highlights the integration of ecosystem restoration, community participation, institutional collaboration, environmental education, and sustainable livelihood development to strengthen coastal landscape resilience.

**Novelty/Originality of this study:** This study provides a comprehensive reconstruction of mangrove conservation history from the Cofish Project period to the present and integrates the findings into a social-ecological resilience framework for coastal landscape management. Unlike previous studies focusing primarily on restoration outcomes or governance mechanisms, this research demonstrates how ecosystem recovery, biodiversity conservation, stakeholder collaboration, and community participation interact to support long-term mangrove conservation and landscape resilience.

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#### Corresponding Author:

Agung Ardiyansah

Department of Fishery Agrobusiness, University of Brawijaya, Veteran Street No.10-11, Ketawanggede, Lowokwaru District, Malang City, East Java 65145, Indonesia

Email: [gungardynsyhkh@gmail.com](mailto:gungardynsyhkh@gmail.com)

## 1. INTRODUCTION

Mangrove forests are among the most productive coastal ecosystems in the world, providing essential ecological, economic, and social benefits for coastal communities. These ecosystems function as natural barriers against coastal erosion, storm surges, and sea-level rise while simultaneously supporting fisheries, biodiversity conservation, carbon sequestration, and local livelihoods [1], [2]. Despite their ecological significance, mangrove ecosystems continue to experience degradation due to land-use conversion, aquaculture expansion, urban development, and unsustainable resource utilization [3], [4]. Globally, mangrove management has shifted from conventional conservation approaches toward participatory and community-based governance models that emphasize stakeholder collaboration and social-ecological resilience [5], [6]. Such an approach recognizes that the sustainability of mangrove ecosystems depends not only on ecological conditions but also on the interactions between communities, institutions, and environmental resources.

Indonesia possesses the largest mangrove area in the world and plays a critical role in global mangrove conservation efforts. However, many mangrove ecosystems in Indonesia have experienced substantial degradation over the past decades due to intensive coastal development and aquaculture activities [7], [8]. In response to these challenges, community-based mangrove management has emerged as a promising strategy to restore ecosystem functions while improving local livelihoods [9], [10]. Several studies have demonstrated that community participation significantly contributes to mangrove rehabilitation success, biodiversity conservation, and coastal protection [11], [12]. Nevertheless, the effectiveness of community-based management varies considerably depending on governance structures, institutional arrangements, and socio-economic conditions.

The mangrove ecosystem of Wringinputih Village, located in Muncar District, Banyuwangi Regency, East Java, represents one of the notable examples of community-driven coastal conservation in Indonesia. Historically, the area experienced significant ecological degradation resulting from pond expansion and unsustainable land use [13], [14]. Since the implementation of the Coastal Fisheries Management Project (Cofish Project) in the late 1990s, extensive mangrove rehabilitation efforts have transformed degraded coastal lands into a thriving mangrove ecosystem. The restoration initiative gradually encouraged community participation, strengthened local environmental awareness, and generated new economic opportunities through ecotourism and sustainable resource utilization [15], [16]. As a result, the mangrove area has continuously expanded and become an important component of coastal environmental management in Banyuwangi.

Recent studies have highlighted the importance of social-ecological approaches in understanding mangrove governance and resilience. For example, Damastuti et al. [17] examined the effectiveness of community-based mangrove management for biodiversity conservation in Central Java and found that long-term community involvement strongly influences restoration outcomes. Damastuti et al. [18] further demonstrated that community-based management contributes significantly to coastal protection and climate adaptation. Sukarmen et al. [19] emphasized the role of socio-ecological interactions in strengthening community-based mangrove protection against climate change impacts. More recently, Nuraeni and Kusum [20] investigated the contribution of community-based tourism to mangrove conservation, while studies applying the Social-Ecological Systems framework have highlighted the importance of integrating governance, ecological conditions, and stakeholder participation in sustainable mangrove management.

Despite the growing body of literature, several research gaps remain. First, previous studies predominantly focus on ecological restoration outcomes, biodiversity conservation, ecotourism development, or governance performance independently, with limited attention to the historical co-evolution of social and ecological systems over long temporal periods [21], [22]. Second, studies in Wringinputih Village have largely examined local wisdom, socio-economic impacts, community empowerment, and ecotourism development, without comprehensively analyzing how social-ecological resilience has evolved from the Cofish Project era to the present. Third, limited research has integrated historical management trajectories, institutional transformation, community participation, and ecological dynamics into a unified social-ecological resilience framework. Consequently, understanding the long-term adaptive processes that shape current mangrove governance remains insufficient, particularly in the context of community-based management in Indonesia.

The novelty of this study lies in its integration of historical analysis and social-ecological resilience assessment within a community-based mangrove governance framework. Unlike previous studies that primarily focus on contemporary ecological or socio-economic conditions, this research investigates the evolution of mangrove management from the initiation of the Cofish Project to current governance practices. Furthermore, the study applies a social-ecological systems perspective to examine interactions among local communities, institutions, ecological restoration processes, and livelihood adaptation over time [23], [24]. By combining historical reconstruction, governance analysis, and social-ecological resilience assessment, this study is expected to provide a more comprehensive understanding of adaptive mangrove management in coastal Indonesia.

This research is urgently needed because mangrove ecosystems are increasingly confronted by environmental change, climate-related hazards, and growing pressures from coastal development. Sustainable management strategies require a deeper understanding of how past management interventions influence current ecological conditions and governance effectiveness [25], [26]. Moreover, lessons learned from successful

community-based conservation initiatives can contribute to the formulation of adaptive management policies applicable to other coastal regions in Indonesia. Therefore, this study aims to analyze the historical development of mangrove conservation and management from the implementation of the Cofish Project to the present and to develop a future management framework based on a social-ecological perspective that supports biodiversity conservation, coastal landscape resilience, and community well-being in Wringinputih Village, Banyuwangi Regency, Indonesia.

## 2. RESEARCH METHOD

### 2.1. Research Design

This study employed a qualitative research approach to explore the historical development and future planning of mangrove forest management from a social-ecological perspective in Wringinputih Village, Muncar District, Banyuwangi Regency, East Java, Indonesia. Qualitative research is appropriate for examining complex social and environmental phenomena within their natural settings, enabling researchers to gain a comprehensive understanding of interactions among stakeholders, institutions, and ecological systems [27], [28]. This approach emphasizes the interpretation of meanings, experiences, and processes rather than statistical generalization. Furthermore, qualitative methods facilitate an in-depth investigation of historical changes, community participation, governance dynamics, and ecological transformations associated with mangrove management. Therefore, this approach was considered suitable for analyzing the evolution of community-based mangrove governance and social-ecological resilience in the study area.

Data were collected through multiple qualitative techniques, including in-depth interviews, field observations, focus group discussions, and document analysis. The use of various data sources enabled methodological triangulation to enhance the credibility and validity of the findings [29], [30]. Historical documents, government reports, project archives, and community records were examined to reconstruct the chronology of mangrove management from the implementation of the Coastal Fisheries Management Project (Cofish Project) to the present. In addition, direct observations and stakeholder interviews were conducted to capture current management practices, community perceptions, and institutional arrangements. The integration of these data collection methods provided a comprehensive understanding of both past and present social-ecological conditions influencing mangrove governance in Wringinputih Village.

### 2.2. Research Participants

In qualitative research, the concept of population is not applied in the same manner as in quantitative studies. Instead, the study focuses on a specific social setting in which individuals, institutions, and activities interact within a particular context [31], [32]. Therefore, the unit of analysis in this research was the social-ecological system of mangrove management in Wringinputih Village, Muncar District, Banyuwangi Regency, East Java, Indonesia. The social setting comprised three interconnected elements: the place, represented by the mangrove ecosystem and surrounding coastal area; the actors, consisting of stakeholders involved in mangrove management; and the activities related to mangrove conservation, rehabilitation, utilization, and governance. Examining these interactions enabled a comprehensive understanding of the historical development and current dynamics of community-based mangrove management.

Participants were selected using purposive sampling based on their involvement, experience, and knowledge of mangrove management in the study area. Key informants included representatives from the Banyuwangi Marine and Fisheries Office, local government officials, Perhutani officers, community leaders, fisher groups, and aquaculture farmer groups who have actively participated in mangrove management activities since the implementation of the Coastal Fisheries Management Project (Cofish Project). These stakeholders were considered capable of providing detailed information regarding the history of mangrove rehabilitation, institutional development, community participation, and future management challenges. Data collection continued until information saturation was achieved, indicating that no substantial new information emerged from additional interviews. The selection of diverse stakeholder groups facilitated the exploration of multiple perspectives and strengthened the validity of the findings through data triangulation.

Table 1. Research Participants

Informant Code	Stakeholder Category	Role in Mangrove Management
I1	Marine and Fisheries Office	Government representative
I2	Village Government	Village head
I3	Perhutani	Forest management officer
I4–I5	Fisher Group	Community representatives
I6–I8	Aquaculture Farmer Group	Community representatives

### 2.3. Data Collection

Data were collected through a combination of field observations, in-depth interviews, and document analysis to obtain a comprehensive understanding of the historical development and future planning of mangrove management in Wringinputih Village. Field observations were conducted to examine both social and ecological conditions within the mangrove ecosystem, including community activities, institutional arrangements, mangrove vegetation characteristics, associated fauna, water conditions, and resource utilization practices [33], [34]. These observations enabled the researchers to directly assess the interactions between local communities and the mangrove ecosystem within the broader social-ecological system.

In-depth interviews were conducted with key stakeholders who have been directly involved in mangrove management and coastal resource governance. These stakeholders included representatives from the Marine and Fisheries Office, village government, Perhutani, community-based mangrove management groups, fisher groups, and aquaculture farmer groups. The interviews focused on reconstructing the historical trajectory of mangrove management from the implementation of the Coastal Fisheries Management Project (Cofish Project) to the present, as well as exploring stakeholder perspectives regarding current challenges and future management strategies. The semi-structured interview format provided flexibility for participants to share their experiences, perceptions, and knowledge related to ecological restoration, institutional development, community participation, and livelihood adaptation.

Document analysis was employed to complement primary data obtained from observations and interviews [35], [36]. Various sources, including government reports, village archives, project documents, management plans, scientific publications, photographs, and other relevant records, were reviewed to verify historical information and identify changes in mangrove governance over time. The integration of documentary evidence with field-based information facilitated a more comprehensive reconstruction of management history and policy development. Furthermore, document analysis provided contextual information regarding ecological conditions, rehabilitation programs, and stakeholder involvement throughout different management periods.

To enhance the credibility and trustworthiness of the findings, data triangulation was applied by comparing information obtained from different sources and data collection methods. Evidence gathered through observations, interviews, and document analysis was systematically cross-checked to identify consistencies and discrepancies among stakeholders' perspectives and historical records [37], [38]. Source triangulation was conducted by collecting information from multiple stakeholder groups, while methodological triangulation involved the use of different data collection techniques to investigate the same phenomenon. This approach strengthened the validity of the findings and minimized potential bias in interpreting the social-ecological dynamics of mangrove management in Wringinputih Village.

### 2.4. Data Analysis

The collected data were analyzed using the interactive qualitative analysis model developed by Miles and Huberman, which consists of data reduction, data display, and conclusion drawing and verification. Data reduction involved organizing, selecting, coding, and simplifying information obtained from interviews, observations, and documentary sources to identify themes relevant to the historical development and governance of mangrove management [5], [39]. Subsequently, the reduced data were systematically displayed in the form of narratives, thematic matrices, timelines, and conceptual relationships to facilitate interpretation and comparison across stakeholder groups. Throughout the analytical process, patterns of interaction among ecological conditions, community participation, institutional arrangements, and management interventions were identified to understand the evolution of the social-ecological system in Wringinputih Village. Conclusions were continuously verified through iterative comparisons among data sources and stakeholder perspectives to ensure the consistency and credibility of the findings.

To reconstruct the historical trajectory of mangrove management, information obtained from interviews and documentary records was arranged chronologically, beginning with the implementation of the Coastal Fisheries Management Project (Cofish Project) and continuing through subsequent phases of rehabilitation, community empowerment, institutional development, and ecosystem utilization. This historical analysis enabled the identification of key events, management transitions, stakeholder roles, and adaptive responses that have shaped current mangrove governance [34], [40]. In addition, the study examined how social, economic, institutional, and ecological factors interacted over time to influence the resilience of the mangrove social-ecological system. The integration of historical and contemporary data provided a comprehensive understanding of long-term management dynamics and future development opportunities.

Ecological data collected during field observations were analyzed descriptively to support the assessment of current ecosystem conditions. Mangrove species were identified based on morphological characteristics, including leaves, roots, flowers, and fruits, using standard mangrove identification guides for Indonesia. Observations of aquatic fauna and wildlife associated with the mangrove ecosystem were used to characterize biodiversity and ecosystem functions within the study area. Environmental parameters, including water temperature, salinity, and pH, were measured using a thermometer, hand refractometer, and pH meter,

respectively, to provide supporting information regarding habitat conditions. The integration of ecological observations with social and institutional data facilitated a comprehensive social-ecological analysis of mangrove governance and resilience in Wringinputih Village.

## 2.5. Research Procedures

The research procedure was conducted through several sequential stages to achieve the study objectives. The first stage involved a preliminary study consisting of literature reviews, document exploration, and initial field visits to obtain a general understanding of the mangrove ecosystem and its management history in Wringinputih Village. This stage also facilitated the identification of key stakeholders and relevant institutions involved in mangrove governance [5], [40]. Furthermore, historical documents related to the Coastal Fisheries Management Project (Cofish Project) and subsequent management programs were collected to support the reconstruction of management trajectories. The information obtained during this stage was used to refine the research focus and prepare data collection instruments.

The second stage consisted of primary and secondary data collection through field observations, in-depth interviews, and document analysis. Field observations were conducted to assess current ecological conditions and community activities associated with mangrove management [41], [42]. Semi-structured interviews were undertaken with government representatives, village authorities, Perhutani officers, fisher groups, aquaculture farmer groups, and community-based mangrove management organizations. In addition, historical records, government reports, project archives, and management documents were reviewed to verify information obtained from interviews. The integration of multiple data sources enabled a comprehensive understanding of both historical and contemporary management practices.

The third stage involved data analysis using the Miles and Huberman interactive model combined with a social-ecological systems perspective. Qualitative data were reduced, categorized, and organized into thematic groups related to ecological restoration, institutional development, community participation, and governance transformation [43], [44]. Historical information was arranged chronologically to identify key management phases and adaptive responses from the implementation of the Cofish Project to the present. Ecological observations were integrated with social and institutional findings to examine interactions within the mangrove social-ecological system. Finally, the results were interpreted to assess social-ecological resilience and identify factors contributing to sustainable mangrove governance.

The final stage focused on developing recommendations for future mangrove management planning. Findings from the historical and social-ecological analyses were synthesized to formulate strategic directions for sustainable mangrove governance in Wringinputih Village. Particular attention was given to strengthening community participation, institutional collaboration, ecological conservation, and adaptive management strategies. The proposed recommendations were developed based on stakeholder perspectives and existing ecological conditions. This stage ultimately produced a framework for future mangrove management from a social-ecological perspective that can support long-term ecosystem sustainability and community well-being.

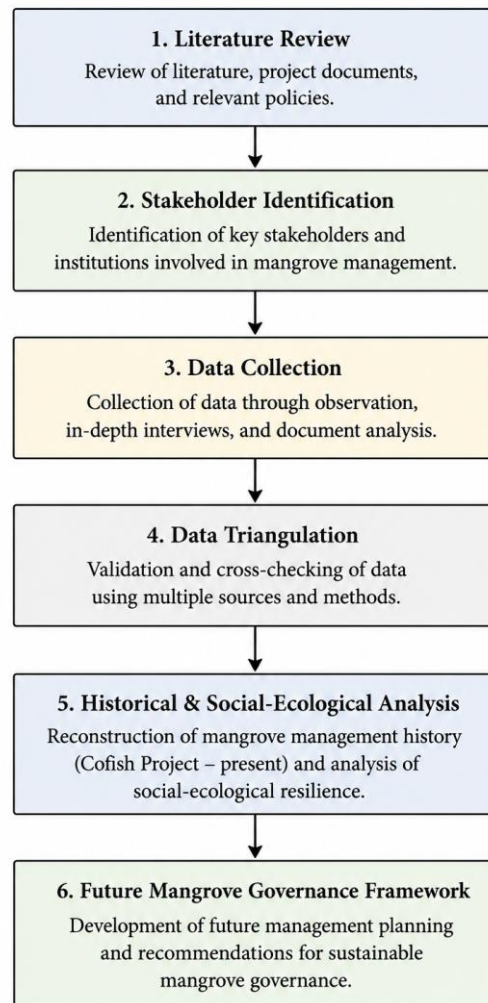


Figure 1. Research Procedures

### 3. RESULTS AND DISCUSSION

#### 3.1. Historical Development of Mangrove Forest Management in Wringinputih Village

The history of mangrove forest management in Wringinputih Village is closely linked to the socio-economic transformation of coastal communities and the expansion of aquaculture activities. Since the 1950s, a substantial portion of the mangrove forest had been degraded due to timber extraction and the conversion of coastal land into fishponds. Initially, aquaculture activities were conducted on a small traditional scale; however, intensive aquaculture practices rapidly expanded during the 1960s. As a result, extensive areas of intertidal mangrove habitat were converted into production ponds throughout Wringinputih Village. Although aquaculture initially generated economic benefits, large-scale mangrove conversion gradually reduced ecosystem functions and contributed to declining fisheries productivity in adjacent coastal waters.

By the late 1980s and early 1990s, environmental degradation became increasingly apparent as many aquaculture ponds experienced reduced productivity and were eventually abandoned. The loss of mangrove vegetation increased coastal vulnerability to erosion and negatively affected fisheries resources that supported local livelihoods [45], [46]. In response to these environmental challenges, local communities initiated small-scale mangrove planting activities in 1998 using a self-help approach. The primary objective of these early restoration efforts was to protect coastal settlements from abrasion and tidal inundation. This period marked the emergence of community awareness regarding the ecological importance of mangrove ecosystems and represented the initial stage of social-ecological adaptation in the study area.

A major turning point in mangrove governance occurred with the implementation of the Coastal Community Development and Fisheries Resource Management Project (Cofish Project) between 1999 and 2003, which was later extended until 2005. The project facilitated collaboration among local communities, government agencies, universities, and other stakeholders through the establishment of community-based fisheries resource management groups known as Community-Based Fisheries Resource Management Groups. The Cofish Project

was designed to rehabilitate coastal habitats, enhance fisheries productivity, reduce poverty, and strengthen institutional capacity for sustainable coastal resource management. During this period, mangrove restoration was supported by the Marine and Fisheries Office and researchers from Universitas Brawijaya, who provided technical assistance and capacity-building programs. The project significantly strengthened local participation and created an institutional foundation for long-term mangrove management.

Large-scale rehabilitation activities were undertaken between 2000 and 2004 through collaboration among various organizations, including Model Desa Konservasi (MDK), LPIP Surabaya, Komisi Riset Malang, and the Environmental-Based Fisheries Productivity Development Program (P3BL). Mangrove planting activities expanded progressively, reaching approximately 100 ha by the end of the Cofish Project period. Although some restoration areas were damaged by tidal waves and environmental disturbances, rehabilitation efforts continued through adaptive management strategies and repeated planting programs. The dominant species planted during this period was *Rhizophora* spp., which was considered highly suitable for the environmental conditions of Wringinputih's coastal zone. These restoration initiatives gradually transformed abandoned aquaculture areas into recovering mangrove ecosystems.

Following the completion of the Cofish Project, mangrove rehabilitation efforts continued through strong community participation and multi-stakeholder collaboration. Between 2006 and 2015, restoration programs involved local communities, the Banyuwangi Marine and Fisheries Office, Perhutani, WWF, OISCA, and other environmental organizations. Planting activities focused not only on expanding mangrove coverage but also on replacing damaged seedlings and restoring pond embankments in Kabatmantren and Tegalpare hamlets. These collaborative initiatives demonstrate the transition from externally supported rehabilitation programs toward locally driven management practices. Continuous stakeholder engagement contributed to strengthening both ecological recovery and institutional resilience within the mangrove management system.

From a social-ecological perspective, the development of mangrove management in Wringinputih Village reflects a gradual transition from resource exploitation to adaptive and community-based governance. The historical trajectory demonstrates how ecological degradation triggered collective action among local communities, leading to the establishment of collaborative management institutions and long-term restoration efforts [47], [48]. Over time, interactions among ecological restoration, stakeholder participation, institutional development, and livelihood adaptation enhanced the resilience of the local social-ecological system. The recovery of mangrove ecosystems has not only improved coastal protection and habitat quality but has also strengthened social capital and community engagement in environmental management. These findings indicate that the success of mangrove governance in Wringinputih Village has been shaped by the integration of ecological restoration and community-based institutional development over more than two decades.

Table 2. Chronology of Mangrove Management

Period	Major Events	Key Actors	Social-Ecological Outcomes
1950–1980	Mangrove conversion to aquaculture ponds	Local communities	Economic growth, ecological degradation
1990–1998	Pond abandonment and coastal erosion	Local communities	Declining fisheries productivity
1999–2005	Cofish Project implementation	Government, PSBK, universities	Rehabilitation and institutional strengthening
2006–2010	Community-based restoration expansion	Community groups, Perhutani, WWF	Increased mangrove cover
2011–2015	Collaborative rehabilitation programs	WWF, OISCA, local groups	Improved ecosystem resilience
Present	Community-based mangrove governance	Multi-stakeholders	Enhanced social-ecological resilience

Although significant progress has been made through the restoration program, the total area of mangrove forest in Wringinputih Village remains below the planned conservation target. According to information provided by the village government, it states:

*“The total area designated for the mangrove planting and conservation program is approximately 450 hectares, and approximately 250 hectares have been successfully planted. This figure is still far from the target because much of the area has been converted into fish ponds by the community”*

Field observations and stakeholder interviews further revealed that the mangrove ecosystem in Wringinputih possesses favorable environmental conditions for natural regeneration. Suitable soil characteristics, extensive intertidal areas, and the availability of propagule sources facilitate the natural establishment and

expansion of mangrove vegetation. As a result, several restored areas have demonstrated continued ecological development even without intensive planting interventions. This natural regeneration process has complemented formal rehabilitation programs and contributed to the gradual recovery of ecosystem functions. Consequently, the combination of active restoration and natural regeneration has become an important factor supporting the long-term resilience of the mangrove social-ecological system in Wringinputih Village.

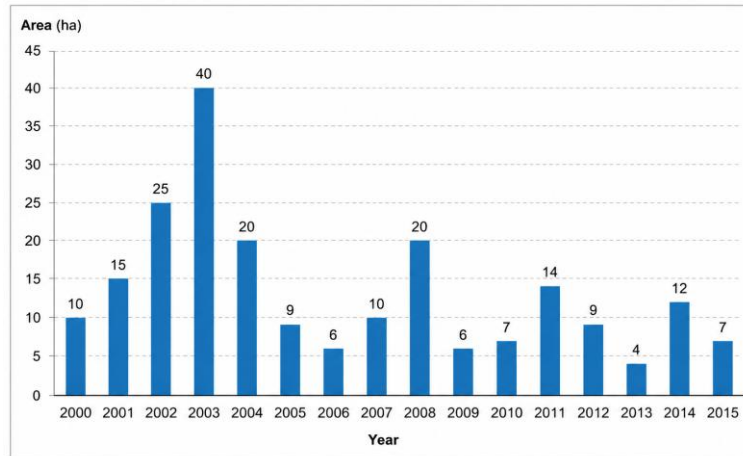


Figure 2. Mangrove forest planting chart in Wringinputih Village

Wringinputih Village possesses a substantial mangrove restoration potential of approximately 500 ha, although only part of this area has been successfully rehabilitated. Large-scale mangrove planting activities were initiated through the Cofish Project between 2000 and 2004, with the highest annual restoration effort recorded in 2003, when approximately 40 ha of mangrove habitat were planted (Figure 2). These rehabilitation programs significantly contributed to the recovery of previously degraded coastal ecosystems that had been converted into aquaculture ponds. By 2015, the total mangrove area had increased to approximately 225 ha, representing a considerable improvement in ecosystem recovery compared with pre-restoration conditions. This trend indicates that long-term rehabilitation efforts have gradually restored ecological functions and brought the existing mangrove cover closer to the estimated restoration potential of the area.

The annual mangrove planting area between 2000 and 2015 increased at an average rate of approximately 11 ha per year. In addition to active planting programs, natural regeneration has played an important role in accelerating mangrove expansion due to favorable environmental conditions, including suitable substrate characteristics and extensive intertidal habitats. Consequently, restored areas have continued to develop beyond the initial planting sites, contributing to the gradual recovery of ecosystem structure and function. Variations in planting area among hamlets were influenced by differences in land availability, environmental conditions, and restoration priorities within each location. The spatial distribution of mangrove rehabilitation activities across Tegalpare, Krajan, and Kabatmantren hamlets reflects the adaptive management strategies implemented by local stakeholders to maximize restoration success and enhance the resilience of the mangrove social-ecological system.

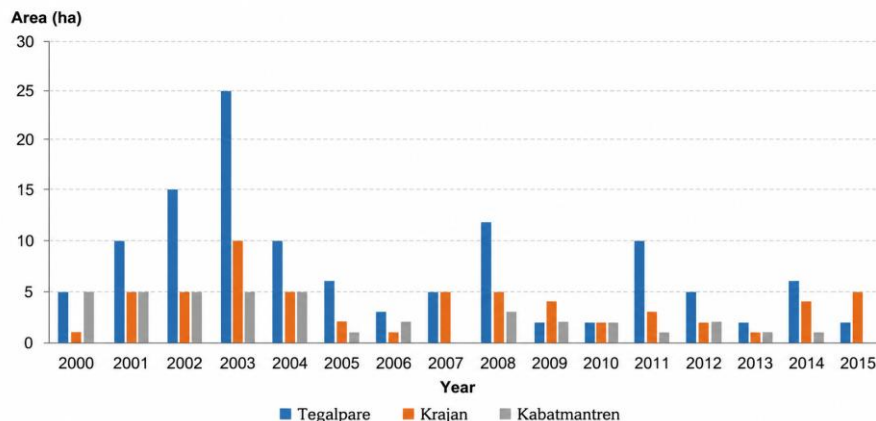


Figure 3. Graph of mangrove forest planting in the three hamlets

The distribution of mangrove forest area varied considerably among the three hamlets of Wringinputih Village. Tegalpare Hamlet possessed the largest mangrove area, covering approximately 130 ha, with an average annual increase of about 7.5 ha during the rehabilitation period. This substantial expansion reflects the intensive restoration efforts undertaken in the area as well as the favorable environmental conditions that support mangrove establishment and growth. In contrast, Krajan Hamlet contained approximately 60 ha of mangrove forest, with an average annual increase of 3.75 ha, while Kabatmantren Hamlet accounted for approximately 33 ha, with an average annual increase of 2.1 ha. These differences indicate that mangrove expansion was influenced by variations in land availability, restoration priorities, and local ecological conditions across the three hamlets.

The dominance of Tegalpare Hamlet in terms of mangrove coverage highlights its strategic role in the overall mangrove management system of Wringinputih Village. The larger restoration area in Tegalpare contributed significantly to enhancing coastal protection, improving habitat availability, and supporting biodiversity conservation. Meanwhile, the rehabilitation efforts in Krajan and Kabatmantren complemented ecosystem recovery by expanding mangrove coverage across different sections of the coastal landscape. The uneven distribution of mangrove areas among hamlets demonstrates the spatial heterogeneity of restoration activities and reflects adaptive management practices implemented by local stakeholders. Collectively, these restoration efforts have strengthened the ecological resilience of the coastal environment and supported the long-term sustainability of community-based mangrove governance.

### 3.2. Ecological System of Mangrove Management

The ecological system of mangrove management in Wringinputih Village represents a critical component of the local social-ecological system. The mangrove ecosystem is distributed across three hamlets—Tegalpare, Krajan, and Kabatmantren—and has undergone substantial recovery following more than two decades of rehabilitation efforts. Field observations revealed that the area supports a diverse mangrove community characterized by mixed-species vegetation and a relatively extensive forest cover. This ecological diversity contributes to ecosystem stability and enhances the capacity of mangrove habitats to provide essential ecosystem services, including coastal protection, nursery grounds for aquatic organisms, and biodiversity conservation [49], [50]. The ecological recovery observed in Wringinputih demonstrates the positive outcomes of long-term restoration and community-based management initiatives.

Environmental parameters indicated that the mangrove ecosystem provides suitable conditions for vegetation growth and aquatic habitat development. Water temperature ranged from 27°C to 34°C, salinity varied between 10 and 35‰, and pH values ranged from 6.8 to 7.5. Variations among hamlets were influenced by tidal dynamics, freshwater inputs from rivers, rainfall patterns, and aquaculture drainage channels. Despite these fluctuations, the measured environmental conditions remained within the tolerance range of most mangrove species commonly found in tropical coastal ecosystems. These findings suggest that the environmental setting of Wringinputih continues to support mangrove regeneration and the maintenance of ecosystem functions.

Table 3. Environmental characteristics of mangrove habitats in Wringinputih Village

Hamlet	Soil Texture	Temperature (°C)	Salinity (‰)	pH
Kabatmantren	Sandy clay	30–32	20–35	7.2–7.5
Krajan	Sandy loam	30–34	30–35	7.2–7.4
Tegalpare	Silty clay	27–31	10–30	6.8–7.2

Mangrove vegetation in Wringinputih Village exhibited relatively high species diversity compared with other coastal areas in Muncar District. A total of twelve mangrove species belonging to six families were recorded during field observations. The dominant species were *Rhizophora mucronata* and *Sonneratia alba*, both of which were widely distributed throughout the rehabilitation areas and demonstrated high adaptability to local environmental conditions. Species richness was highest in Tegalpare Hamlet, where six mangrove families were identified, indicating greater habitat heterogeneity and ecological complexity. The dominance of *Rhizophora* species is closely associated with restoration programs, as these species were extensively planted due to their high survival rates and suitability for coastal protection.

The spatial distribution of mangrove species differed among hamlets. Tegalpare exhibited the highest diversity, followed by Kabatmantren and Krajan. The presence of species such as *Avicennia marina*, *Rhizophora apiculata*, *Bruguiera gymnorrhiza*, *Ceriops tagal*, and *Sonneratia caseolaris* reflects the ecological maturity of several restoration sites. Increased species diversity contributes to ecosystem resilience by enhancing habitat complexity and improving ecological functions. Consequently, maintaining species diversity should remain a priority in future management planning.

The mangrove ecosystem supports a diverse assemblage of economically important aquatic fauna associated with Pangpang Bay. Field observations identified fourteen fish species belonging to twelve families

and seven crustacean species belonging to three families. Common fish species included mullets (*Valamugil seheli*), anchovies (*Stolephorus* spp.), sardines (*Sardinella* spp.), and gobies (*Acentrogobius caninus*), while crustaceans were represented by shrimp, mud crabs (*Scylla serrata*), and blue swimming crabs (*Portunus pelagicus*). The abundance of these species highlights the important role of mangrove habitats as feeding, spawning, and nursery grounds for coastal fisheries resources. This ecological function directly contributes to local livelihoods and reinforces the linkage between ecosystem health and community welfare.

Interviews with local fishers indicated that fisheries productivity has improved following the expansion of mangrove cover, particularly for fishers using stationary fishing gears such as trap nets (sero). The increasing abundance of aquatic resources demonstrates the positive ecological impacts of restoration programs and provides tangible socio-economic benefits to coastal communities. These findings illustrate how ecological recovery has strengthened the resilience of both natural and human systems within the study area.

The mangrove forests of Wringinputih also provide habitat for various terrestrial and semi-aquatic wildlife species. Observations recorded several bird species, including egrets (*Ardeola speciosa*), lesser adjutants (*Leptoptilos javanicus*), whimbrels (*Numenius phaeopus*), and collared kingfishers (*Halcyon chloris*). In addition, other wildlife species such as long-tailed macaques (*Macaca fascicularis*), water monitor lizards (*Varanus salvator*), otters (*Lutra lutra*), and arboreal snakes were frequently observed within the mangrove ecosystem. The presence of these species indicates that the mangrove forest functions as an important habitat supporting biodiversity conservation in Pangpang Bay.

From a social-ecological perspective, wildlife diversity serves as an indicator of ecosystem health and ecological integrity. The recovery of wildlife populations following mangrove rehabilitation demonstrates the success of restoration efforts in re-establishing ecological interactions and food-web dynamics. Consequently, biodiversity conservation should be integrated into future mangrove management strategies to ensure the long-term sustainability of ecosystem services and strengthen the resilience of the mangrove social-ecological system in Wringinputih Village.

### 3.3. Future Mangrove Management Planning from a Social-Ecological Perspective

The findings indicate that future mangrove management in Wringinputih Village should be developed through an integrated social-ecological approach that simultaneously considers ecological sustainability, community welfare, and institutional collaboration. Stakeholder interviews revealed a shared vision among local communities, government agencies, Perhutani, and other institutions to transform the mangrove ecosystem into a multifunctional landscape that supports conservation, sustainable livelihoods, education, and ecotourism. Such an approach reflects the growing recognition that mangrove ecosystems provide not only ecological services but also economic and social benefits for coastal communities. Therefore, future management strategies should balance ecosystem protection with community-based economic development. This integrated perspective is essential for strengthening the resilience of both ecological and social systems in Wringinputih Village.

One of the primary management priorities identified by stakeholders is the development of community-based mangrove ecotourism. Interviews with village authorities and community groups indicated that the unique landscape characteristics of the mangrove forest, particularly in Tegalpare Hamlet, provide substantial opportunities for ecotourism development. Proposed initiatives include the construction of boardwalks, observation platforms, small-scale tourism facilities, environmental education programs, and community-based tourism services. In addition to generating alternative income sources, ecotourism is expected to increase public awareness of mangrove conservation and strengthen local stewardship of natural resources [51], [52]. Consequently, ecotourism can serve as an important mechanism linking environmental conservation with local economic development.

Another strategic component of future management involves strengthening ecological restoration and habitat conservation. Stakeholders emphasized the need to continue mangrove planting programs, particularly in degraded coastal areas that have not yet been fully rehabilitated. The establishment of conservation zones was also identified as a priority to protect critical habitats for fish, crustaceans, birds, and other wildlife associated with the mangrove ecosystem. Maintaining ecological integrity is essential for sustaining fisheries productivity, enhancing biodiversity conservation, and improving coastal protection functions [53], [54]. Continuous restoration and habitat management are therefore expected to increase the adaptive capacity of the mangrove ecosystem in response to environmental changes and anthropogenic pressures.

Institutional strengthening emerged as another key element of future management planning. Existing village regulations concerning mangrove protection primarily focus on prohibitions and sanctions, while limited provisions address sustainable utilization, benefit-sharing mechanisms, and stakeholder responsibilities. Consequently, respondents highlighted the importance of revising and strengthening local regulations to support adaptive and collaborative governance. Improved coordination among community groups, village authorities, the Marine and Fisheries Office, Perhutani, tourism agencies, and academic institutions will be necessary to ensure effective implementation of future management programs. Strengthened governance structures can enhance

social resilience by improving stakeholder participation, conflict resolution, and collective decision-making processes.

Capacity building and environmental awareness programs were also identified as critical components of sustainable mangrove governance. Stakeholders proposed regular training and outreach activities focusing on mangrove ecology, sustainable fisheries practices, environmentally friendly aquaculture, biodiversity conservation, and mangrove-based product diversification. Such programs can improve local knowledge and strengthen community capacity to manage coastal resources sustainably. In addition, educational activities may encourage innovation in the development of value-added products derived from mangrove resources, including food products, handicrafts, and ecotourism services. These initiatives can contribute to livelihood diversification while reducing pressure on natural resources.

Based on the integration of stakeholder perspectives and ecological assessments, a future social-ecological management framework for Wringinputih Village can be proposed (Figure 4). The framework emphasizes the interaction between ecological restoration, community participation, institutional governance, sustainable livelihoods, and environmental education. Ecological restoration supports biodiversity conservation and fisheries productivity, while community participation strengthens monitoring, maintenance, and stewardship activities. Institutional collaboration facilitates policy implementation and resource mobilization, whereas sustainable livelihood programs provide economic incentives for conservation. Together, these interconnected components contribute to the development of a resilient and adaptive mangrove social-ecological system capable of supporting both environmental sustainability and community well-being in the long term.

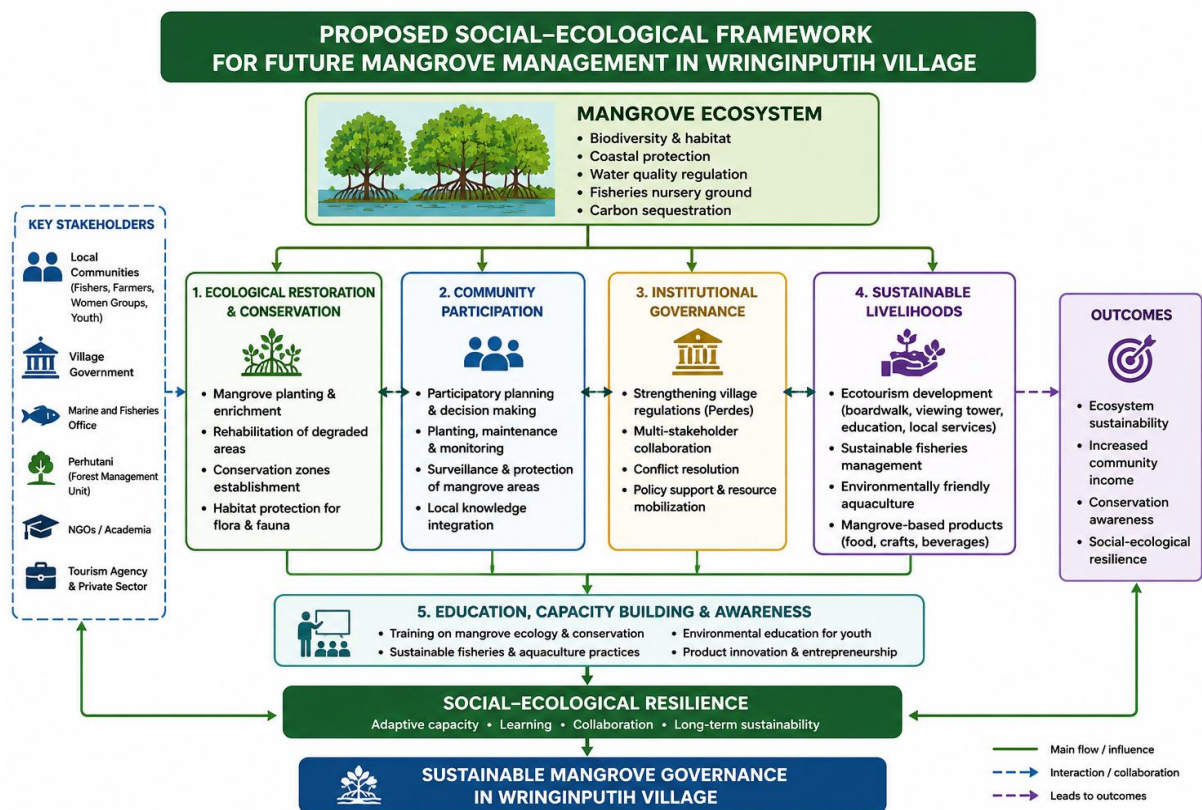


Figure 4. Proposed Social-Ecological Framework for Future Mangrove Management in Wringinputih Village

### 3.4. Contribution to Mangrove Conservation and Coastal Landscape Resilience

The rehabilitation and protection of mangrove ecosystems in Wringinputih have generated important conservation outcomes at both ecosystem and landscape levels. The recovery of mangrove vegetation has improved habitat availability for fish, crustaceans, birds, and other wildlife associated with Pangpang Bay. These findings indicate that community-based restoration efforts contribute not only to vegetation recovery but also to the enhancement of biodiversity and ecological integrity. Consequently, mangrove rehabilitation plays an important role in supporting long-term conservation objectives in tropical coastal ecosystems.

From a landscape perspective, the expansion of mangrove cover has strengthened the ecological connectivity of coastal habitats and increased the capacity of the coastline to withstand environmental disturbances. Mangrove ecosystems function as natural barriers against coastal erosion, wave action, and other climate-related hazards while simultaneously providing habitat for numerous species. The restoration process

observed in Wringinputih therefore represents an important contribution to coastal landscape resilience and ecosystem stability.

The findings highlight the importance of integrating conservation objectives with community participation and local governance. Rather than treating conservation and livelihood development as competing goals, the Wringinputih experience demonstrates that both objectives can be pursued simultaneously through adaptive and collaborative management approaches. This integrated conservation model may provide valuable lessons for other coastal regions seeking to balance biodiversity conservation, ecosystem restoration, and community development.

The findings demonstrate that the evolution of mangrove governance in Wringinputih Village reflects a long-term process of social-ecological adaptation in response to environmental degradation and livelihood challenges. The transition from intensive mangrove conversion for aquaculture toward community-based rehabilitation indicates a shift in local perceptions regarding the value of ecosystem services [55], [56]. Rather than viewing mangroves solely as a source of land for economic production, local stakeholders increasingly recognize their role in coastal protection, fisheries support, and community well-being. This transformation illustrates the adaptive capacity of coastal communities to respond to ecological disturbances through collective action and institutional innovation [57], [58]. Such adaptive processes are considered fundamental characteristics of resilient social-ecological systems, where human and ecological components continuously interact and co-evolve over time.

The development of collaborative governance arrangements in Wringinputih further highlights the importance of institutional diversity in strengthening social-ecological resilience. The involvement of local communities, government agencies, Perhutani, universities, and non-governmental organizations created opportunities for knowledge exchange, resource mobilization, and collective decision-making. Previous studies have similarly demonstrated that multi-stakeholder collaboration enhances the effectiveness of mangrove restoration and conservation initiatives. For example, Friess et al. [59] emphasized that successful mangrove restoration depends not only on ecological suitability but also on stakeholder engagement and long-term governance support. Community participation and institutional coordination are among the most important determinants of sustainable mangrove management outcomes across tropical coastal regions [60], [61]. The experience of Wringinputih supports these findings by demonstrating how collaborative governance can facilitate ecosystem recovery while simultaneously strengthening local social capital.

Another important finding concerns the relationship between ecological restoration and livelihood sustainability. The recovery of mangrove ecosystems has contributed to improving habitat quality, fisheries productivity, and opportunities for alternative economic activities. This finding is consistent with recent studies highlighting the socio-economic benefits generated by healthy mangrove ecosystems. For instance, Goldberg et al. [62] found that restored mangroves enhance fisheries resources and strengthen food security in coastal communities. Mangrove conservation contributes significantly to livelihood diversification through fisheries, ecotourism, and ecosystem-based enterprises [63], [64]. The Wringinputih case therefore reinforces the argument that ecological restoration should not be viewed solely as an environmental intervention but also as an investment in community resilience and sustainable development.

The proposed social-ecological management framework also aligns closely with several Sustainable Development Goals (SDGs). The restoration and conservation of mangrove ecosystems contribute directly to SDG 14 (Life Below Water) through the protection of coastal habitats and fisheries resources. The enhancement of community livelihoods through fisheries and ecotourism development supports SDG 1 (No Poverty) and SDG 8 (Decent Work and Economic Growth) [65], [66]. Furthermore, collaborative governance and stakeholder partnerships reflect the principles of SDG 17 (Partnerships for the Goals), while mangrove rehabilitation contributes to SDG 13 (Climate Action) through carbon sequestration and climate adaptation functions [67], [68]. These interconnections demonstrate that community-based mangrove governance can simultaneously generate environmental, economic, and social benefits, thereby supporting integrated sustainable development objectives.

From a theoretical perspective, this study contributes to the growing literature on social-ecological systems by providing empirical evidence of how resilience emerges through long-term interactions among ecological restoration, institutional development, and community participation. While many studies focus primarily on ecological outcomes of mangrove rehabilitation, this research highlights the importance of historical governance trajectories in shaping contemporary management systems [34], [69]. The findings support resilience theory, which emphasizes adaptation, learning, and transformation as key mechanisms enabling social-ecological systems to respond to environmental change. In addition, the study extends community-based natural resource management literature by demonstrating how externally initiated interventions, such as the Cofish Project, can evolve into locally sustained governance systems over time. This perspective contributes to a more comprehensive understanding of resilience-building processes in tropical coastal ecosystems. The study further contributes to conservation science by demonstrating how community-based governance can facilitate habitat recovery, biodiversity conservation, and landscape resilience through long-term social-ecological adaptation.

The findings also generate several important policy implications. First, future mangrove management programs should prioritize long-term institutional strengthening rather than focusing exclusively on short-term planting targets. Second, local governments should integrate mangrove conservation into broader coastal development planning to minimize future land-use conflicts between aquaculture expansion and ecosystem protection [50], [70]. Third, policies should encourage greater participation of local communities in planning, monitoring, and evaluation processes to enhance ownership and sustainability. Finally, the development of mangrove-based ecotourism and other sustainable livelihood initiatives should be supported through capacity-building programs, financial assistance, and market access [71], [72]. Such policy interventions can strengthen both ecological sustainability and community resilience in coastal regions. Policy interventions should prioritize the integration of mangrove conservation into coastal landscape planning and biodiversity conservation strategies at the regional level.

Despite its contributions, this study has several limitations. The research focused on a single village and therefore may not fully capture the diversity of social-ecological conditions found in other mangrove systems across Indonesia. In addition, the historical reconstruction relied partly on stakeholder recollections and archival documents, which may contain potential biases or incomplete information. The ecological assessment was conducted within a limited temporal framework and did not evaluate long-term ecological dynamics using quantitative monitoring data. Future studies should employ comparative approaches across multiple coastal communities and integrate longitudinal ecological datasets to provide a more comprehensive understanding of social-ecological resilience. Further research may also examine the economic valuation of ecosystem services and the effectiveness of specific governance interventions in supporting sustainable mangrove management.

#### 4. CONCLUSION

The findings demonstrate that mangrove management in Wringinputih Village has evolved from a period of extensive mangrove degradation caused by aquaculture expansion into a more adaptive and community-based governance system. The Cofish Project played a pivotal role in initiating ecological restoration, strengthening local institutions, and fostering collaboration among communities, government agencies, non-governmental organizations, and academic institutions. These collective efforts have contributed to the recovery of mangrove ecosystems, the enhancement of biodiversity, and the improvement of ecosystem services that support fisheries productivity and coastal protection. The historical trajectory of mangrove management in Wringinputih illustrates how ecological restoration and stakeholder participation can jointly strengthen the resilience of coastal social-ecological systems.

From a social-ecological perspective, sustainable mangrove governance in Wringinputih depends on the integration of ecological conservation, community participation, institutional capacity, and sustainable livelihood development. The proposed management framework emphasizes the importance of continued rehabilitation, collaborative governance, environmental education, and mangrove-based economic opportunities to ensure long-term ecosystem sustainability and community well-being. The recovery of mangrove ecosystems has also strengthened biodiversity conservation and enhanced the resilience of the coastal landscape against environmental pressures. Future studies should conduct comparative assessments across different coastal regions to evaluate the broader applicability of the proposed social-ecological governance framework. Additionally, long-term research integrating ecological monitoring, ecosystem service valuation, and governance performance analysis is needed to better understand the dynamics of resilience and sustainability in mangrove social-ecological systems.

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#### AUTHOR CONTRIBUTIONS

Conceptualization, A.A. and G.S.; Methodology, A.A. and G.S.; Software, A.A.; Validation, A.A., G.S., S.M.L., and A.O.; Formal Analysis, A.A. and G.S.; Investigation, A.A.; Resources, G.S. and A.O.; Data Curation, A.A.; Writing – Original Draft Preparation, A.A.; Writing – Review & Editing, G.S., S.M.L., and A.O.; Visualization, A.A.; Supervision, S.M.L. and A.O.; Project Administration, G.S.; Funding Acquisition, A.O. All authors have read and agreed to the published version of the manuscript.

**CONFLICTS OF INTEREST**

The authors declare no conflict of interest.

**USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY**

Not applicable.

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