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A multi-dimensional sustainability assessment of marine protected area management in Jemur Island on the Malacca Strait, Indonesia

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Abstract. *Warningsih T, Ramadona T, Zulkarnain, Nuraini, Khairunissa R, Deviasari, Muthmainnah A, Aswandi A. 2026. A multi-dimensional sustainability assessment of marine protected area management in Jemur Island on the Malacca Strait, Indonesia. Biodiversitas 27 (1): d270140. https://doi.org/10.13057/biodiv/d270140.* Jemur Island in the Aruah Islands archipelago in the Malacca Strait, Riau Province, Indonesia, is a marine protected area (MPAs) with significant ecological value as a nesting habitat for green turtles and various economically valuable fish species. However, pressure from human activities and institutional limitations pose challenges to its sustainable management. This study aims to assess the sustainability of marine protected area management on Jemur Island using the Rapfish (Rapid Appraisal for Fisheries) method through a Multi-dimensional Scaling (MDS) approach across four dimensions: ecological, economic, social, and institutional. Data were obtained from in-depth interviews with stakeholders and field observations in mid-2024. The ecological dimension scored 61.44, indicating moderate sustainability, driven primarily by coral reef conditions and turtle nesting habitat quality, with fish abundance identified as the key leverage attribute. The economic dimension scored 64.08, also moderately sustainable, supported by fisheries-based livelihoods and emerging ecotourism, while resource dependency emerged as the critical leverage variable. In contrast, the social dimension scored 41.94, reflecting weak sustainability, with community awareness and participation identified as its main sensitivities. The institutional dimensions were categorized as less sustainable, scored 42.63, and similarly weak, largely influenced by coordination effectiveness and the adequacy of local management capacity. Pareto and leverage analysis further highlight that improvements in fish abundance, livelihood diversification, community engagement, and institutional strengthening offer the greatest potential to enhance overall sustainability. These findings emphasize the need for targeted, evidence-based management and interventions that prioritize ecological monitoring, community involvement, and institutional capacity building. The study provides a structured baseline for evaluating MPA performance in small-island settings and supports future efforts to design more adaptive and participatory conservation strategies.

Keywords: Jemur Island, marine protected area, Multi-dimensional Scaling (MDS), Rapfish, sustainability

INTRODUCTION

Marine Protected Areas (MPAs) are an established tool for conserving marine biodiversity, sustaining fisheries, and ensuring ecosystem services. Their effectiveness, however, varies widely across countries due to differences in ecological pressures, governance capacity, and levels of community engagement (Gill et al. 2017; Blouet et al. 2025). As a result, recent studies emphasize the importance of evaluating MPAs through integrated ecological, social, economic, and institutional perspectives rather than focusing on single dimensions. This shift reflects a growing recognition that MPA performance depends not only on biophysical conditions but also on community behavior, livelihood incentives, and governance structures.

In Southeast Asia, governance challenges are especially pronounced. The coral triangle, with some of the world's highest marine biodiversity, illustrates persistent issues such as weak enforcement, limited institutional capacity, and misalignment between conservation goals and community livelihoods (Fidelman et al. 2012; Cinner et al. 2016). These constraints are amplified in strategic maritime corridors such as the Malacca Strait, where intense fishing activity, coastal development, and transboundary dynamics intersect. At the same time, several studies in the region have assessed ecological conditions or documented biodiversity trends (Salgueiro-Otero et al. 2022; Al-Qadami et al. 2024; Hazri and Noor 2024; O'Hara et al. 2024; James 2025). Integrated sustainability assessments that incorporate governance and social aspects remain extremely limited. This gap is noteworthy because MPAs in high-pressure straits require management approaches that account for ecological vulnerability, economic dependency, and institutional fragmentation.

Small islands within such corridors face additional constraints, including limited livelihood alternatives, high dependence on marine resources, and low tolerance for ecological shocks. Research indicates that the sustainability of MPAs in small-island contexts is strongly influenced by the interaction between ecological integrity, household economic resilience, and governance effectiveness (Laurino et al. 2024). However, despite the importance of this interaction, few empirical studies in Indonesia have examined these dimensions simultaneously. Existing research on ’Indonesia's MPAs often focuses on ecological characteristics such as coral reef status and species richness (Ceccarelli et al. 2022; Meilana et al. 2023), or socio-economic features, such as livelihood strategies, fishing practices, and community attitudes (Ali et al. 2022; Rosadi et al. 2022; Tranter et al. 2022). Other studies highlight governance challenges, including limited coordination, weak co-management arrangements, and inconsistent enforcement (Clifton 2003; Meilana et al. 2023; Syarif et al. 2024). However, these studies treat each dimension separately and do not provide a unified sustainability diagnosis. Several recent studies highlight the importance of a multi-dimensional approach to assessing MPA sustainability - encompassing ecological, economic, social, and institutional dimensions-to understand the interrelationships between factors influencing conservation effectiveness (Munasinghe 2016; Jiang and Guo 2023; de Oliveira et al. 2024).

Jemur Island, located in the Aruah Archipelago of Riau Province, represents a small-island MPA exposed to ecological, social, and governance pressures. The island contains coral reefs, seagrass beds, and important sea turtle nesting sites, and supports small-scale fisheries that are the core livelihood of the local community (Tebaiy et al. 2021; Estradivari et al. 2022; Capriati et al. 2025). Although its ecological potential has been noted, the island also experiences zoning noncompliance, weak institutional presence, and resource-use conflicts. Despite its strategic position, approximately 63-72 km from major landing sites and neighboring Malaysia (Effendi et al. 2019). No prior study has conducted a comprehensive sustainability assessment that integrates ecological, economic, social, and institutional indicators for Jemur Island. As a result, critical questions remain unanswered: What is the current sustainability status of the island's MPA? Which attributes most strongly influence its performance? Moreover, which dimensions should be prioritized in management interventions?

The Rapfish (Rapid Appraisal for Fisheries) or Multi-dimensional Scaling (MDS) method is well-suited to answer these questions because it enables rapid, transparent, and multi-dimensional evaluation of complex systems using both quantitative and qualitative indicators (Alder et al. 2000; Pitcher and Kavanagh 2004). The approach has been applied in several Indonesian fisheries and aquaculture studies (Nandita et al. 2021; Farid et al. 2024), but its application to small-island MPAs in strategic maritime corridors is virtually absent. Thus, beyond filling an empirical gap for Jemur Island, this study also contributes to the broader literature by demonstrating how a unified sustainability framework can diagnose interlinked ecological, economic, social, and institutional challenges in a transboundary conservation setting. To address these gaps, this study aims to: (i) assess the sustainability status of the Jemur Island MPAs across four dimensions; (ii) identify leverage attributes that most strongly influence sustainability outcomes; and (iii) formulate evidence-based recommendations for strengthening management.

MATERIALS AND METHODS

Study area

This study was conducted from 21 to 25 May 2024 on Jemur Island, part of the Aruah Islands located in the Malacca Strait, Rokan Hilir Regency, Riau Province, Indonesia. Jemur Island is part of a Marine Protected Area that functions as a habitat for marine resources due to its high biodiversity and important ecological functions, such as a spawning ground for green turtles (*Chelonia mydas* (Linnaeus, 1758)).

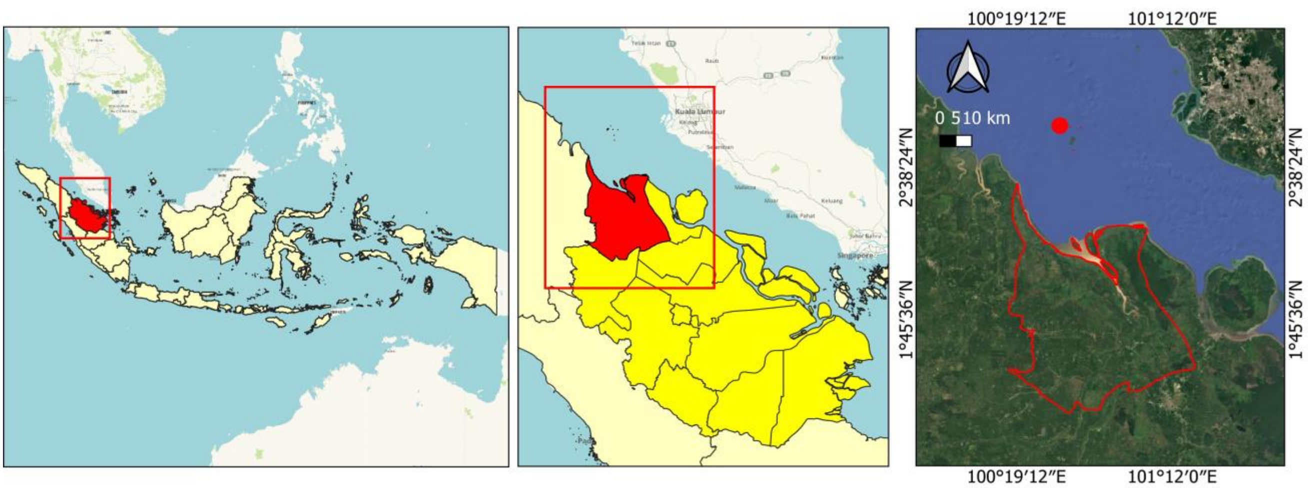

Figure 1. The research location, Jemur Island in the Malacca Strait, Rokan Hilir Regency, Riau Province, Indonesia

This area has a total area of 18,536.10 ha and was initially reserved through a decree of the Governor of Riau in 2017. The designation status was finally confirmed through the Decree of the Ministry of Maritime Affairs and Fisheries Number 73 of 2021. This area consists of several management zones, namely a core zone of 123.80 ha, a limited-use zone of 18,323.25 ha, a port zone of 19.90 ha, and a ship passage zone of 69.15 ha, each of which functions for different conservation purposes and regulates the use of marine resources. The location was chosen because it represents a conservation system of small islands that serve important ecological functions as turtle habitat and fishing grounds facing pressure from fisheries, tourism, and governance constraints, making it suitable for sustainability assessment using multi-dimensional indicators (Pitcher and Kavanagh 2004; Casimiro et al. 2023; Islam and Nayak 2025; Thapa et al. 2025).

Table 1. Operationalization of sustainability attributes in each of the four dimensions of sustainability

Dimension	Attribute	Criteria "Good" (3)	Criteria "Bad" (0)
Ecology (7)	1. Fish abundance	Fish populations are high; catches are stable without a significant decline	Fish populations are declining sharply; catches are declining drastically
	2. Fish biomass	High	Low
	3. Use of destructive fishing gear	Doesn't happen anymore	Still happens frequently
	4. Presence of ETP species	>4	None
	5. Number of fish species	High	Low
	6. Average percentage of coral cover	75-100 very good	0-24% poor
	7. Turtle egg collection	Low	High
Economic (7)	1. Additional income through tourism	Yes, and very helpful	None
	2. Additional income through aquaculture	Present and running	None
	3. Resource dependency within the area	Low	Very high
	4. Purchasing power of the community	Increase	Decrease
	5. Fishermen's income within the area	Above the district minimum wage	Below the district minimum wage
	6. Additional jobs within the area	Fairly even	
	7. Incentive funds from conservation managers	Yes, and evenly distributed	Very poor None
Social (7)	1. Community understanding level of conservation area zoning	>70% of the community understands the boundaries and functions of conservation zones	<40% of the community understands conservation zones
	2. Community education level	Higher (Diploma and S1)	Low (SD)
	3. Resource utilization conflicts	No or rare conflicts	Still happening
	4. Community understanding of coral reefs	>70% of the community understands the ecological functions of coral reefs	<40% of the community understands the functions of coral reefs
	5. Community involvement in management	>70% involved	<40% involved
	6. Community understanding of conservation	>70% of the community understands conservation objectives	<40% of the community understands conservation
	7. Efforts to improve resources in the area	Initiative of all stakeholders	No initiative
Institutional (9)	1. Resource management institutions at the village level	Yes (active)	None
	2. Level of compliance with conservation regulations	High	Low
	3. Regulations that overlap with local governments	Absent	Present (not resolved)
	4. Policy coordination between governments	High	Low
	5. Recognition of international institutions related to conservation areas	High	Low
	6. Conflict between resource managers and users	High	Low
	7. The role of customary institutions in the area	Present (active)	None
	8. Conservation area surveillance patrols	Regularly, 4 times per month	Not done
	9. Conservation regulations UU and PP	>3 rules	None

Table 2. Categories for assessing management sustainability status

Index values	Category
0-25	Bad (not sustainable)
>25-50	Less (less sustainable)
>50-75	Fair (moderately sustainable)
>75-100	Good (highly sustainable)

Source: Widyawati et al. (2024); Setyaningrum et al. (2025)

Data types and sources

This study used a mixed-method approach combining primary and secondary data. Primary data were obtained through structured interviews, field observations, and questionnaires administered to 30 key informants selected using purposive sampling. Purposive sampling was applied because sustainability assessment of conservation management requires expert-based and stakeholder-based judgments rather than random sampling (Reed et al. 2009; Yigzaw et al. 2025). The respondents consisted of local community leaders, fisheries and conservation officers, staff from the Coastal and Marine Resources Management Agency (BPSPL) of Jemur Island, and academic experts (lecturer at Universitas Riau). The number of respondents was determined based on information saturation, where additional respondents did not sustainability change the attribute scores, which is consistent with sustainability assessment practice using RAP-MDS (Pitcher and Kavanagh 2004; Nandita et al. 2021). Secondary data included official policy documents, conservation area management plans, fisheries statistics, and previous scientific studies related to marine conservation and small-island management. Data triangulation was applied by comparing interview results, field observations, and documentary evidence to ensure internal consistency and validity (Creswell and Poth 2024).

Data analysis

The sustainability of Jemur Island's marine protected area management was assessed using the Rapid Appraisal for Fisheries (RAP-Fish) approach based on Multi-dimensional Scaling (MDS). RAP-MDS is widely used for evaluating sustainability in Fisheries and coastal resource management because it integrates ecological, economic, social, and institutional dimensions into a single ordination framework (Alder et al. 2000; Pitcher and Kavanagh 2004; Hartati et al. 2021; Thapa et al. 2025). Four dimensions of sustainability were analyzed: ecological, economic, social, and institutional. Each dimension was represented by a set of attributes derived from the literature review and expert consultation. A total of 30 attributes were used, consisting of 7 ecological, 7 economic, 7 social, and 9 institutional attributes (Table 1). These attributes represent key indicators of sustainability commonly applied in small-island and marine protected area management (Pitcher and Kavanagh 2004; Arkema et al. 2024; Pegorelli et al. 2024).

Each attribute was scored on an ordinal scale from 0 (worst condition) to 3 (best condition), following the RAP-fish scoring system. Intermediate values (1 and 2) represent conditions between the worst and best states. The scoring was based on expert judgment, field data, and available documents. This ordinal scaling allows the transformation of qualitative and semi-quantitative information into numerical data suitable for MDS analysis (Pitcher and Kavanagh 2004; Widyawati et al. 2024). For each attribute, the final score was obtained using the value across respondents to reduce at the influence of extreme values and improve robustness (Nandita et al. 2021).

The MDS ordination produces a sustainability index on a scale of 0 to 100, where higher values indicate better sustainability. The index values were classified into four sustainability categories: not sustainable (0-25), less sustainable (>25-50), moderately sustainable (>50-75), and highly sustainable (75-100), following recent applications of MDS in sustainability assessment (Widyawati et al. 2024; Setyaningrum et al. 2025) (Table 2).

The goodness of fit of the MDS model was evaluated using the Stress value and the coefficient of determination (R^2). A stress value below 0.25 and an R^2 value close to 1 indicate a reliable ordination (Pitcher and Kavanagh 2004). In this study, Stress = 0.14 and R^2 = 0.94, indicating that the ordination accurately represents the data structure. Monte Carlo analysis was applied to test the stability of the results by introducing random variations in the attribute scores. Small differences between the Monte Carlo and original MDS result indicate that the sustainability index is robust and not sensitive to random scoring errors (Pitcher and Kavanagh 2004; Setyaningrum et al. 2025). Leverage analysis was used to identify sensitive attributes that have the greatest influence on the sustainability indices. Attributes with high root mean square (RMS) values were considered critical for management intervention (Pitcher and Kavanagh 2004; Nandita et al. 2021).

RESULTS AND DISCUSSION

Ecological dimension

Figure 2 shows that the ecological sustainability index of the Jemur Island Marine Protected Area is 61.44, which falls within the moderately sustainable category. This indicated that the ecological structure of the island is still functioning, supported by the presence of coral reefs, seagrass, and active turtle nesting beaches, but also facing pressures that could undermine long-term resilience if not managed carefully. A similar "intermediate" ecological status has been reported in other Indonesian coastal systems, where habitats remain productive yet are increasingly exposed to fishing and habitat disturbance (Fauzi et al. 2021; Rahayu et al. 2023). Ecological sustainability focuses on maintaining ecosystem balance, preserving the environmental capacity of marine conservation areas, and improving the quality and resilience of aquatic ecosystems as key priorities in marine conservation (Asokan 2024; Hoppit et al. 2025). To identify the attributes most influential to the sustainability index, a leverage analysis was conducted. Sensitive attributes can be visually identified by examining the length of the bars representing the evaluated attributes (Farid et al. 2024).

Leverage analysis prioritizes attributes based on the Root Mean Square (RMS) ordination values along the X-axis. Attributes with the highest leverage values are regarded as the most important for sustainability (Abdillah et al. 2023).

Leverage analysis (Figure 3) and Pareto results (Table 3) indicate that fish abundance is the most influential ecological attribute, followed by fish biomass, use of destructive fishing gear, presence of endangered and protected (ETP) species, and species richness. Rather than merely listing these attributes, it is essential to interpret why they are sensitive in Jemur Island. Local fishers report declining catches in some seasons and increasing effort to maintain income, which suggests that fish stocks are under pressure. Similar patterns have been documented in small pelagic fisheries in Indonesian coastal waters, where declining fish abundance and biomass were identified as key ecological leverage factors driving overall sustainability status (Warningsih et al. 2020a). These findings reinforce the role of fish abundance as a robust indicator of ecological condition and fisheries pressure in tropical coastal systems. This is consistent with broader evidence that fish abundance and biomass are robust indicators of MPA performance and respond strongly to changes in fishing effort and habitat quality (Perisic et al. 2025).

This attribute serves as a key indicator of marine ecosystem health and the effectiveness of conservation areas (Pieckiel et al. 2024; e Costa et al. 2025; Perisic et al. 2025). In Jemur, the decline in fish abundance reflects ecosystem disruption due to fishing pressure and habitat degradation. Therefore, ecosystem-based management and restrictions on destructive fishing gear are top priorities. The presence of ETP species, particularly green turtles (*C. mydas*), adds to the ecological significance of the island. Jemur's sandy beaches function as an important nesting site in a region where many other islands have experienced a decline in nesting due to human disturbance, coastal infrastructure, and light pollution. This pattern is consistent with case studies from Fiji and other Pacific islands showing that turtle nesting sites are increasingly restricted to locations where disturbance is controlled (Kitolelei et al. 2022; Hays et al. 2025). The relatively intact nesting habitat in Jemur, therefore, represents both a conservation asset and a management responsibility.

The Pareto analysis shows that a small set of attributes, fish abundance, fish biomass, destructive gear use, and ETP presence, contribute more than 80% of the overall ecological leverage. This implies that targeted interventions focusing on gear regulation, habitat protection, and turtle nesting beach management are likely to yield the most significant ecological benefits. However, these results should be interpreted with caution: the ecological indicators are based on a combination of limited field observations and stakeholder perceptions, and the Rapfish scoring remains semi-quantitative. Although Monte Carlo analysis indicates that ordination uncertainty is small, future work with more systematic ecological monitoring (e.g., standardized reef surveys, long-term fish counts) would strengthen confidence in these patterns.

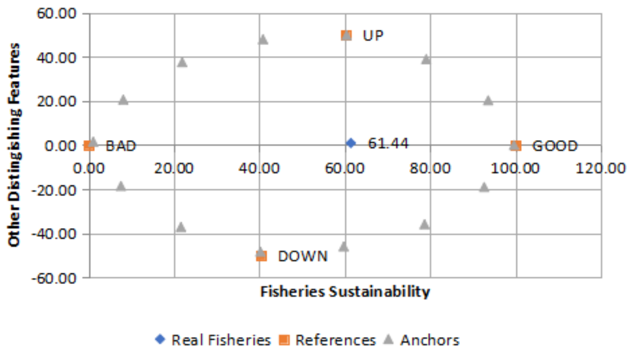

Figure 2. Rapfish ordination results of the ecological dimension

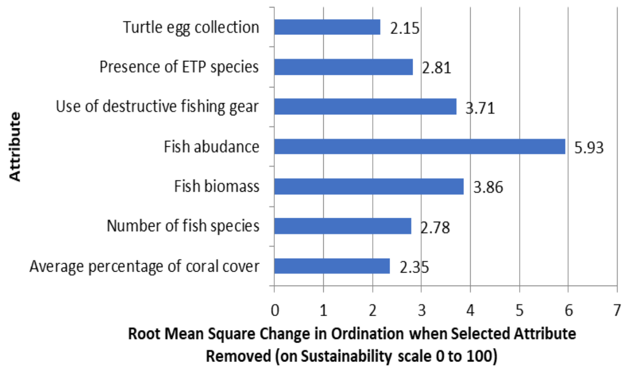

Figure 3. Sensitive attributes of the ecological dimension as identified by leverage analysis

Table 3. Pareto analysis and RMS value of the ecological dimension

Ecological dimension	Root Mean Square (RMS)	Percentage (%)	Cumulative (%)
Fish abundance	5.93	25	25
Fish biomass	3.86	17	41
Use of destructive fishing gear	3.71	16	57
Presence of ETP species	2.81	12	69
Number of fish species	2.78	12	81
Average percentage of coral cover	2.35	10	91
Turtle egg collection	2.15	9	100
Total	23.59		

Source: Primary data processing, 2025

Economic dimension

The economic sustainability index of 64.08 also falls within the moderately sustainable category (Figure 4). This reflects a mixed situation: livelihoods in Jemur remain heavily dependent on capture fisheries, but there are emerging opportunities from ecotourism (notably turtle watching and coral-based tourism) and small-scale aquaculture. The economic attribute highlights how the management activities within marine conservation areas affect their economic dimensions, which in turn influences the sustainability of these activities and the broader ecosystem (Costello 2024; Pegorelli et al. 2024). Evidence from mangrove-based coastal systems in Riau Province shows that ecosystem services generate significant direct and indirect economic values for local communities, strengthening the economic rationale for conservation-oriented management (Warningsih et al. 2020b). Such valuation studies highlight that conservation areas can deliver long-term economic benefits beyond capture fisheries.

The leverage analysis (Figure 5) shows that the additional income from tourism and aquaculture, along with resource dependency and purchasing power, are the most sensitive economic attributes. In Jemur, tourism and aquaculture currently provide supplementary rather than primary income. Their high leverage indicates that even modest growth in these sectors can significantly improve livelihood stability and reduce vulnerability to fluctuations in fish stocks. These findings align with studies from other MPAs and coastal systems showing that marine-based economic diversification through ecotourism, fishery-based tourism, and sustainable aquaculture can enhance resilience and reduce exploitation pressures on wild stocks when properly governed (Uddin et al. 2021; Engle and Senten 2022; Casimiro et al. 2023; Viana et al. 2024). In Rupat Island, marine ecotourism development has been shown to increase household income diversification while simultaneously enhancing community awareness of coastal ecosystem conservation (Warningsih et al. 2023). This supports the argument that ecotourism, when properly managed, can strengthen both economic resilience and conservation outcomes in small-island contexts.

At the same time, the high sensitivity of resource dependency underscores a structural risk: many households still derive most of their income from fishing. Without viable and equitable alternative livelihoods, efforts to reduce fishing effort or restrict specific gears may be perceived as threatening household welfare, which can undermine compliance. Diversification through ecotourism can provide economic incentives while strengthening biodiversity conservation (Refulio-Coronado et al. 2021; Casimiro et al. 2023), while sustainable aquaculture plays a role in increasing income and food security in coastal communities (Engle and Senten 2022; Evans et al. 2023). Global studies also emphasize that successful diversification requires adaptive governance and cross-sectoral policy support, including capacity building for local communities.

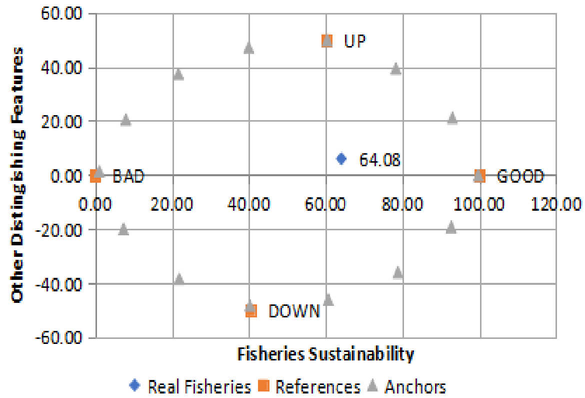

Figure 4. Rapfish ordination results for the economic dimension

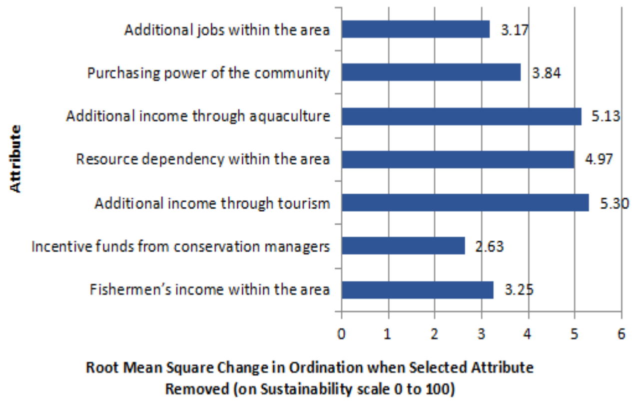

Figure 5. Sensitive attributes of the economic dimensions as identified by leverage analysis

Table 4. Pareto analysis and RMS value of economic dimension

Economic dimension	Root Mean Square (RMS)	Percentage (%)	Cumulative (%)
Additional income through tourism	5.30	19	19
Additional income through aquaculture	5.13	18	37
Resource dependency within the area	4.97	18	55
Purchasing power of the community	3.84	14	69
Fishermen's income within the area	3.25	11	80
Additional jobs within the area	3.17	11	91
Incentive funds from conservation managers	2.63	9	100
Total	28.29		

The Pareto analysis (Table 4), indicates that tourism income, aquaculture income, resource dependency, purchasing power and fishermen's income together account for the bulk of economic leverage. This suggests a blue economy-oriented strategy for Jemur should not simply promote tourism or aquaculture in isolation, but rather develop them as part of an integrated livelihood portfolio, supported by infrastructure, market access, and skill development (World Bank and United Nations DESA 2022). Policy interventions include: training for micro-enterprises based on marine tourism, providing conservation incentives, and facilitating green credit (green microfinance) for fishermen to switch to sustainable cultivation activities.

Social dimension

The social dimension of a sustainability index of 41.94, categorized as less sustainable (Figure 6). This indicates that social conditions are a significant constraint to effective MPA management in Jemur Island. The leverage analysis (Figure 7) and Pareto results (Table 5) identify the community's understanding of conservation area zoning and education level as the most influential attributes, followed by resource-use conflicts, understanding of coral reefs, community involvement, and broader conservation awareness.

Low zoning literacy means that many residents are not fully aware of the differences between core zones, sustainable use zones, and other designated areas, nor of the specific activities allowed in each. This is consistent with findings from other Indonesian coastal communities showing that inadequate communication and limited outreach significantly reduce public understanding and support for conservation regulation (Ali et al. 2022; Miller et al. 2024). In Jemur, low education levels compound this problem, making it more difficult for residents to access and interpret technical information or written regulations. As a result, some violations may be unintentional, while others may reflect a lack of perceived legitimacy of the rules. According to Ali et al. (2022), public knowledge and attitudes play a significant role in influencing behaviors related to conservation, including participation in rehabilitation and environmental protection activities. Therefore, a lack of understanding can lead to behaviors that do not support the sustainability of the conservation area. Similar challenges have been observed in mangrove-based socio-ecological systems in Indonesia, where limited education and low awareness of ecosystem services reduced community participation and weakened conservation effectiveness (Rumondang et al. 2024). These findings underline the importance of social capacity building as a prerequisite for sustainable coastal management.

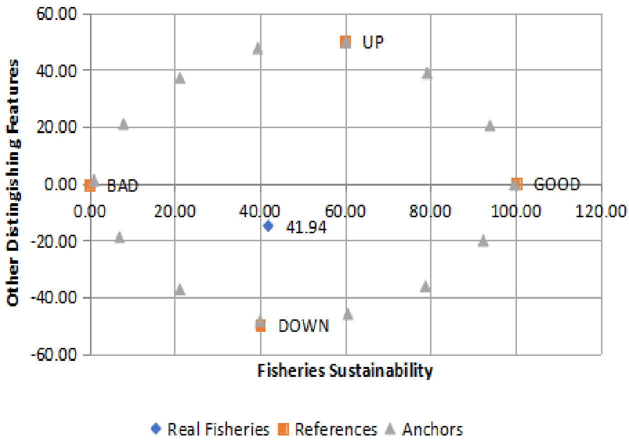

Figure 6. Pareto analysis for the social dimension

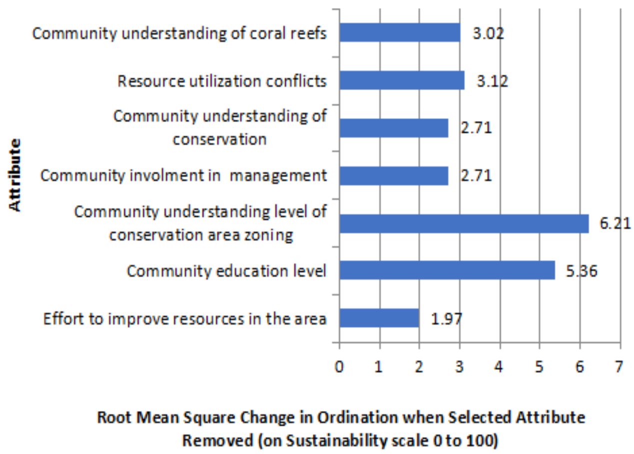

Figure 7. Sensitive attributes of the social dimensions as identified by leverage analysis

Table 5. Pareto analysis and RMS value of social dimension

Social dimension	Root Mean Square (RMS)	Percentage (%)	Cumulative (%)
Community understanding level of conservation area zoning	6.21	25	25
Community education level	5.36	21	46
Resource utilization conflicts	3.12	12	58
Community understanding of coral reefs	3.02	12	70
community involvement in management	2.71	11	81
community understanding of conservation	2.71	11	92
Efforts to improve resources in the area	1.97	8	100
Total	25.01		

A risk associated with the community's limited understanding of the conservation area's zoning is an increased likelihood of ecosystem damage. This is especially concerning if the community engages in activities that violate zoning regulations, such as overfishing in protected core zones. Such actions can harm natural habitats and threaten the sustainability of existing natural resources. Poorly managed conservation areas may fail to protect critical ecosystems, ultimately impacting the community that relies on these resources. To improve the community's understanding of conservation area zoning, several strategies can be implemented. One effective approach is to enhance outreach through structured environmental education programs. These programs should consider the community's educational backgrounds and utilize accessible media, including discussion forums, hands-on training, and community outreach initiatives.

Social conflicts over resource use, although not the highest leverage attribute, are also relevant. Competing interests between fishers, tourism operators, and conservation authorities can intensity when benefits and restrictions are perceived as unevenly distributed. Studies from other MPAs in Indonesia and Southeast Asia show that co-management arrangements, participatory planning, and recognition of local knowledge can reduce conflict and increase compliance (Kusumawati and Huang 2015; Gurney et al. 2019). The Jemur case fits this broader pattern: social sustainability is limited not because of ecological indifference, but because communication, participation, and trust remain underdeveloped.

From a management perspective, the Jemur Island results point to several practical interventions. First, targeted environmental education and zoning awareness campaigns are needed, using methods adapted to local education levels and cultural context (e.g., visual maps, community meetings, peer-to-peer learning). Second, participatory mechanisms such as community forums, joint patrols, and co-management committees can help build a sense of ownership and reduce conflict. These approaches are in line with global evidence that community-based management and meaningful participation improve compliance and long-term conservation outcomes (Bennett and Dearden 2014; Dyer et al. 2014; Gurney et al. 2019; Syarif et al. 2024).

Institutional dimension

The institutional dimension has a sustainability index of 42.63, also classified as less sustainable (Figure 8). This confirms that governance structures are one of the weakest components of MPA performance in Jemur Island. Leverage and Pareto analysis (Figure 9; Table 6) show that village-level resource management institutions, compliance with conservation regulations, overlapping regulations, policy coordination between government, and recognition of international institutions related to conservation areas levels account for most of the institutional leverage.

In practice, the Jemur MPA is influenced by multiple layers of governance: village, district, provincial, and national, each with its own regulations and mandates. Respondents reported that coordination among these levels is intermittent and often focused on administrative requirements rather than joint problem-solving. Overlapping rules, for example, between provincial MPA decrees and district coastal management plans, can create ambiguity about who is responsible for enforcement or community engagement. This situation is similar to governance challenges documented in extensive marine commons and coastal wetlands, where fragmented mandates and insufficient coordination weaken institutional effectiveness (Fidelman et al. 2012; Bohorquez et al. 2023; de Oliveira et al. 2024). Comparable governance constraints have been reported in mangrove management systems in Siak Regency, where overlapping regulations, weak coordination, and limited local institutional capacity reduced management effectiveness (Warningsih et al. 2021). These similarities indicate that institutional fragmentation remains a common challenge across Indonesian coastal conservation areas.

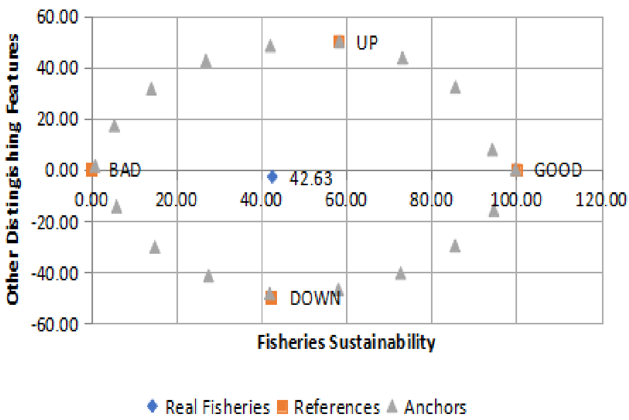

Figure 8. Rapfish ordination results for the institutional dimension

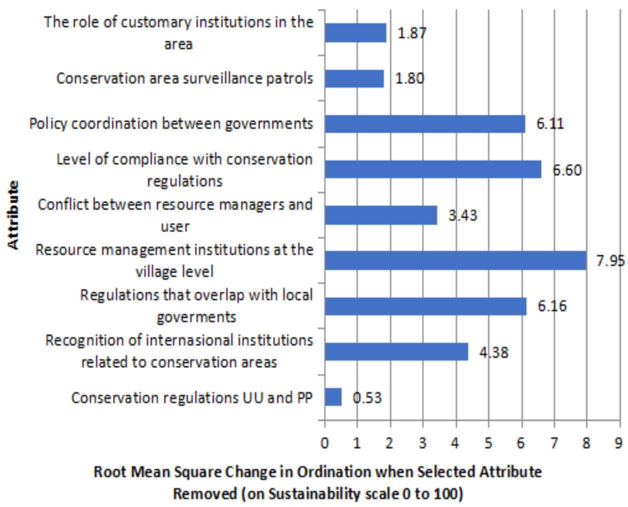

Figure 9. Sensitive attributes of the institutional dimension as identified by leverage analysis

Table 6. Pareto analysis and RMS value of institutional dimension

Institutional dimension	Root Mean Square (RMS)	Percentage (%)	Cumulative (%)
Resource management institutions at the village level	7.95	20	20
Level of compliance with conservation regulations	6.60	17	37
Regulations that overlap with local governments	6.16	16	53
Policy coordination between governments	6.11	16	69
Recognition of international institutions related to conservation areas	4.38	11	80
Conflict between resource managers and users	3.43	9	89
The role of customary institutions in the area	1.87	5	94
Conservation area surveillance patrols	1.80	5	99
Conservation regulations UU and PP	0.53	1	100
Total	38.83		

Resource management institutions at the village level greatly influence the success of conservation efforts, particularly regarding community participation and the implementation of conservation programs. The active involvement of the community in managing conservation areas is largely shaped by the role of these institutions, which help educate and organize residents to participate in environmental preservation activities. Furthermore, these institutions often maintain strong connections with customary institutions, which possess valuable local knowledge for conserving natural resources. They also play a crucial role in patrolling and monitoring conservation areas to prevent activities that can harm the ecosystem, such as illegal fishing. This shows that local institutions play a vital role in conservation effectiveness; without strong local institutional capacity, conservation policies are often not implemented consistently (Gurney et al. 2019; Berkes 2021).

Local institutions at the village level play a critical bridging role, yet their capacity is limited. They are expected to facilitate community participation, mediate conflicts, and support monitoring, but often lack sufficient training, funding, and formal authority. Comparative studies on community-based conservation emphasize that without sustained support for local institutions through capacity building, recognition of customary rules, and clear roles in decision-making policies remain “on paper” and are inconsistently implemented (Berkes 2021; Shemshad et al. 2025). The Jemur findings reinforce this point: institutional weaknesses are not simply administrative gaps, but structural constraints that shape how communities interact with conservation rules daily.

Strengthening the institutional dimension in Jemur, therefore, requires: (i) clarifying mandates and reducing regulatory overlap across government levels; (ii) formalizing and supporting village-level management bodies; (iii) increasing the frequency and quality of coordination meetings; and (iv) integrating community representatives and customary institutions into governance processes. These recommendations are consistent with evidence that multi-level, networked governance can improve conservation outcomes when local, governmental, and external actors share information and responsibilities (Gurney et al. 2019).

Linking ecological, economic, social, and institutional dimensions

The interconnections among ecological conditions, economic dependency, social awareness, and institutional capacity observed in Jemur Island are consistent with socio-ecological system frameworks developed for Indonesian coastal and mangrove ecosystems (Warningsih et al. 2020b; Rumondang et al. 2024). These studies emphasize that sustainability outcomes emerge from feedback among resource dynamics, community behavior, and governance structures rather than from single dimensions in isolation.

Taken together, the four indices show a coherent pattern: ecological and economic conditions are moderately sustainable, while social and institutional dimensions lag. Ecologically, Jemur still supports healthy reefs and turtle nesting sites, but fish abundance and habitat quality are vulnerable to continued fishing pressure and limited enforcement. Economically, households benefit from fisheries and have emerging opportunities in tourism and aquaculture, yet remain highly dependent on marine resources. Socially, zoning awareness and participation are low, and institutionally, local management capacity and coordination are weak.

The leverage results highlight that fish abundance, resource dependency, community awareness, and institutional capacity are the key drivers of sustainability. These attributes are not independent: weak institutions contribute to low compliance and limited outreach; low outreach leads to poor understanding of zoning; poor compliance affects ecological recovery and fish abundance; and unstable ecological conditions, in turn, amplify economic vulnerability in highly dependent communities. This mutually reinforcing pattern is consistent with social-ecological systems research in other coral reef and MPA settings (Gurney et al. 2019; Refulio-Coronado et al. 2021; Uddin et al. 2021).

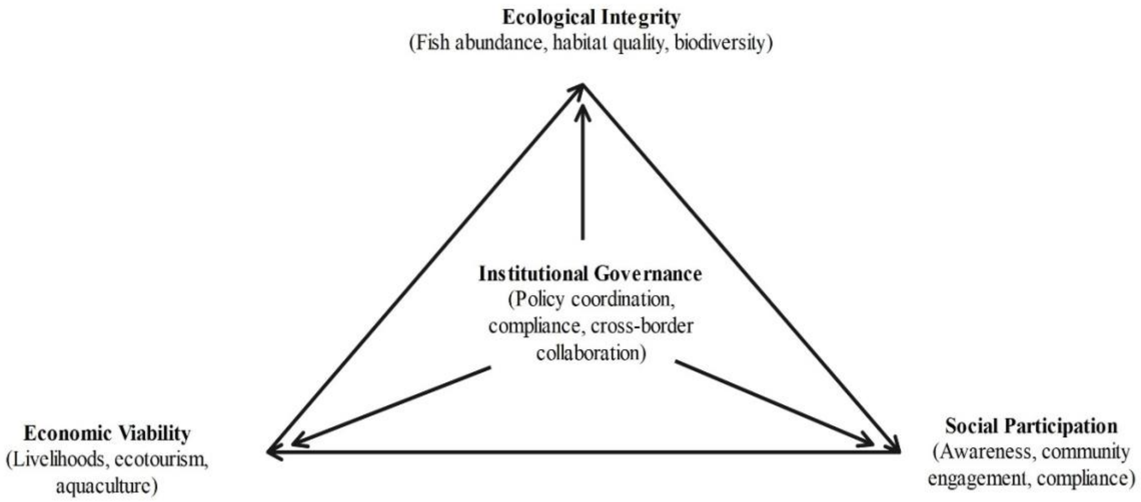

Figure 10. Conceptual interaction among the four sustainability dimensions of the Jemur Island Marine Protected Area

Based on these empirical linkages, the study proposes a conceptual model (Figure 10) that integrates ecological, economic, social, and institutional dimensions for the Jemur Island MCA. The model is not a mechanistic or statistically derived causal diagram, but a hypothesized interaction framework grounded in the observed data: (i) Ecological integrity (fish abundance, habitat quality, ETP species) underpins economic benefits from fisheries and tourism; (ii) Economic improvement, when diversified and inclusive, can enhance community welfare and create space for participation in conservation; (iii) Social awareness and participation strengthen compliance, reduce conflict, and support co-management arrangements; (iv) Strong and coherent institutions enable effective coordination, provide rules and incentives, and maintain long-term monitoring and enforcement. These relationships form a reinforcing feedback loop, with institutional governance occupying a central position as the stabilizing core of the local and intergovernmental levels, and is therefore a strategic entry point for improving ecological conditions and livelihood resilience simultaneously (Bohorquez et al. 2023; de Oliveira et al. 2024; Shemshad et al. 2025).

Finally, it is important to acknowledge limitations. The Rapfish approach relies on expert judgment and semi-quantitative scoring with a relatively small number of respondents, and the analysis represents a snapshot in time. Although MDS diagnostics and Monte Carlo analysis suggest that the ordination is robust, uncertainties remain regarding the exact magnitude of sustainability scores and leverage values. Future research should combine repeated Rapfish assessments with more detailed ecological monitoring, socio-economic surveys, and quantitative modelling to test and refine the hypothesized linkages presented in Figure 10.

In conclusion, the sustainability assessment of the Jemur Island Marine Protected Area shows that ecological (61.44) and economic (64.08) dimensions are moderately sustainable, while the social (41.94) and institutional (42.63) dimensions remain weak. Key ecological assets such as coral reefs and turtle nesting sites persist, but fish abundance and biomass are highly sensitive to fishing pressure. Economically, emerging ecotourism and aquaculture offer diversification potential, yet strong dependence on capture fisheries increases vulnerability. Weak community awareness, limited participation, fragmented governance, and overlapping regulations constrain compliance and management effectiveness. Overall, the results demonstrate that while ecological and economic conditions remain functional, long-term sustainability is constrained by social and institutional weaknesses. Strengthening community awareness, enhancing participation, clarifying governance mandates, and improving institutional capacity represent the most critical leverage points for improving MPA performance on Jemur Island, Riau Province, Indonesia.

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