International Journal of Chemical and Biochemical Sciences
(ISSN 2226-9614)

Journal Home page: www.iscientific.org/Journal.html

Environmental Health Impacts on The Sustainability of The Coral Reef Ecosystem in Gede Island, Indonesia

Yuyun Khoirun Nisak, Pujiono Wahyu Purnomo*, and Diah Ayuningrum

Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, Diponegoro University. Semarang 50275, Central Java, Indonesia

Abstract

Gede Island, located north of Rembang Regency in Central Java, Indonesia, hosts coral reefs in poor environmental health. This study aimed to assess the impact of environmental health on various dimensions of sustainability to guide stakeholder decision-making. A descriptive quantitative method was employed. Observations of coral reef variables, including type and percentage of cover, were conducted using the Point Intercept Transect (PIT) method. The sustainability status of management practices was analysed using the Multidimensional Scaling (MDS) method with Rapfish (Rapid Assessment Techniques for Fisheries) 2013 version R software. The results identified 16 genera from three sampling points: Station 1 had 30.35% hard coral cover, Station 2 had 1%, and Station 3 had 12.94%. The sustainability status of Gede Island's coral reefs was evaluated across five attributes: ecological (41.61%), social (48.05%), economic (40.08%), institutional (26.36%), and technological (57.03%). Among these, only the technological attribute was classified as moderately sustainable, while the others were deemed less sustainable. A high sustainability status offers significant potential and benefits for the local community, such as opportunities for ecotourism and fisheries sustainability.

Keywords: MDS, PIT, Rapfish, small island

Full length article **Corresponding Author*, e-mail: purnomopoed@gmail.com Doi # https://doi.org/10.62877/34-IJCBS-24-25-19-34

1. Introduction

Small islands are typically defined as landmasses with an area of 2,000 km² or less, encompassing their ecosystem units [1]. Among these is Pulau Gede, situated in the northern region of Rembang Regency, specifically within Tasikharjo Village, Kaliori District. Pulau Gede lies approximately 2 miles or 3.89 km off the coast of Wates, Tasikharjo Village, Kaliori, Rembang, falling under the governance of the Provincial Government of Central Java, Indonesia. The Provincial Government holds authority over five key areas concerning the management of natural resources in the sea [2], which include exploration, exploitation, conservation, administrative regulation, spatial planning, as well as participation in maritime security maintenance and national sovereignty defence. Pulau Gede is an uninhabited island within the Rembang Regency, with significant potential as a tourist destination. The Rembang Government can undertake various initiatives to formulate a marketing strategy for Pulau Gede's tourism, focusing on promotion, facility improvements, and effective ecosystem management. Community engagement plays a pivotal role in management practices, as it can greatly enhance community well-being [3, 4]. The journey from Pantai Wates, the nearest beach, to Pulau Gede takes approximately 30 minutes by a 6 GT (Gross Ton) boat [5].

The island has coral reefs exhibiting higher productivity and diversity compared to other ecosystems [6]. The condition of the surrounding waters undoubtedly influences the growth and development of these coral reefs [7, 8], which serve as crucial ecosystems for marine biodiversity and contribute significantly to the marine environment's balance. However, coral reefs worldwide face severe threats, including global warming, pollution, and overfishing, among others. Adopting sustainable coral reef management practices becomes important, involving the implementation of strategies that set limits on human utilization [9]. Effective coral reef management should prioritize economic, ecological, and social considerations, focusing on long-term sustainability [10, 11]. The involvement of local communities and collaboration with various stakeholders can aid in the preservation of coral reefs for future generations [12, 13]. Successful natural resource management necessitates collaborative efforts among governments, NGOs, scientists, and local communities. This collaboration allows for the exchange of knowledge and resources, leading to the development of more sustainable solutions. Community-based natural resource management should strive to balance coral reef conservation with the socio-economic needs of communities [14]. To safeguard coral reefs, it is imperative to enforce key regulations and educate local communities on the importance of coral reefs, their threats, and methods for sustaining them [15]. Sustainable natural resource management is influenced by social, cultural, and economic factors [16].

Given the increasing vulnerability of the island to loss, analyzing its multidimensional sustainability status is crucial. The Rapfish 2013 version R ordination technique can be utilized to evaluate fisheries [17], considering ecological, social, and economic aspects holistically. This study advocates for sustainability evaluations of fisheries operations not solely relying on environmental parameters but also considering their social and economic impacts. Its objective is to identify the dimensions influencing sustainability status, aiding stakeholder decision-making efforts and supporting fisheries resource conservation and environmental sustainability [18].

2. Materials and methods

2.1. Materials

The ecological survey required various equipment, including a GPS, underwater camera, underwater stationery (paper, pencil, and baseboard), measuring tape, current meter, dissolved oxygen (DO) meter, thermometer, refractometer, and Secchi disk. Conducted in March 2024, the ecological survey took place at Gede, situated in Rembang Regency, Indonesia (Figure 1). The economic survey, spanning from July 2023 to March 2024, involved questionnaires for fishermen and other interview equipment.

2.2. Method

A descriptive quantitative method was employed, aiming to depict the current conditions directly relevant to the research subject [19]. Coral reef variables were observed, encompassing type and percentage of cover, utilizing the Point Intercept Transect (PIT) method [20]. Line transects, spaced at 50 cm intervals, covered a total distance of 2 x 50 meters. Coral cover was recorded, and species were identified based on morphology and life form.

2.2.1. Calculation of coral cover percentage

The percentage cover of corals (both live and dead), sand, and coral fragments was determined using the formula [20]:

$$\text{Coral reef coverage } (\%) = \frac{a}{b}\, x\, 100 \ldots\ldots \text{ F1}$$

Description

a = Number of closure points across transects

b = Number of points across transects

Coral reef condition was categorized as per the classification: poor (0–24.9%), medium (25–49.9%), good (50–74.9%), and excellent (75–100%) [21].

2.2.2. Sustainability Status

The Multidimensional Scaling (MDS) method was utilized to analyse sustainability status, a technique categorizing respondents' preferences and perceptions spatially through visual displays [22]. Sustainable management was evaluated using Rapfish software (Rapid Assessment Techniques for Fisheries) 2013 version R [23].

The sustainability dimensions considered comprised ecological, economic, social, technological, and institutional dimensions (Table 1), determined based on conceptual sustainability indicators from modified Rapfish analysis. Coral reef management condition was classified into four categories [24], namely poor/unsustainable (≤ 25), less sustainable (25–49), moderately sustainable (50–75), and good/very sustainable (> 75).

3. Results and Discussions

3.1. Water Quality

Table 2 shows the water quality across three stations within the coral reef ecosystem of Gede Island. According to Government Regulation of the Republic of Indonesia No. 22 of 2021, water quality variables at coral reef sampling sites were classified as good. Salinity levels at all three observation stations were within the stipulated standard of 33 ‰. At station 1, visibility was limited to 1 meter, indicative of poor visibility due to Total Suspended Solid (TSS) levels of 39.5 mg/L exceeding the 20 mg/L standard. Conversely, stations 2 and 3 had good visibility, with readings of 2 meters and 1 meter, respectively, while maintaining TSS levels within the acceptable range. Water temperatures were 26–27 °C, slightly below standard due to the rainy season conditions during the research period. However, this range remains conducive for biota, underscoring the favourable environmental quality for coral reef sustenance [21]. Indeed, deviations from these quality standards can potentially disrupt the aquatic environment, influencing coral reef growth and development [7].

Several factors impact water quality and subsequently coral reef growth, including salinity, temperature, visibility, current, depth, and TSS. Salinity, subject to seasonal variations, is influenced by factors such as water circulation patterns, evaporation, and precipitation [25]. Water temperature fluctuates influenced by weather and depth variances. Depth influences sunlight penetration, thereby impacting temperature levels [26]. Current velocity facilitates nutrient transport, water temperature distribution, and marine organism movement, potentially affecting organic compound particle presence and visibility reduction [27]. Elevated TSS concentrations limit visibility and hinder photosynthesis, thereby impeding coral reef growth [28].

3.2. Percentage of coral cover

Observations across the three stations reveal that station 1 had the highest coral cover percentage, with hard coral at 33.5% and soft coral at 0.5% (Table 3). Conversely, station 2 had the lowest coral reef cover, with 1% for hard coral with no soft coral detected.

Coral reef health on Gede Island varies across stations, with station 1 classified as moderate and stations 2 and 3 as poor. This discrepancy can be attributed to various factors, including water quality. High TSS levels can lead to coral mortality, as prolonged sediment cover can result in coral death [29].

Coral reefs play pivotal roles in various life functions, serving as wave breakers, habitats for diverse organisms, and sites for feeding, nursing, and spawning marine biota. The loss of coral reefs not only disrupts important ecological functions but also compromises island protection against rising sea levels. Unsustainable fishing activities, particularly in capture fisheries, predominantly drive coral reef degradation on Gede Island. This degradation is indicated by the high percentage of coral fragment cover [30].

3.3. Sustainability Status

Rapfish scoring across ecological, economic, social, technological, and institutional dimensions (Figure 2-5(A)) can be used to determine the coral reef ecosystem management sustainability status. Additionally, the sensitivity analysis (leverage) of each attribute is depicted in Figure B (2-5). In the technology dimension, the highest sustainability status of 57.03% is classified as moderately sustainable. However, the ecological, economic, social, and institutional dimensions are classified as less sustainable. The Rapfish ordination technique, utilizing the Multidimensional Scaling (MDS) method, facilitates the comparative evaluation of fisheries sustainability based on easily scored attributes. It assesses sustainability levels by comparing attributes such as fishing rates, catch, resource utilization, and environmental impacts [17]. Scoring within the context of Rapfish involves assigning scores to attributes. The utilization of MDS then aids in summarizing these scores and placing fisheries in a measurable order, reflecting their relative sustainability levels. MDS, a statistical technique, simplifies and visualizes relationships between multidimensional data, such as Rapfish attributes. It assists in summarizing complex data into more understandable visual representations [31]. The sustainability index of coral reef ecosystems on Gede Island was analysed multidimensionally using Rapfish software. Each dimension comprises attributes used for evaluating ecosystem sustainability. The analysis revealed that out of the five dimensions, only one showed moderate sustainability, while the remaining four were less sustainable. Improved management strategies are necessary to minimize the impact on coral reef ecosystems. Leverage analysis is also essential to identify attributes significantly influencing the sustainability index [17].

The sustainability index value for the ecological dimension of 41.61% indicates less sustainability. This dimension includes attributes like temperature, current, visibility, salinity, and percentage of coral cover. Visibility stands out as a sensitive attribute, which affects coral reef survival. Poor visibility, often due to water runoff containing sediment particles, limits light penetration and impacts reef health [32]. The economic dimension, with a sustainability index value of 40.08%, is also classified as less sustainable. Fishermen's income is a sensitive attribute here. Decreased income reflects declining catches, influenced by ecosystem quality. Coral reef degradation threatens long-term fishery sustainability, necessitating rehabilitation and conservation efforts to restore ecosystem health and abundance. The social dimension, with a sustainability index value of 48.05%, is similarly classified as less sustainable. Increasing fishermen numbers intensify fishing trips, raising the risk of ecosystem damage. Without sufficient knowledge, this can lead to unsustainable exploitation, driven by economic pressures within coastal communities. Efforts to increase community understanding aim to mitigate exploitation and ensure resource sustainability [17, 33]. The technology dimension fares slightly better with a sustainability index value of 57.03%, indicating moderate sustainability. Fishing gear selectivity is the sensitive attribute. The Leverage analysis suggests that local fishing communities in Tasikharjo predominantly use environmentally friendly gear, aligning with ecosystem conditions and sustainability goals [34]. Maintaining consistency in gear use is crucial for resource conservation and ecosystem sustainability.

In contrast, the institutional dimension lags with a sustainability index value of 26.38%, indicating that it is less sustainable. Despite no official regulation on small islands and in the north of Tasikharjo Village, community compliance regarding the use of fishing equipment in the coral reef ecosystem area significantly influences this dimension. The economic welfare of fishing communities is significantly impacted by the role of institutions [17] whose legal legitimacy is vital for effective participation in government programs. Overall, the sustainability status of coral reef ecosystem management is discerned through Rapfish ordination across ecological, economic, social, technological, and institutional dimensions (Figure 7). While the technology dimension shows moderate sustainability, the ecological, economic, social, and institutional dimensions exhibit less sustainability. The sustainability status of Gede Island's coral reef ecosystem is deemed less sustainable, owing to various sensitive attributes across dimensions. Issues like low visibility impacting coral health, declining fishermen's income due to reduced catches, and inadequate fishing gear selectivity contribute to ecosystem degradation. Effective sustainability requires synergistic efforts across dimensions [35]. The increasing unawareness about the ecosystem and the selectivity of fishing gear among fishermen can negatively impact marine environments. The use of inappropriate fishing gear has the potential to damage coral reefs. During our research, we discovered a net used for crab fishing [34] that was caught on coral reefs, resulting in extensive damage to the corals. Even with a high level of ecosystem knowledge, effective management is hindered if community compliance is low. Therefore, achieving a good sustainability status requires effective synergy between various dimensions. Efforts to improve sustainability status can be pursued through multiple strategies. An analysis of fisheries sustainability in the Madura Strait, East Java, revealed that it was less sustainable in the economic, technological, and ecological dimensions. This finding suggests management strategies should focus on reducing the use of environmentally harmful fishing gear, coastal rehabilitation, and policy-making to provide alternative economic opportunities for the local community. Additionally, implementing advanced technology can support sustainable fishing practices [17]. To manage coral reef ecosystems with a 'moderately sustainable' status, it is crucial to optimize attributes classified as sensitive. The goal of such optimization is to enhance the sustainability status of the management practices [36].

Table 1: Assessment of Sustainability Analysis of Coral Reef Management of Gede Island, Rembang, Central Java

No.	Attribute	Description	Score
A. Ecological Dimensions [21]			
1.	Coral coverage	The assessment is based on Kepmen LH No. 4 of 2001 on Coral Reef Damage Standard Criteria	0–24.9% (0); 25–49.9% (1); 50–74.5% (2); 75–100% (3).
2.	Salinity	Salinity affects the life of coral animals due to osmosis pressure on living tissues.	< 33‰ and > 34‰ (0); 33 –34‰ (1)
3.	Visibility	Visibility affects the penetration of sunlight which aids the photosynthesis process.	< 5 m and > 5 m (0); 5 m (1)
4.	Current	Currents are necessary for the delivery of food and oxygen from the open sea, as well as for sediment removal.	> 0.51 m/det (0); 0.34–0.51 m/det (1); 0.17–0.34 m/det (2); 0–0.17 m/det (3).
5.	Temperature	Temperature affects the metabolic rate and reproduction of corals.	< 28 ˚C and > 30 ˚C (0); 28–30 ˚C (1).
B. Economic Dimensions [23]			
1.	Dependence on resources	The lower the level of sustainability, the greater the dependence on resources.	Low (0); medium (1); high (2).
2.	Fishing intensity	The higher the fishing intensity, the lower the sustainability level.	Casual (0); Full-time (1); Seasonal (2); Part-time (3).
3.	Dependence on tourist	The greater the dependence on tourists, the lower the level of sustainability.	Low (0); medium (1); high (2).
4.	Fishermen's income	Assessment by comparing the prevailing UMK of Rembang Regency	Very less (0); Less (1); Same (2); Greater (3); Very greater (4).
5.	Alternative livelihoods	Assessment of other sources of livelihood or income	None (0); Low (1); High (2).
6.	Profit	Who benefits from economic activity	Local people (0); mixed (1); foreigners (2).
7.	Market	Assess the extent of the market for fishery products, especially economically important fish.	Local market (0); National market (1); International market (2).
8.	Marketing System	Assess the impact of the marketing system.	Through intermediaries (0); Fish market (1); and Industry (2) [37]
C. Social Dimensions [23]			
1.	Number of fishing households	The assessment is based on data from the related agencies	High (0); Medium (1); Low (2).
2.	Growth of fishermen	Growth in the number of fishermen is based on data from the related agencies	High (0); Medium (1); Low (2); Almost none (3).
3.	Social network	Number of fisherman households joining an organised community	< 10% (0); 10–30% (1); > 30% (2).
4.	Community knowledge	Assessment of community knowledge of resources around Gede Island	Very low (0); Fair (1); Good (2).
5.	Community participation	Assessment using the Likert scale	Very low (0); Fair (1); Good (2).
6.	Conflict	Assessing conflicts that occur in the community	None (0); Low (1); High (2).
D. Technological Dimensions [23]			
1.	Type of fishing gear	Assessment is based on the nature of the fishing gear used	Active majority (0); Balanced (1); Passive majority (2).
2.	Fishing gear selectivity	Assessment is based on the selectivity of the fishing gear used	Somewhat selective (0); Selective (1); Highly selective (2).
3.	Impact of fishing gear	Assessment is based on the impact of the use of fishing gear on coral reefs	Many (0); Moderate (1); Few (2); None (3).
4.	Rehabilitation technology	Assessment based on the application of technology in coral reef rehabilitation	None (0); Low (1); High (2).
5.	Use of illegal fishing gear	Assessment is based on whether or not there is much use of environmentally unfriendly fishing gear	Many (0); Medium (1); Few (2); None (3) [33]
6.	Supervision infrastructure	Assessment based on the presence or absence of monitoring facilities and infrastructure.	None (0); Existing, not optimal (1); Existing and optimal (2). [38]
E. Institutional Dimensions [39]			
1.	Legality/ Regulations	The role of regulations in coral reef resource management	None (0); Present and sub-optimal (1); Optimal (2).
2.	Inter-agency coordination	The involvement of multiple parties are important factors.	Poor (0); Medium (1); Good (2) [38]
3.	Monitoring and supervision	Public awareness can lead to active participation in monitoring and supervision systems.	Low (0); Medium (1); High (2).
4.	Level of community compliance	The higher the community's compliance with the rules in the resource location, the higher the level of sustainability.	Non-compliant (0); Moderate (1); Compliant (2).
5.	The role of the private sector	Private sector involvement is needed related to corporate social responsibility in coral reef management	No role (0); Existing but less than optimal (1); Optimal role (2)
6.	The role of higher education	Involvement of higher education is needed related to the development of science and technology in coral reef management	No role (0); Existing but less than optimal (1); Optimal role (2)

Table 2: Water Quality

No.	Variable	Station			Water quality standards for marine biota (Government Regulation of the Republic of Indonesia No. 22 of 2021)
		1	**2**	**3**	
1	Salinity (‰)	33	33	33	33–34
2	Visibility (m)	1	2	1	>5
3	Current (m/s)	0.17	0.13	0.15	-
4	Temperature (˚C)	26	26	27	28–30
5	Depth (m)	4	2	1	-
6	TSS (mg/L)	39.5	12.89	11.24	20

Table 3: The percentage cover of corals

No.	Categories	Percentage (%)		
		Sation 1	**Sation 2**	**Sation 3**
1	Hard Coral	30.35	1.00	12.94
2	Soft Coral	0.50	0.00	0.00
3	Dead Coral with Algae	7.96	0.50	1.49
4	Rock	8.46	1.00	3.48
5	Rubble	7.96	77.61	33.33
6	Silt	32.34	1.49	0.00
7	Sand	10.95	17.41	48.26
8	Other	1.49	1.00	0.50
Total		100.00	100.00	100.00

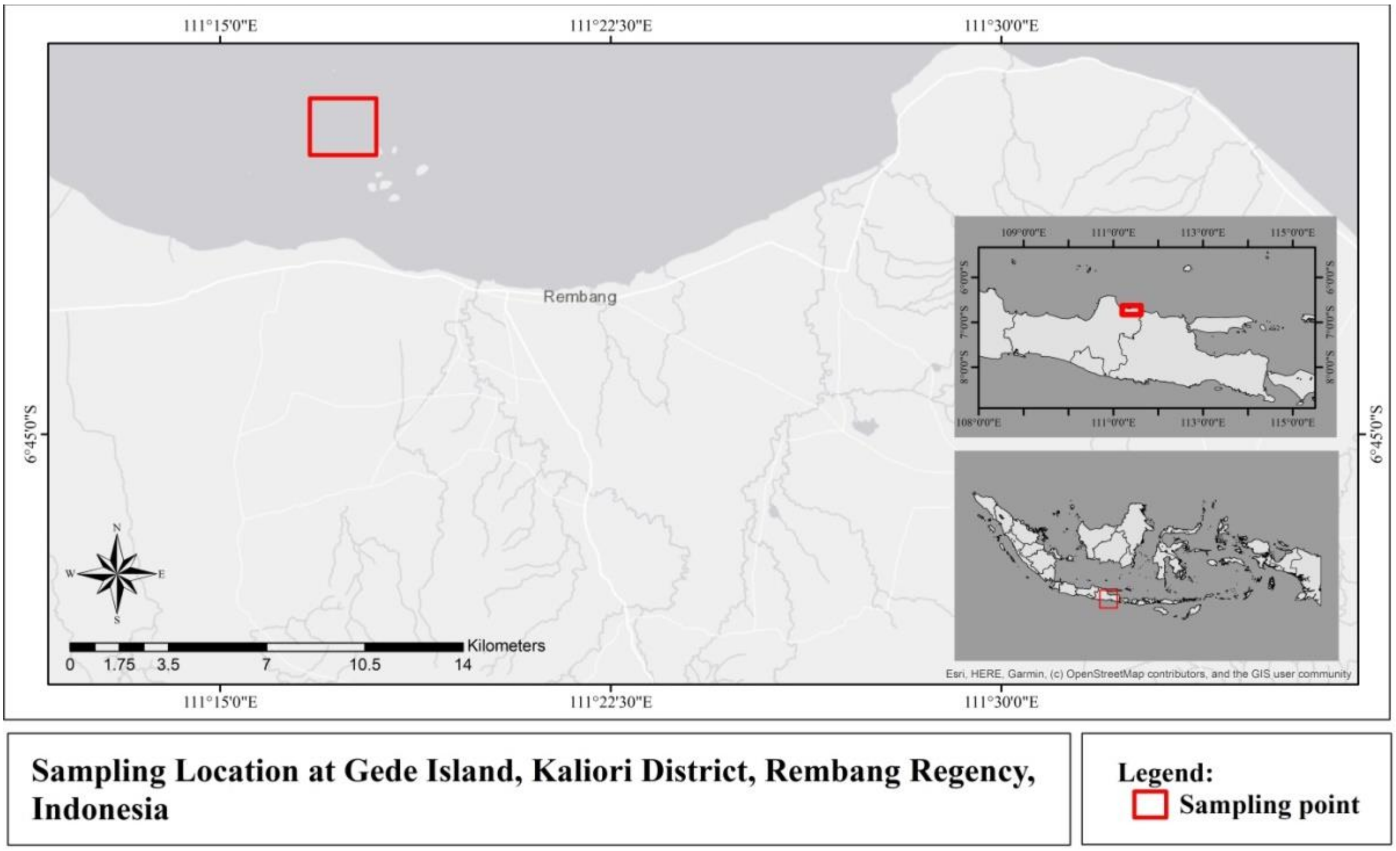

Figure 1. Sampling Location at Gede Island

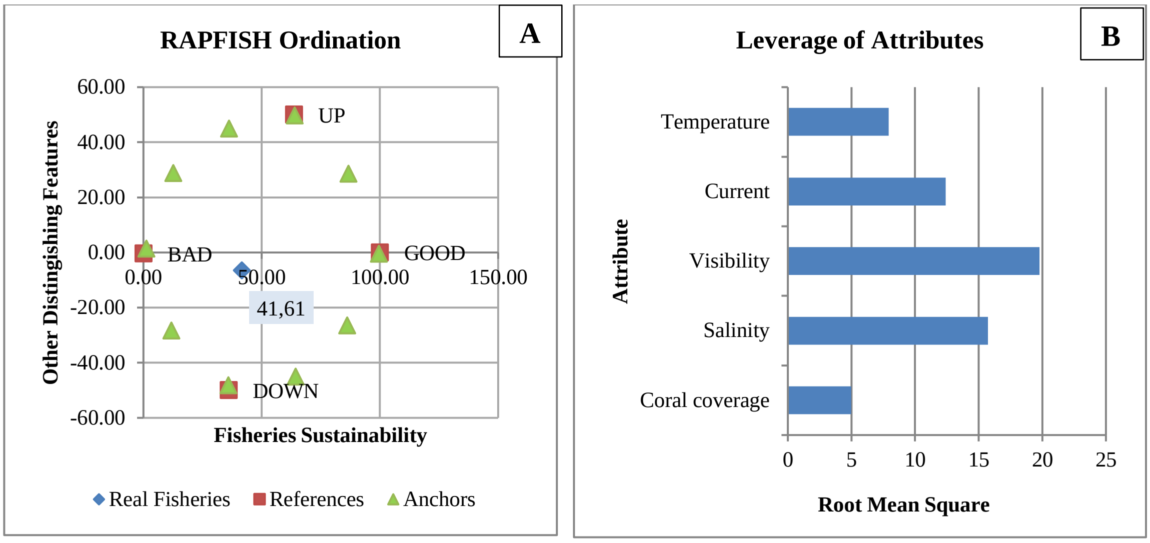

Figure 2. Ecological dimension (A. Rapfish ordination; B. The sensitivity analysis (leverage))

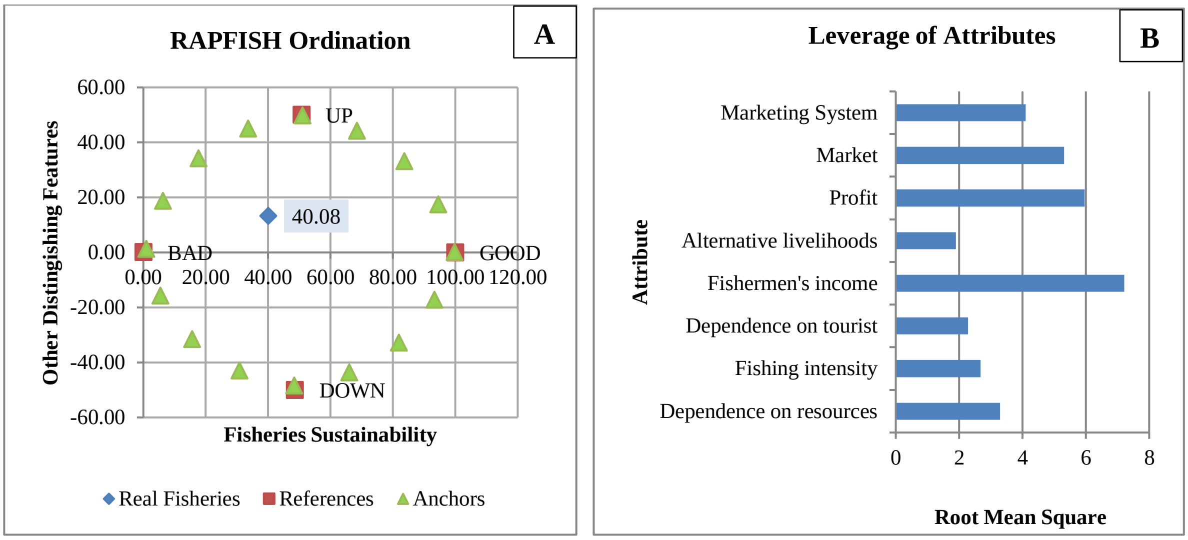

Figure 3. Economic dimensions (A. Rapfish ordination; B. The sensitivity analysis (leverage))

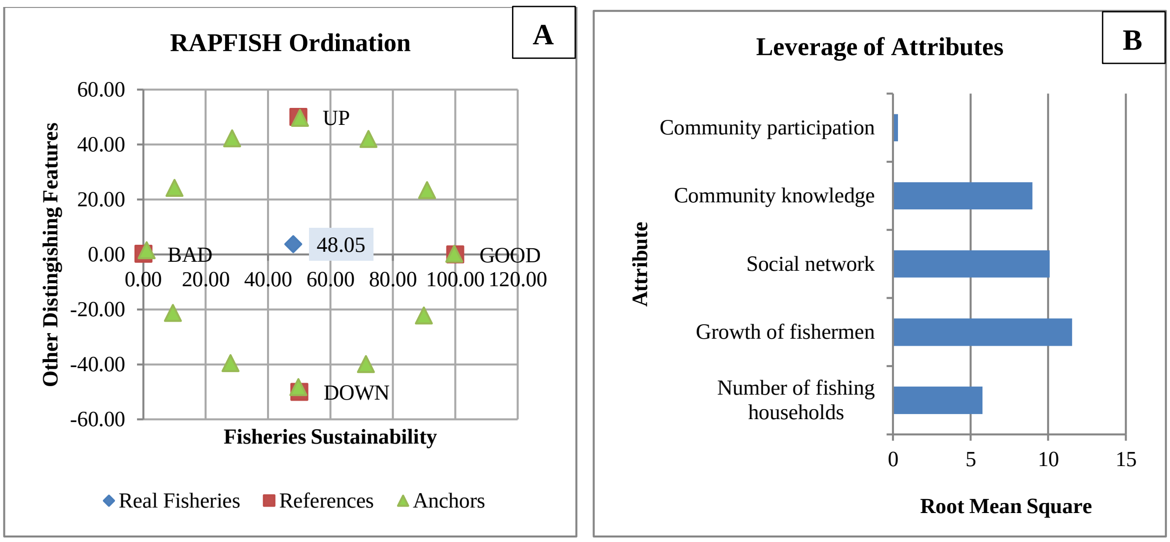

Figure 4. Social dimensions (A. Rapfish ordination; B. The sensitivity analysis (leverage))

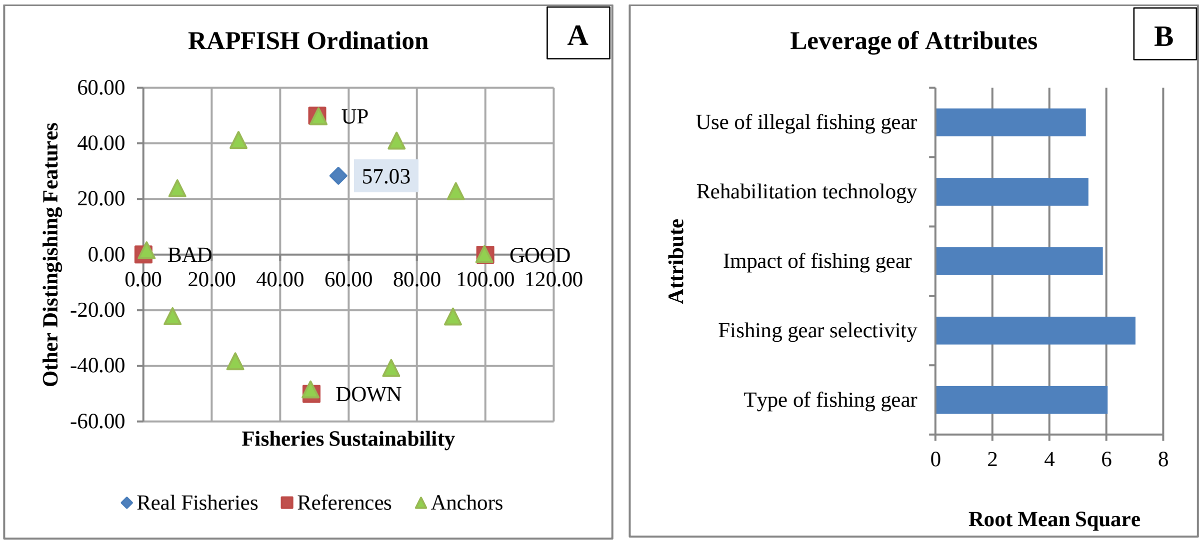

Figure 5. Technological dimensions (A. Rapfish ordination; B. The sensitivity analysis (leverage))

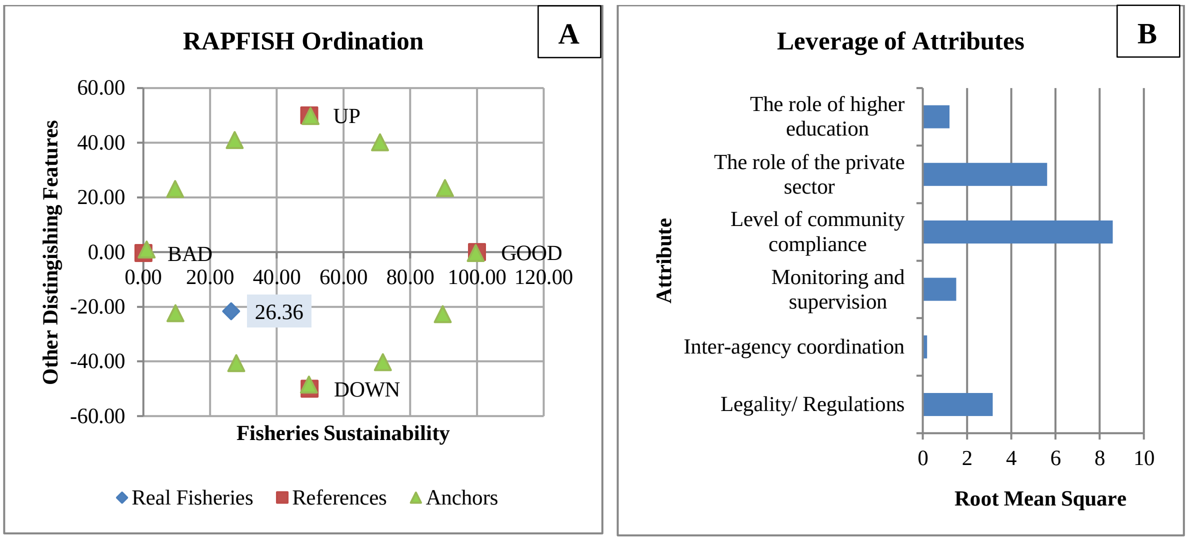

Figure 6. Institutional dimensions (A. Rapfish ordination; B. The sensitivity analysis (leverage))

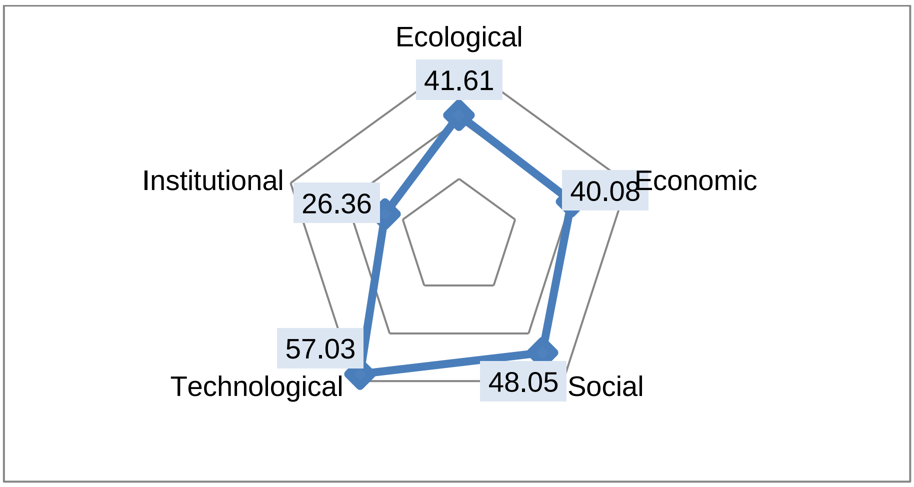

Figure 7. Coral Reef Ecosystem Sustainability Diagram of Gede Island Rembang

4. Conclusions

The coral reef cover percentage at station 1 on Gede Island, Rembang, Central Java, Indonesia, is moderate. However, at stations 2 and 3, it is poor. The sustainability status of coral reef ecosystem management is classified as moderately sustainable in the technological dimension but as less sustainable in the ecological, economic, social, and institutional dimensions. Multidimensional analysis using Rapfish software indicates that the management of coral reef ecosystems has not been optimal. Therefore, further appropriate management measures are necessary to fully utilize the existing potential.

5. Acknowledgment

This study was fully funded by the Ministry of Education, Culture, Research and Technology through the Penelitian Pascasarjana – Penelitian Tesis Magister (PPS-PTM) scheme, with contract number 449A-67/UN7.D2/PP/VI/2023.

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