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# The fate of mangrove ecosystem sustainability on the shrimp cultivation area in Tulang Bawang District, Lampung, Indonesia

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**Abstract.** *Bakri S, Hartati F, Kaskoyo H, Febryano IG, Dewi BS. 2023. The fate of mangrove ecosystem sustainability on the shrimp cultivation area in Tulang Bawang, Lampung, Indonesia. Biodiversitas 24: 379-390.* The exploitation of mangrove forests for economic purposes is rampant in tropical countries nowadays, particularly for shrimp farming, such as in the Lampung green belt in the front of the Java Sea. So, ensuring the sustainability of existing mangroves is the need of the hour. In view of above, this study aims to analyze the sustainability index of mangrove ecosystem management and the sustainability status of the mangrove ecosystem from the ecological, economic, social, and institutional dimensions using the Multidimensional Scaling (MDS) method through the Rapid Appraisal for Fisheries (RAPFISH) approach in East Rawajitu Sub-district, Tulang Bawang District, Lampung Province, Indonesia. The analysis revealed that mangrove ecosystem management's sustainability index was categorized as 'less sustainable' (index 43.01 out of 100). Meanwhile, the social dimension (51.65) was categorized as 'quite sustainable', and other dimensions (ecological, economic, and institutional) were 'less sustainable.' Therefore, it is proposed that further development of the social dimension is a strategic way to develop the other three sustainability dimensions to achieve ecosystem sustainability as a whole in the study area. Alternative strategies that can be applied for sustainable management of mangrove ecosystems in East Rawajitu Sub-district, Tulang Bawang District are increasing coordination between stakeholders, creating formal regulations, increasing the productivity and creativity of Ikatan Istri-istri Petambak Dipasena (ISTANA), formulating an integrated mangrove ecosystem management plan program, undertaking rehabilitation efforts, increasing the role of mangrove groups, and increase the attention of researchers.

**Key words:** Mangrove ecosystem, RAPFISH, shrimp cultivation, strategy, sustainability

## INTRODUCTION

Coastal zone is a transitional area between terrestrial and marine ecosystems that has a wealth of potential natural resources (Askar et al. 2021) and is able to maintain water productivity (Fithor et al. 2018). Mangroves ecosystem is one of the transitional ecosystems in the coastal areas that play an important role in ensuring the sustainability of the coast (Hartati et al. 2020). Mangroves are a group of salt-tolerant plant species that occur in intertidal estuarine regions of tropical and subtropical coast (Jia et al. 2020). Mangroves offers wide array of ecological, social and economic services (Basyuni et al. 2018; Melet et al. 2020). Ecologically, the mangrove ecosystem plays a role as a life support system, shoreline protection (Naharuddin 2021), seawater intrusion barrier, preventing abrasion, breakwaters, and marine biota habitat (Marlianingrum et al. 2021), while the socio-economic benefits of mangroves are as a means of ecotourism (Agaton and Collera 2022), a source of food and medicine, and can increase income (Alam et al. 2022). In addition, the mangrove ecosystem has a strategic function as a primary producer capable of sustaining and stabilizing other ecosystems around it.

The various benefits of the mangrove ecosystems have an impact on people's lives, but these benefits can also have severe consequences for their existence (Menéndez et al. 2020). The higher the rate of population growth and economic development, the more changes in land use and excessive use of natural resources occur, especially in mangrove ecosystems (Marques et al. 2019). As a result, the environment's carrying capacity for human activities will decreases and rate of environmental degradation increases.

The recent estimate has revealed that the total area of mangrove forests globally is 1.7 million hectares, spread over 118 countries and territories (Wang and Gu 2021). Currently, mangrove forests are declining in quality and quantity at an alarming rate worldwide (Carugati et al. 2018; Matatula et al. 2019). Globally, mangroves have experienced an annual loss of between 0.16% and 0.39%, because of rapid coastal development (Hamilton and Casey 2016). In South Asia, mangrove forests have been lost at an average rate of 0.18% per year (Richards and Friess 2016). The global area of mangrove forests decreased by 1.04 million ha between 1990 and 2020 (Leal and Spalding 2022).

The rate of mangrove loss has more than halved over the three decades, from 46,700 ha per year in 1990-2000, to 36,300 ha per year in 2000-2010, to 21,200 ha per year in the most recent decade. There was a substantial increase in the average annual rate of mangrove loss in Asia, from 1,030 ha in 1990-2000 to 38,200 ha in 2010-2020. The increased rate of loss was due mainly to Indonesia, which reported an average annual loss of 6,800 ha in 1990-2000 and 21,100 ha in the most recent decade (Leal and Spalding 2022). Even though the rate of mangrove deforestation is high (Richards and Friess 2016) and mangrove degradation is increasing (Bunting et al. 2018), Indonesia remains the country with the largest mangrove area in the world (Hamilton and Casey 2016).

One of the mangrove ecosystems currently experiencing damage and requires special attention in Indonesia is the mangrove forest in East Rawajitu Sub-district, Tulang Bawang District, Lampung Province. This area has long been used for the aquaculture sector, especially shrimp ponds, so it can cause changes in the ecological system of the local area (Hartati 2022). In this regard, to optimize the use of coastal areas as shrimp farming areas without neglecting the decline in environmental quality, an effort is needed to maintain the productivity of the aquatic environment (Lovelock et al. 2022).

The management of mangrove damage in East Rawajitu Sub-district is still limited to local community self-help and has not been fostered by government officials. Even so, the efforts made have been quite good, namely carrying out mangrove rehabilitation activities in stages starting with planting *gelugu* (coconut), because there has been no assistance for mangrove seedlings from any party. In addition, the local community also took collective action through contributions to mangrove planting funds to repair damaged areas. This action invited sympathy from various communities concerned with the environment, so mangrove seed aid began to arrive and mangrove planting activities began to be carried out regularly. Hai et al. (2020) revealed that mangrove rehabilitation by replanting is one step to restoring ecosystem function.

Problems of environmental damage, policy changes, and socio-economic dynamics encourage a decline in the function of the mangrove ecosystem. Mangrove exploitation for economic purposes, especially shrimp farming, is suspected to threaten its sustainability. Sustainability still remains a major theme in every development process (Utama et al. 2022). Several key stakeholders, such as government, business people, and communities who play a major role in coastal areas' development, have different motives for utilizing these ecosystems. If the utilization policy does not follow the agreement between stakeholders, this ecosystem damage can occur continuously (Tresiana et al. 2022). This problem must be overcome by formulating appropriate strategies and policies to create sustainability while maintaining its functions, benefits, and roles.

Policy strategies for sustainability of mangrove ecosystems need to be built based on current ecosystem conditions, management evaluation, and analysis of stakeholder needs in the future use of mangroves (Fatima et al. 2018; Arifanti et al. 2022). Understanding these elements is the basis for developing the sustainability of mangrove ecosystems so that there is a synergy between the use and preservation of natural resources. Latysheva et al. (2020) has stated that in order to implement a sustainable management strategy at the level of the management hierarchy and systematic regulation, an assessment of the ecological, social, economic, and institutional aspects is needed. Therefore, this research is decisive to be carried out as an instrument to reduce the rate of mangrove damage and determine the right strategy for sustainably managing mangrove ecosystems. Furthermore, this study aims to analyze mangrove ecosystem management's index and sustainability status and formulate management strategies.

## MATERIALS AND METHODS

### Study area

This research was conducted from February to March 2022 in East Rawajitu Sub-district, Tulang Bawang District, Lampung Province, Indonesia (Figure 1). The location was selected because it has the potential of mangrove forests that function as a green belt, but has been damaged due to the failure of revitalization techniques for coastal areas, thus requiring the right strategy in its management.

### Data collecting

The types of data collected in this study are primary data and secondary data. Primary data was obtained through respondent survey techniques by conducting semi-structured interviews with the community and key informants, while secondary data was obtained through literature studies. The community sample was determined based on the simple random sampling method of 40 respondents (out of 367 households) in Bumi Sentosa Village and 42 respondents (out of 665 households) in Bumi Dipasena Utama Village. The number of the samples is determined using the Slovin formula with a precision of 15%. Sugiyono (2017) describes the Slovin formula as follows:

$$n = \frac{N}{1+N(e)^2}$$

Where, n is number of respondents; N is the population (number of households); e is precision (error tolerance); and 1 is constanta. The sample in this study is homogeneous, because the entire population is shrimp farmers whose lives are directly adjacent to the mangrove forest, so the number of samples used can represent the actual situation. According to Sumargo (2020), the more homogeneous the population, the fewer samples are needed. Kwak and Kim (2017) have proven that a minimum sample size of 30 respondents is the golden rule to fulfill a normal distribution.

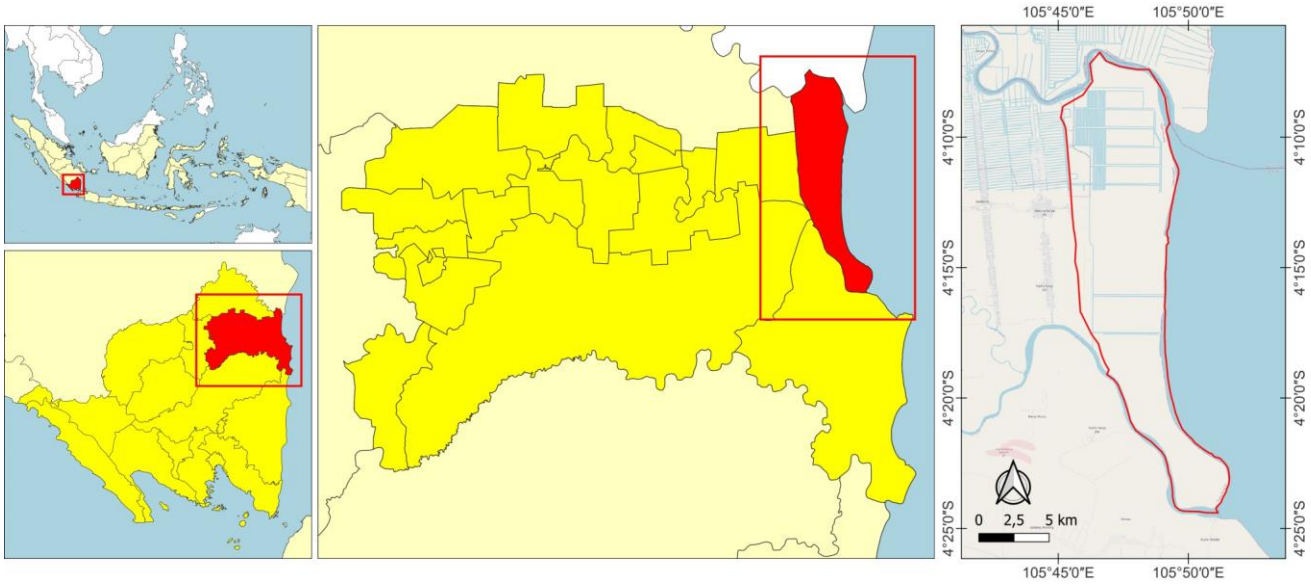



**Figure 1.** Research location in East Rawajitu Sub-district, Tulang Bawang District, Lampung Province, Indonesia

In addition, the sample was determined by purposive sampling of key informants with the criteria that respondents understood the problem and could make decisions directly related to mangrove ecosystem management. Based on these criteria, the key informants in this study consisted of five respondents: the village head, the chairman of the mangrove group, the *Badan Pengurus Infra* (BPI), *Badan Pengurus Pusat Perhimpunan Petambak Plasma Udang Windu* (BPP P3UW), and the Lampung Province Marine and Fisheries Service. Thus, the total number of respondents in this study was 87 respondents.

**Data analysis**

The sustainability of mangrove ecosystem management was analyzed using a Multidimensional Scaling (MDS) approach using Rapid Appraisal for Fisheries (RAPFISH) software. This method is done by determining the attributes of each dimension that can represent the sustainability of mangrove ecosystem management. Determination of dimensions and attributes that affect the sustainability of mangrove ecosystem management is determined based on regulatory reviews, expert judgments such as practitioners and academics, and literature studies (Melo et al. 2020).

This study uses four sustainability dimensions: ecological, economic, social, and institutional. Each attribute will be assigned a value according to predetermined criteria. The value of each attribute describes the condition of the sustainability of mangrove ecosystem management. The "bad" value reflects the most unfavorable conditions in management, while the "good" value reflects the most favourable conditions in resource management. Each ecological, economic, and social dimension consists of seven attributes, while the institutional dimension comprises six attributes that most influence the sustainability of mangrove ecosystem management (Table 1).

The data obtained from each attribute was then analyzed using RAPFISH software to determine the sustainability status of mangrove ecosystem management. The determination of sustainability status is divided into four categories. Status results describe the sustainability of each dimension studied on a scale of 0 to 100 (Table 2).

In the next stage, a sensitivity analysis (leverage of attributes) was carried out to see which attributes were the most sensitive in contributing to the sustainability index at the research site. Each dimension requires an anomaly analysis which indicates the sensitivity of each attribute in each dimension. In this study, the leverage factor was examined from the RAPFISH analysis, especially from the highest value of Root Mean Square (RMS) for each dimension of sustainability. The attribute with the highest value represents the important attribute in the sustainability index of each dimension. Then, based on the priority of the most sensitive attributes, managerial implications or strategies for managing mangrove ecosystems in a sustainable manner can be proposed.

The confidence level in the sustainability index's value for each dimension and multidimensional was analyzed using Monte Carlo analysis. This analysis aims to see the effect of scoring errors on each attribute of each dimension, the effect of variations in scoring, the stability of the MDS analysis process, data entry errors or missing data, and too high "*stress*" values (Muksin et al. 2021). If the difference between the Monte Carlo sustainability index and the MDS sustainability index is less than 1, the error effect in the analysis is small. Therefore, the smaller the difference between the sustainability index and the simulation on Monte Carlo, the more accurate the results will be (Fauzi and Anna 2005). The difference between MDS and Monte Carlo will show the confidence interval of the results of the sustainability index values for each dimension of mangrove management.

**Table 1.** Attributes of each sustainability dimension

| Dimension | Attributes |
|---|---|
| Ecology | Mangrove pressure |
| | Density of mangroves |
| | Mangrove rehabilitation |
| | Seashore abrasion |
| | Environmental sanitation |
| | Groundwater utilization |
| | Mangrove zoning |
| Social | Community knowledge |
| | Community participation |
| | Attention researchers |
| | Community education level |
| | Social conflict |
| | Public awareness |
| | The role of mangrove groups |
| Economy | Community utilization of mangrove ecosystem products |
| | Mangrove ecosystem management plan |
| | Business actors in the mangrove sector |
| | Community income |
| | Funding support from Corporate Social Responsibility (CSR) |
| | Mangrove accessibility |
| | Government budget |
| Institutional | Coordination between stakeholders |
| | Local government commitment to conservation |
| | Involvement of community institutions |
| | Availability of extension workers |
| | The legality of mangrove areas |
| | Availability of formal regulations for mangrove ecosystem management |

**Table 2.** Category of sustainability status of mangrove ecosystem management

| Index value | Category |
|---|---|
| <25 | Not sustainable |
| 26-50 | Less sustainable |
| 51-75 | Quite sustainable |
| 76-100 | Sustainable |

Source: Pitcher and Preikshot (2001)

The statistical parameters used to determine the feasibility of the study results in the mangrove forest of East Rawajitu Sub-district are the stress value and $R^2$. These two parameters determine whether or not adding attributes to each dimension is necessary so that it can reflect that the dimensions studied are close to the actual conditions. According to Kavanagh and Pitcher (2004) the 'goodness of fit' in the MDS calculation is indicated by the magnitude of the stress value, whereas the validity of the model is indicated by the magnitude of the coefficient of determination ($R^2$). The analysis results that can present the model well are indicated by the stress value below 0.25 and $R^2$, which is close to 1 or 100%.

## RESULTS AND DISCUSSION

### Ecological dimension

The ecological dimension is used to describe the good and bad conditions of the mangrove environment. The sustainability status of mangrove ecosystem management in this dimension is determined by seven attributes viz., (i) pressure on mangrove land; (ii) mangrove density; (iii) mangrove zoning; (iv) seashore abrasion; (v) mangrove rehabilitation; (vi) environmental sanitation; and (vii) utilization of groundwater. The results of the RAPFISH ordination analysis show that the sustainability index value on the ecological dimension is 38.32, meaning that it is included in the less sustainable category (Figure 2A). This finding reflects that the management of mangrove ecosystems from an ecological perspective is experiencing various problems which are feared to disrupt the shrimp cultivation process and threaten the existence of the mangrove ecosystem itself.

The leverage factor analysis confirms that among the seven attributes of ecological dimension, two attributes are most sensitive to the sustainability index value, namely seashore abrasion (RMS = 4.71) and mangrove rehabilitation (RMS = 4.57) (Figure 2B). Since the extent of mangrove forest in East Rawajitu Sub-district has witnessed significant decrease from 7,529 ha to 5,551 ha between 2000 and 2020 (Hartati 2022), it is anticipated that seashore abrasion could be the major causes for the loss of mangrove forest. Hartati (2022) has also noted that aggressive abrasion in East Rawajitu Sub-district causes a reduction in the green belt formed by mangroves for about 2 km, resulting in a change in the coastline.

In East Rawajitu Sub-district, mangrove rehabilitation efforts have actually been carried out by the local community. However, the results rare not significant due to the severe damage caused by the impulsive actions of the people who turned mangrove land into shrimp ponds and carried out logging. Earlier, Rudianto et al. (2020) has also stated that community members in East Rawajitu Sub-district uses wood from felled mangroves for the purposes of building roads and bridges.

The wider level of damage causes the spatial and temporal multifunctionality of mangroves to shrink sharply. Kusumaningtyas et al. (2019) stated that degraded mangroves will not be able to maintain their surface elevation relative to seawater, resulting in increased abrasion. This extreme condition is a serious problem and must be addressed immediately so that the existence of mangrove forests can be well maintained (Lukman et al. 2021). Therefore, an agreement between stakeholders and appropriate management efforts is needed to build a sustainable mangrove forest.

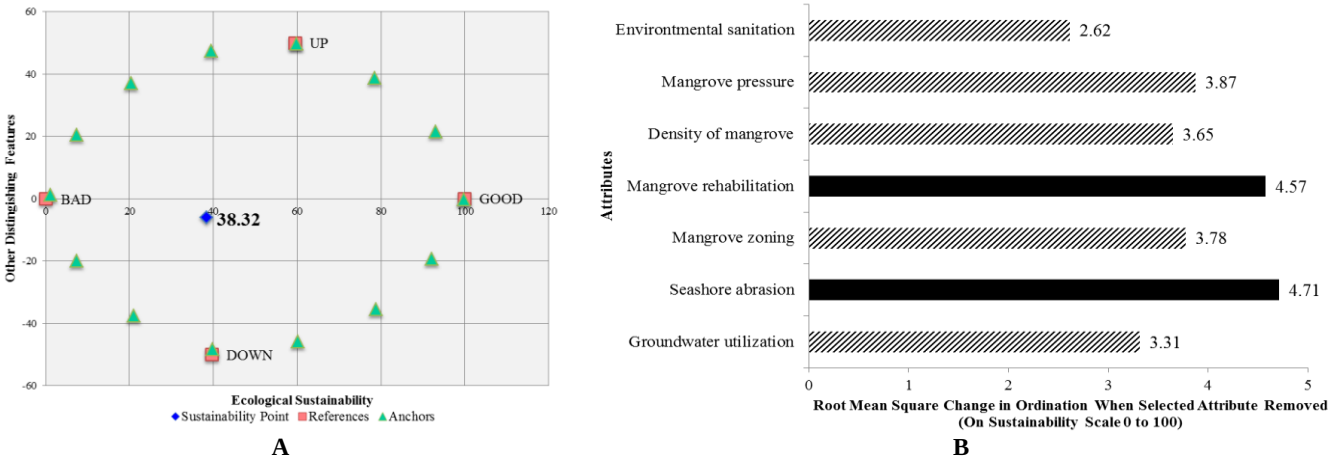



**Figure 2.** A. RAPFISH ordination ecological dimension, B. Leverage of the attributes in ecological dimension

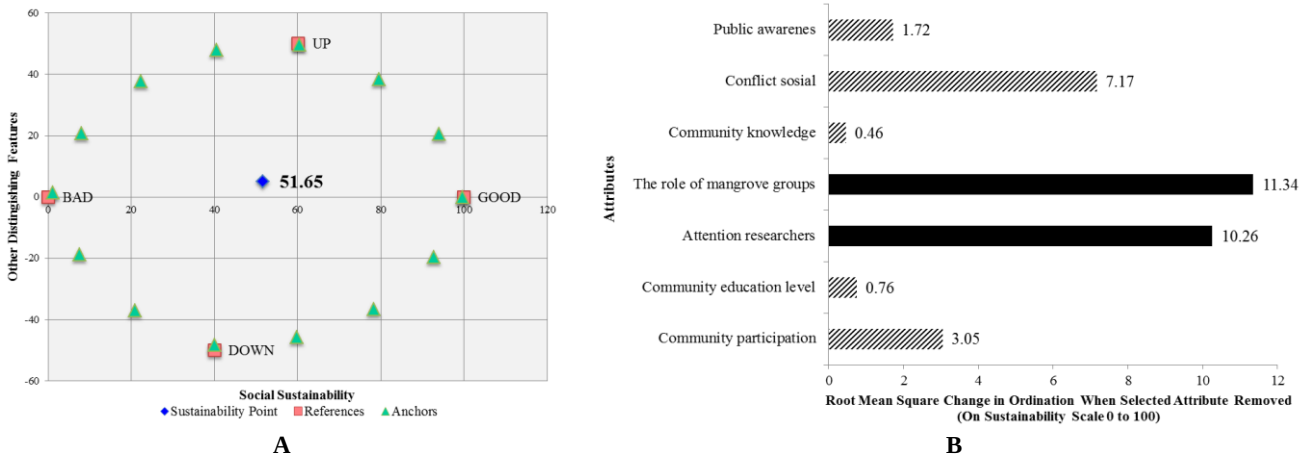



**Figure 3.** A. RAPFISH ordination social dimension, B. Leverage of the attributes in social dimension

**Social dimension**

The social dimension relates to the interaction between community life and the existence of the mangrove ecosystem. The social activities of local communities largely determine the sustainability of an ecosystem. Sustainability status of the mangrove ecosystem management on the social dimension is determined by seven attributes viz., (i) community knowledge; (ii) community participation; (iii) the researcher's attention; (iv) the level of public education; (v) social conflict; (vi) public awareness; and (vii) the role of mangrove groups. The results of the RAPFISH ordination show that the value of the sustainability index of mangrove ecosystem on the social dimension is 51.65, so it is included in the category of quite sustainable (Figure 3A). It shows that the sensitive attributes in this dimension still require maintenance and management at a sustainable level. There are two attributes that are most sensitive to the social dimension viz., the role of mangrove groups (RMS = 11.34) and researcher's attention to mangroves (RMS = 10.26) (Figure 3B).

The success of mangrove rehabilitation, which is still far from expectations, is a major concern for the local community in East Rawajitu Sub-district, so the community formed a mangrove group called the Pelangi Sentosa Group (Hartati 2022). The community living in Bumi Sentosa Village initiated this group on July 13, 2020. The group's management structure comprises a chairman, secretary, treasurer, and 37 members. The group is active in procuring seeds and planting, maintaining, and caring the rehabilitated mangrove areas.

The type of seed (propagules) collected and cultivated by the Pelangi Sentosa Mangrove Group is *Rhizophora mucronata*. Procurement of seeds is carried out as an effort to increase the mangrove growing area and embroider dead mangroves. However, the mangrove seedlings cultivated by this group are relatively few, so they still need the help of seeds from any party. In December 2021, the community in Bumi Sentosa Village planted 15,000 mangrove seedlings along the shoreline and canals. The activity was initiated by the Head of the Pelangi Sentosa Mangrove Group's head, which involved the community's participation and BPP P3UW. Mangrove planting activities cost as much as IDR 20,000,000. The funds came from cash labor-intensive amounting to IDR 15,000,000 and village funds of IDR 5,000,000.

The high public awareness on environment has encouraged concrete actions in capital activities, planting, and caring for mangroves. Local people think that planting mangroves is the same as planting life. However, the success rate of the rehabilitation program being pursued is still far from expectations. Factors that cause these problems are environmental conditions that have changed, mistakes in choosing a location, lack of preparation and experience, weak coordination, and lack of clarity in spatial planning. Therefore, the existing mangrove groups still need the role of researchers and academics to provide intensive assistance, so that, the mangrove rehabilitation currently being pursued produces maximum results.

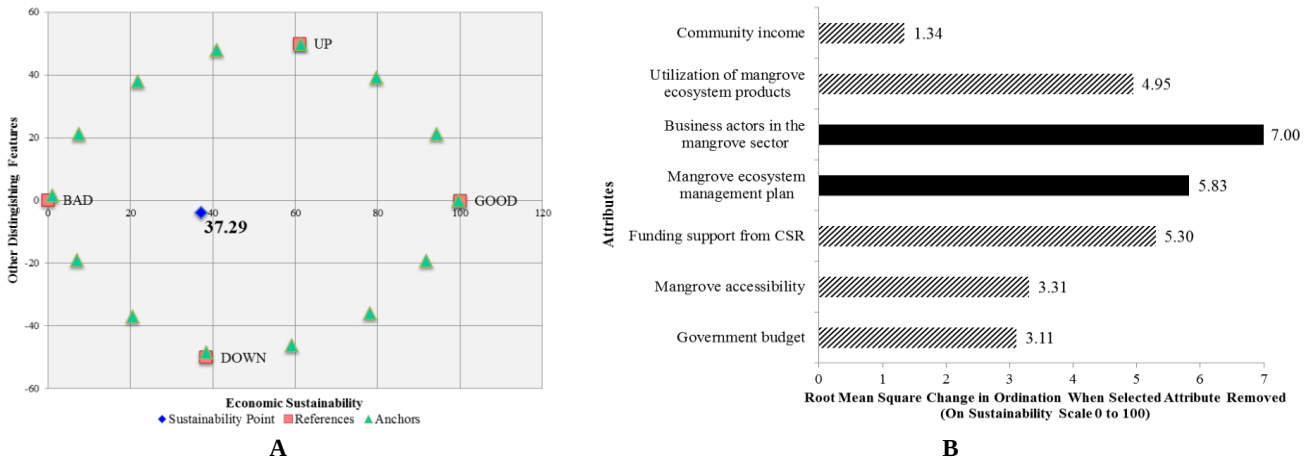
According to Dencer-Brown (2022), researchers and other academics act as sources of scientific information in mangrove management, so their existence is able to open up public insight to create innovations that support mangrove ecosystem management programs. Researchers and academics are facilitators who can provide comprehensive assistance and guidance to the community. Treviño's (2022) research reveals that the community is the subject who best understands the surrounding natural conditions, so the management of mangrove ecosystems must be carried out in a complex manner by prioritizing the participation of local communities. Assistance and community development in mangrove conservation efforts can control the level of area degradation as a buffer for coastal areas and improve people's living standards in an integrated and sustainable manner (Alves et al. 2020; Swangjang and Kornpiphat 2021; Buncag 2022).

**Economic dimension**

The existence of the mangrove ecosystem affects the economy of the surrounding community through the potential of existing resources. The location of mangrove forests adjacent to residential areas causes the community to feel the economic benefits directly or indirectly. The economic dimension is everything related to meeting the community's needs for survival. Economic activities carried out by the community on the mangrove ecosystem can be detrimental if they are not regulated in harmony with the environment. Therefore, the utilization of the mangrove ecosystem must align with its management to be sustainable.

Determination of the sustainability status of mangrove ecosystem management on the economic dimension is based on seven attributes viz., (i) mangrove accessibility; (ii) community income; (iii) utilization of mangrove ecosystem products; (iv) business actors in the mangrove sector; (v) mangrove ecosystem management plan; (vi) government budget; and (vii) financial support from Corporate Social Responsibility (CSR). The results of the RAPFISH ordination analysis show that the value of the sustainability index on the economic dimension is 37.29 (Figure 4A). It illustrates that the management of mangrove ecosystems in the economic dimension is included in the less sustainable category. Therefore, the value of the sustainability index of the economic dimension needs to be increased through sensitive attributes with leverage of attributes analysis. There are two attributes that are most sensitive to the economic dimension viz., business actors in the mangrove sector (RMS = 7.00) and mangrove ecosystem management plan (RMS = 5.83) (Figure 4B).

In East Rawajitu Sub-district mangrove forests is used as green belt. However, people often use mangrove forests to benefit shrimp farming. Research by Do and Thuy (2022) has revealed that the productivity of shrimp pond cultivation would decrease if there were no mangrove ecosystems. The mangrove ecosystem can become a source of additional income for the local community by developing its potential. On January 13, 2021, BPP P3UW formed a wing of a women's organization called *Ikatan Istri-istri Petambak Dipasena* (ISTANA). The organization provides opportunities for women farmers to develop their potential. The wives of farmers who are members of the ISTANA Group are expected to be able to become motivators that lead to the development of productivity and creativity for the betterment of society. However, the group has never developed the potential of the mangrove ecosystem into products that have a selling value. According to Anhar (2018), the involvement of women in mangrove management allows for more inclusive management.




A B

**Figure 4.** A. RAPFISH ordination economic dimension, B. Leverage of the attributes in economic dimension

Utilizing mangroves for processed products can increase local communities' productivity, impacting the economy and mangrove sustainability. This statement is in agreement with the research of Razafindratsima et al. (2021), which states that the diversification of mangrove-based food products not only reduces the burden of environmental degradation but also further sharpens the ecological and economic functions of mangroves. However, careful planning related to utilizing the potential of mangroves into products with high selling value is very much needed to keep paying attention to environmental aspects. Singgalen et al. (2020) state that the optimal and environmentally friendly form of resource utilization is an effort to preserve natural resources.

**Institutional dimension**

The institutional dimension plays an important role as an association and is responsible for facilitating and developing community participation in the sustainable management of mangrove ecosystems. Community institutions function as a forum to produce suggestions and make decisions through communication, coordination, and interaction between the community, government, and other private institutions (Febryano et al. 2014). Good coordination between institutions and the community will positively impact the management of mangrove ecosystems. The sustainability status of the mangrove ecosystem management on the institutional dimension is based on six attributes, namely: (i) coordination between stakeholders; (ii) local government commitment to conservation; (iii) involvement of community institutions; (iv) availability of formal regulations; (v) the capacity of the implementing apparatus; (vi) area legality.

The results of the RAPFISH ordination analysis show that the value of the institutional dimension sustainability index is 29.49, so it is included in the category of less sustainable (Figure 5A). Therefore, it is necessary to increase the value of the sustainability index by selecting the most sensitive attributes through leverage of attributes analysis of institutional dimensions. Based on the analysis of the leverage of attributes, two attributes are most sensitive to the institutional dimension viz., coordination between stakeholders (RMS = 8.09) and the availability of formal regulations (RMS = 6.53) (Figure 5B).

The absence of formal regulations and strict sanctions related to managing mangrove ecosystems causes people to be more impulsive in utilizing their resources. According to Firdaus et al. (2021), the availability of formal regulations is very important for all stakeholders, including the community, to have strong guidelines for managing mangrove ecosystems. It is in agreement with Kaskoyo et al. (2017), who states that environmental policies will result in better decisions because the community has information that can be used to make decisions.

Formal regulations function as policies that can determine the direction and respond to various community interests so that people will be more daring to act in preserving their resources (Seering et al. 2019; Tresiana et al. 2022). In addition, formal regulations are also the basis for managing mangrove ecosystems, although later in their work, they are non-formal. Therefore, there must be good coordination between stakeholders in making formal regulations and their implementation.

Coordination between stakeholders is important to optimize the management of mangrove ecosystems sustainably. According to Suharti et al. (2021), a harmonious collaboration between stakeholders in mangrove ecosystem management must be built for sustainable management of mangrove ecosystem. Arifanti et al. (2022) also emphasized that mangrove ecosystem management actions need to be supported by all stakeholders at all levels so that their sustainability can be guaranteed. In the case of a government that deals with many sectors, there must be good coordination among stakeholders regarding the duties, authorities, and responsibilities for horizontal and vertical sector integration.

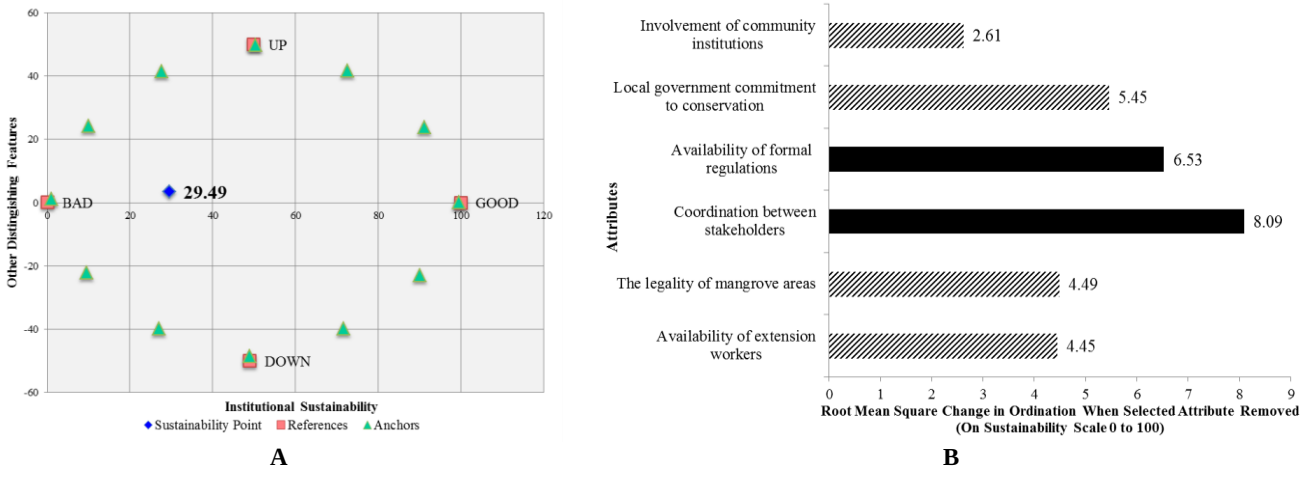



**Figure 5.** A. RAPFISH ordination institutional dimensions, B. Leverage of the attributes in institutional dimension

**Multidimensional sustainability status**

Multidimensional analysis has been conducted by combining all dimensions including ecological, social, economic and institutional. Accordingly, a total of 27 attributes has been used to determine the sustainability status of mangrove ecosystem management in this study. Based on the result of the analysis, multidimensional sustainability index value is 43.01, suggesting that the mangrove ecosystems management in East Rawajitu Sub-district is generally included in the less sustainable category (Figure 6A).

The sustainability index value in the four dimensions can be visualized in a kite diagram (Figure 6B). Kite diagrams/radar diagrams describe the status of sustainability in an integrated manner between dimensions. The closer the analysis result is to the zero point, the more it shows a low level of sustainability. On the other hand, the farther the distance between the analysis results and the zero point, the higher the level of sustainability (Fauzi and Anna 2005).

The highest sustainability index value is found in the social dimension (51.65), while the lowest is found in the institutional dimension (29.49). The ecological, economic, and institutional dimensions are included in the less sustainable category because they have an index value that lies between 25-50, while the social dimension is included in the fairly sustainable category because it has an index value that lies between 51-75. All dimensions included in the less sustainable category require appropriate efforts to increase the sustainability value index. In contrast, the dimensions in the moderately sustainable category must be maintained so that their sustainability value index does not decrease and continues to increase (Patawari et al. 2022).

Based on the results of the Monte Carlo analysis at a 95% confidence interval with 25 repetitions, it shows that there is no significant difference in the value of the sustainability index value from the MDS analysis and the Monte Carlo analysis. The difference between the MDS value and the Monte Carlo value results in a value of less than 1, which means that the analysis conducted on the value of the sustainability index of mangrove ecosystem management has a high confidence level (Table 3). The results in line with Adiga et al. (2016), which state that the difference in the low sustainability index value (<5%) between the results of the MDS and Monte Carlo analysis proves that errors that occur will not change the sustainability index value of each dimension, so that the effect of errors can be avoided. Therefore, the method developed in this study can be used as an evaluation tool to assess systemically, quickly, objectively, and quantify the sustainability of mangrove ecosystem management in an area.

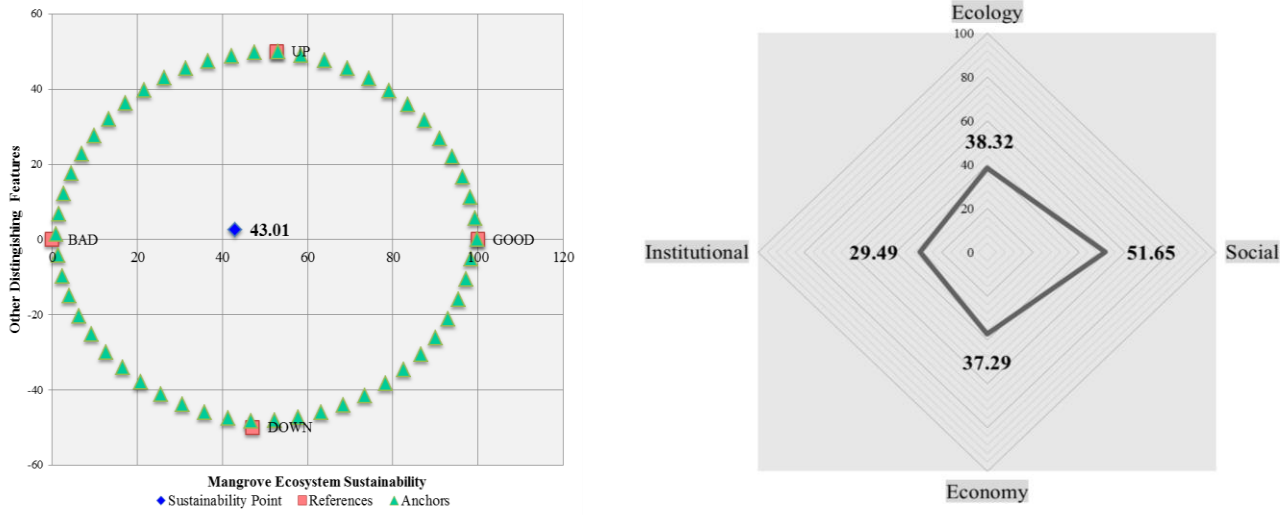
In this study, each dimension has a stress value of less than 0.25, meaning that the stress value in the analysis using the MDS method is sufficient. It shows the accuracy of the point configuration or goodness of fit model built for sustainability can represent a good model. The smaller the stress value obtained, the better the quality of the analysis results. The $R^2$ value of each dimension in this study is close to 1. Generally, if the value of $R^2$ gets closer to 1 indicates that the quality of the analysis results gets better. Hence, all indicators studied in the present study have a big enough role in explaining diversity (Table 4).

**Table 3.** Results of the Monte Carlo analysis for the value of the sustainability index on each dimension

| Dimension | MDS | Monte Carlo | Difference |
|---|---|---|---|
| Ecology | 38.32 | 39.24 | 0.92 |
| Social | 51.65 | 51.11 | 0.54 |
| Economy | 37.29 | 37.92 | 0.63 |
| Institutional | 29.49 | 30.36 | 0.87 |

**Table 4.** Stress and $R^2$ values for each dimension of mangrove ecosystem sustainability

| Dimension | Stress | $R^2$ | Number of iterations |
|---|---|---|---|
| Ecology | 0.15 | 0.94 | 2 |
| Social | 0.14 | 0.94 | 2 |
| Economy | 0.14 | 0.94 | 2 |
| Institutional | 0.15 | 0.94 | 2 |




A B

**Figure 6.** A. Multidimensional RAPFISH ordination, B. Kite diagram of the sustainability mangrove ecosystem management

**Table 5.** Leverage factors that are a priority in determining the mangrove ecosystem management strategy in East Rawajitu Sub-district, Tulang Bawang District, Lampung, Indonesia

| Priority dimension | Ordination value | Leverage factor | RMS |
|---|---|---|---|
| Institutional | 29.49 | 1. Coordination between stakeholders | 8.09 |
| | | 2. Availability of formal regulations | 6.53 |
| Economy | 37.29 | 1. Business actors in the mangrove sector | 7.00 |
| | | 2. Mangrove ecosystem management plan | 5.83 |
| Ecology | 38.32 | 1. Seashore abrasion | 4.71 |
| | | 2. Mangrove rehabilitation | 4.57 |
| Social | 51.65 | 1. The role of mangrove groups | 11.34 |
| | | 2. Attention researchers | 10.26 |

**Table 6.** Strategy and policy direction for mangrove ecosystem management in East Rawajitu Sub-district, Tulang Bawang District, Lampung, Indonesia

| Dimension | Strategy | Policy direction |
|---|---|---|
| Institutional | • Improve coordination between stakeholders horizontally or vertically in protecting mangrove ecosystems | • Involve all stakeholders in planning and implementing programs for the management and conservation of mangrove ecosystems<br>• Creating integrated and integrated regulations so that management activities are more optimal, comprehensive, and policy synergy between sectors in managing mangrove ecosystems can be carried out both at the central and regional levels.<br>• Determine the legality of mangrove areas following applicable regulations<br>• Improving institutional effectiveness through outreach and outreach to the community |
| | • Creating an integrated formal regulation related to mangrove ecosystem management | • Formal regulations can be drawn up by referring to existing regulations, namely:<br>• Law Number 5 of 1990 concerns the conservation of living natural resources and their ecosystems.<br>• Law Number 1 of 2014 concerning amendments to Law Number 27 of 2007 concerning the management of first-aid areas<br>• Presidential Regulation Number 73 of 2012 concerning the National Strategy for Mangrove Ecosystem Management.<br>• Regulation of the Coordinating Minister for Economic Affairs Number 4 of 2017 concerning policies, strategies, programs, and performance indicators for managing national mangrove ecosystems.<br>• Lampung Province Regional Regulation Number 1 of 2018 concerning Rencana Zonasi Wilayah Pesisir dan Pulau-Pulau Kecil (RZWP3K) |
| Economy | • Increase human resource capacity | • Increase the productivity and creativity of the ISTANA group by utilizing the potential of mangroves into high-selling value products<br>• Facilitating community empowerment activities through counseling to the ISTANA group about the types and parts of mangroves that can be used to make processed products with high selling value.<br>• Conducting practice and mentoring related to how to process the potential of mangroves (fruit, leaves, and seeds) into high-selling value products that can be consumed and accepted by the wider community |
| | • Develop an integrated and integrated mangrove ecosystem management plan program | • Prepare proposals for the status of mangrove ecosystem management to policymakers at the local government level<br>• Create a master plan for mangrove ecosystem management<br>• Making the mangrove ecosystem an ecotourism area |
| Ecology | Carry out mangrove rehabilitation activities involving local communities to reduce abrasion | • Identify suitable species for rehabilitation activities<br>• Increase the area and density of mangroves by planting in degraded areas<br>• Embroidering dead mangrove seedlings<br>• Conduct monitoring and evaluation |
| Social | • Increasing the role of mangrove groups in managing mangrove ecosystems | • Placing the community as the main actor in the management process starts from planning, procurement of seeds, seeding, planting, maintenance, and supervision, so the community is expected to have a sense of responsibility towards the environment. |
| | • Increase the attention of researchers | • Provide insight to the community regarding mangrove conservation<br>• Produce scientific papers that can be used as input for stakeholders in mangrove ecosystem management |

Based on the Monte Carlo analysis, the value of voltage and $R^2$ can be said that the analysis results are quite accurate and scientifically justified from the effect of scoring errors on each indicator, scoring variations due to differences of opinion, and errors in data entry. Thus, the parameters indicate that all the attributes used in analyzing the sustainability of mangrove ecosystem management in East Rawajitu Sub-district are good enough to explain the four analyzed management dimensions.

**Mangrove ecosystem management strategy**

Mangrove ecosystems are very vulnerable to environmental changes, so they are difficult to restore and require careful management. This ecosystem has a role in ecologically, socially, economically, and institutionally sustainable development (Wibowo et al. 2018). The basic objective of mangrove ecosystem management is to increase sustainable use by considering physical and non-physical aspects, conservation, rehabilitation, and involving several stakeholders. The large number of stakeholders involved has the potential to cause conflict, so sustainable mangrove management strategies become ineffective and constrained (Nijamdeen et al. 2022). Therefore, management must be carried out in an integrated and comprehensive manner and based on sustainable management principles, namely maintaining the sustainability of natural resources and achieving community welfare without compromising the fulfillment of the needs of the next generation.

An effective mangrove ecosystem management strategy must be carried out integrally and holistically based on ecological, social, economic, and institutional aspects. The results of the analysis of the sustainability of the mangrove ecosystem in East Rawajitu Sub-district show that three dimensions are fall in the 'less sustainable' category, namely the ecological, economic, and institutional dimensions. In contrast, the social dimension is fall in the 'quite sustainable' category. Therefore, a management strategy is needed to prioritize the less sustainable dimensions and the sensitive attributes that are the levers. The priority of mangrove ecosystem management based on the level of sustainability that needs to get more attention with each attribute sequentially (Table 5). The condition of the attribute score and sensitivity value obtained from each dimension is used to determine the priority of mangrove ecosystem management.

Eight sensitive attributes become priorities in formulating strategies to improve the sustainability of mangrove ecosystem management. The most sensitive dimension to mangrove ecosystem management is the institutional dimension, so this dimension becomes a priority in determining the mangrove ecosystem management strategy. The results of the management priorities based on analyzing the sustainability of the mangrove ecosystem in East Rawajitu Sub-district were then developed to develop several strategic recommendations (Table 6).

In conclusion, the status of mangrove ecosystem management in East Rawajitu Sub-district is generally classified as less sustainable (index 43.01 out of 100). This status is caused by the low sustainability index in 3 of the 4 dimensions used, namely institutional (29.49); ecology (37.29); and economy (38.32) , while the status of mangrove ecosystem management on the social dimension is 'quite sustainable' with an index value of 51.65, so there is still hope to improve its sustainability. Therefore, the management of mangrove ecosystems requires policy intervention, especially on sensitive attributes. These attributes are critical for policy interventions, leading to sustainable management of mangrove ecosystems. Mangrove ecosystem management strategies that must be implemented include increasing coordination between stakeholders, creating formal regulations, increasing productivity and creativity of the ISTANA group, developing an integrated mangrove ecosystem management plan program, carrying out mangrove rehabilitation efforts, increasing the role of mangrove groups, and increasing the attention of researchers and academics.

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