Sustainability status of mangrove ecosystem management in Sungai Apit Subdistrict, Siak Regency, Indonesia

[1]Adriman, [1]Eko Prianto, [2]Romie Jhonnerie, [1]Nur El Fajri

[1] Aquatic Resources Management Department, Faculty of Fisheries and Marine Science, Riau University, Indonesia; [2] Fisheries Resources Utilization Department, Faculty of Fisheries and Marine Science, Riau University, Indonesia. Corresponding author: Adriman, adry04pku@yahoo.com

Abstract. The study aimed to determine the sustainability status of mangrove forest ecosystem management in Sungai Apit Subdistrict, Siak Regency, Riau Province, Indonesia. Data analysis used the multi-dimensional scaling (MDS) approach with the Rapid Appraisal-Index Sustainability of Mangrove Forest Management (Rap-Insus MFMAG) technique modified from the RAPFISH program. The results showed that the sustainability status of mangrove forest ecosystem management in Sungai Apit District according to each dimension were: the ecological dimension was sustainable (83.54), the socio-economic dimension was sustainable (69.08), the sociocultural dimension was sustainable (57, 54. 25), and the institutional dimension is highly sustainable (99.81). Likewise, multi-dimensionally, it is included in the "very sustainable" category (76.11). Fourteen sensitive attributes that affect the sustainability of the mangrove ecosystem management in the Sungai Apit Subdistrict, Siak Regency, were identified, which consist of two factors of ecological dimension, seven factors of economic dimension, four factors of sociocultural dimension, and one factor of institutional dimension.

Key Words: environmental management, forest, multi-dimensional scaling, Rapfish, sensitive attributes, Sustainable development.

Introduction. Sustainable development is a concept born from the world community's concern about environmental damage due to the excessive extraction of natural resources. This concept calls for long-term development to meet the needs of the present generation without compromising the ability of future generations to meet them (WCED 1987). According to Damai et al (2011), since the 1972 Stockholm declaration in the UN Conference on Human Environment to the Rio+20 Conference, various countries in the world, including Indonesia, have tried to implement the concept of sustainable development. In Indonesia, implementing the concept of sustainable development in managing mangrove forest ecosystems has its challenges. The interaction between socio-economic activities, spatial planning, and population causes environmental problems in coastal areas to increase.

Samekto (2005) describes that changes in the social order, both on a global and local scale, have affected the implementation power of the concept of sustainable development itself. In the local context, reforms, and the enactment of a decentralized system of power have strengthened the economic growth paradigm in the regions so it often ignores the principles of sustainable development.

The concept of sustainability is complex, so sustainability is multi-dimensional and multi-interpreted. According to Heal (1998) in Fauzi (2004), the concept of sustainability contains at least two dimensions: the first is the time dimension because sustainability is only what will happen. The second is the interaction dimension between the economic system and natural resource systems, and the environment.

Likewise, in managing mangrove forest ecosystems in Sungai Apit Subdistrict, a sustainable management approach is needed, where there is a link between various

dimensions, namely ecological, economic, social, technological, and institutional dimensions. The mangrove forest ecosystem in Sungai Apit Subdistrict has been widely used to meet the needs of people's lives, such as settlements, ports, agriculture, and mangrove tourism areas. But the mangrove ecosystem's many functions are no less important, such as fisheries, coastal protection, recreation areas and so on.

Sungai Apit Subdistrict is the only Siak Regency subdistrict with an extensive mangrove forest. It is estimated that the mangrove forest area in Sungai Apit Subdistrict is around 511.4 hectares spread over nine villages (Warningsih et al 2021). Since 2014, the local community has become increasingly aware of the importance of the mangrove forest ecosystem. One form of public awareness is the emergence of mangrove conservation groups in each village. There are eight mangrove conservation groups in each village in Sungai Apit Subdistrict. For example, the Mangrove Nursery and Conservation Group in Mengkap Village, the Mangrove Conservation Group in Rawa Mekar Jaya Village, the Sungai Kayu Ara Village Conservation Group, and other villages. According to Adriman et al (2020, 2022), the management of mangrove ecosystems in each of these conservation groups has not considered sustainability aspects, namely ecological, socio-economic, sociocultural, and institutional aspects.

To realize the concept of sustainable development in managing mangrove forest ecosystems in Sungai Apit District, it is necessary to analyze its sustainability status. This is important to be a basis for formulating policy strategies implemented in future management. Knowledge of the sustainability status will make it easier to improve the performance of sensitive indicators in supporting the management of mangrove forest ecosystems more sustainably.

Research on the sustainability status of mangrove forest management in Sungai Apit Subdistrict has never been reported before. Assessment of the sustainability status of natural resource management can be done quickly (rapid appraisal) based on multi-dimensional scaling (MDS) analysis (Kavanagh & Pitcher 2004; Fauzi & Anna 2005). This method has also been reported to assess the sustainability of mangrove forest management in West Seram (Pattimahu et al 2010), mangrove forest management on Kangean Island, East Java Province (Kuvaini et al 2019), and coral reef management in the East Bintan MPA (Adriman 2012). This study aims to determine the sustainability status of mangrove forest ecosystem management in Sungai Apit Subdistrict, Siak Regency, Riau Province.

Material and Method

Description of the study sites. This research was conducted from May to September 2022 in Sungai Apit Subdistrict, Siak Regency, Riau Province (Figure 1).

Data types and sources. The data used in this study include primary data and secondary data. Primary data, such as the biophysical mangrove forest ecosystem, was obtained and collected directly through field observations, while some economic, social, and institutional parameters were obtained through interviews with the community and community leaders (key informants). The secondary data collection was carried out through a literature study from various documents in several related agencies and the results of previous research.

Collection of data technique. The data to be collected is biophysical data on mangrove ecosystems and socio-economic, sociocultural, and institutional data in mangrove management.

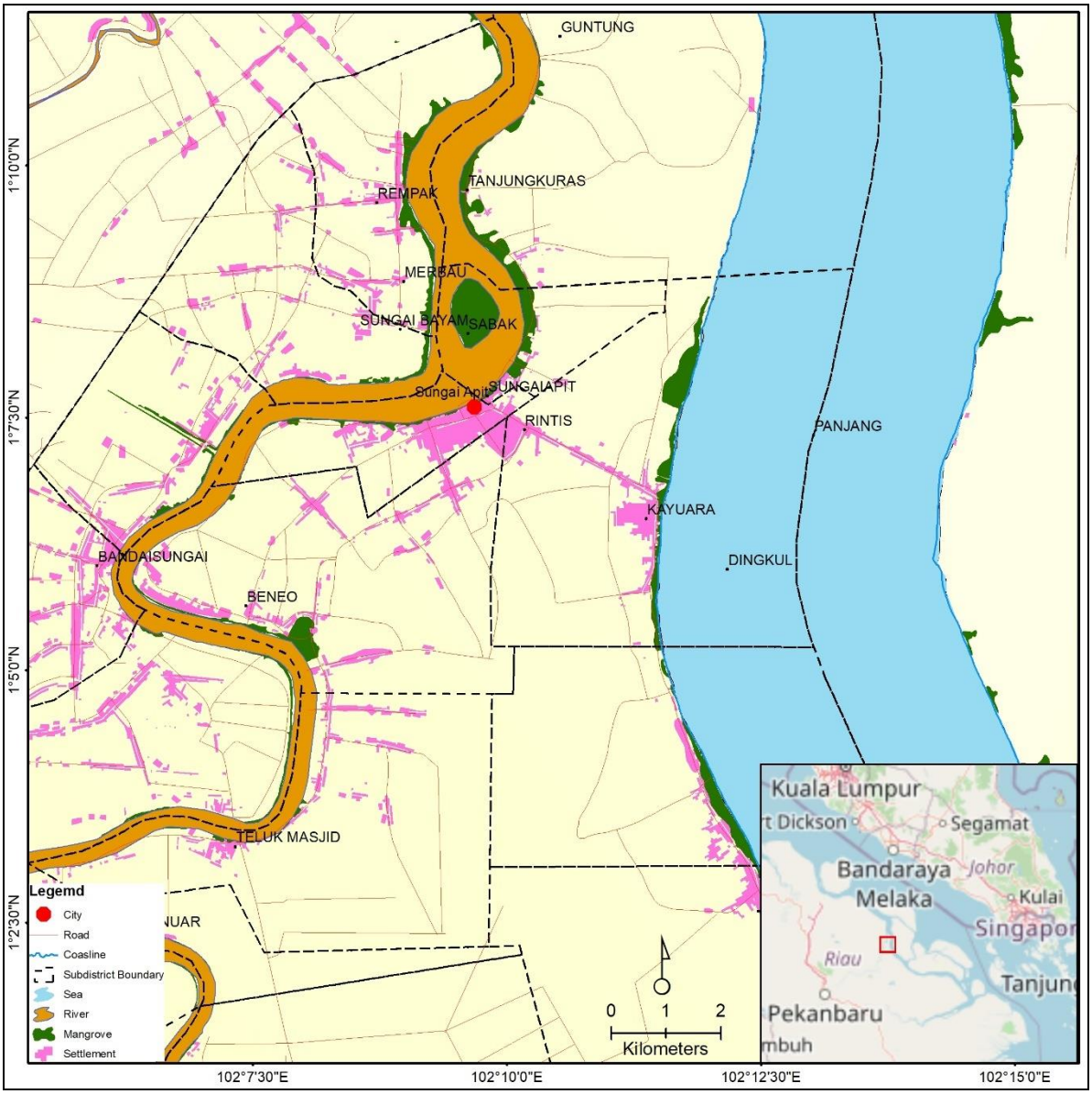

Figure 1. The sampling site at Sungai Apit Subdistrict (map generated using QGIS 3.20).

Biophysical data collection. Mangrove ecosystem biophysical data will be collected in several (villages) by purposive sampling, which is based on a conceptual approach by looking at the possible distribution of mangrove characteristics. In this study, five observation stations and mangrove observation stations were set, which were distributed in 5 villages from nine existing villages. The location of each station is determined after a preliminary survey. Observation of the mangrove ecosystem using the line transect method refers to Bengen (2001) with the following procedure:

1. At each station, a line transect is drawn from the sea to the land (perpendicular to the coastline along the mangrove forest's zoning).
2. In each mangrove forest zone along the line transect, 3 (three) square plots are laid out with a size of 10x10 m^2, 3 (three) plots placed alternately.
3. Using the mangrove introduction guidebook by Rusila et al (2006), the mangrove species in each sample plot are identified, and then the number of individuals for each species is calculated.
4. What was observed during the study were all individual tree-level mangrove stands found in each station.

Socio-economic and sociocultural data collection. Socio-economic and sociocultural data was collected through interviews with a questionnaire guide. The target community who become respondents are people who live around mangrove forests and people whose family economic activities are related to mangrove forests. Respondents were determined by purposive random sampling (Walpole 1995 in Adriman 2012). As many as 5 to 10 respondents were assigned to each observation location. In addition, in-depth interviews (deep interviews) with 16 informal and 48 formal figures as key respondents (key informants) were also conducted. The community leaders interviewed include subdistrict officials, village heads, heads of mangrove conservation groups, youth leaders, and local traditional leaders. A focus group discussion (FGD) was conducted to collect information and collective aspirations.

Sustainability analysis. Analysis of the sustainability status of mangrove debt ecosystem management was carried out using the multi-dimensional scaling (MDS) approach using the Rapid Appraisal-Index Sustainability of Mangrove Forest Management (Rap-Insus MFMAG) technique modified from the RAPFISH program (Kavanagh & Pitcher 2004; Fauzi & Anna 2002). The MDS method is a computer-based statistical analysis technique using SPSS software, which performs a more straightforward transformation of each dimension and multi-dimensional (Fauzi & Anna 2002). This analysis is carried out through several stages, including:

1. Determination of sustainable attributes of mangrove ecosystem management in this study includes four dimensions: ecological, economic, sociocultural, and institutional. The dimensions and attributes of each dimension are presented in Table 1.
2. Assessment of each attribute on an ordinal scale based on the sustainability criteria of each dimension.
3. Preparation of the index and sustainability status.

Table 1

Dimensions and attributes of sustainable forest ecosystem management mangroves in Sungai Apit Subdistrict

Dimension	*Attribute*
Ecology	(1) species diversity (2) dominant species (3) substrate type (4) availability of mangrove seeds (5) beach abrasion rate (6) header density (7) usage type (8) mangrove rehabilitation (9) substrate organic matter content
Economic	(1) dependence on mangroves for livelihood (2) the average income of the community to district minimum wage (DMW) (3) the average income of the community from use of mangrove ecosystems (4) CSR funding support (5) the existence of a market for mangrove forest products (6) direct benefits of mangrove (7) accessibility of mangrove areas (8) sightseeing visits
Social	(1) community participation in management mangrove forest (2) education on mangrove ecosystems by mangrove forest management

	(3) community knowledge about mangrove forest (4) social conflict (5) community education level (6) social impact of mangrove existence towards society (7) public awareness
Institutional	(1) formation of mangrove conservation groups (2) availability of law enforcement personnel on site (3) involvement of community institutions in mangrove forest management (4) Law enforcement (5) availability of forest management regulations mangrove (6) the legality of the mangrove forest area (7) coordination between stakeholders (8) community participation (9) role models

Each attribute in each dimension is given a score based on the scientific judgment of the scorer. The score ranges from 0–5 depending on the state of each attribute, which is defined as ranging from bad to good. The score results for each attribute are analyzed with multi-dimensional analysis to determine one or several points that reflect the position of the sustainability of the development of sustainable management being studied relative to two reference points, namely good points, and bad points. The definitive score is the mode value, which is analyzed to determine points that reflect the sustainability position of the system under study relative to the good and bad points using the MDS statistical ordinance technique. The estimated score for each dimension is expressed on a scale of worst (bad) 0% to best (good) 100%) (Fauzi & Anna 2002). The score value, which is the sustainability index value of each dimension, can be seen in Table 2.

Table 2

Category of sustainability status of mangrove forest ecosystem management, Sungai Apit Subdistrict

Index value	*Category*
0.00-25.00	Bad (unsustainable)
25.01-50.00	Less (less sustainable)
50.01-75.00	Enough (sufficiently sustainable)
75.01-100.00	Good (very sustainable)

Source: Fauzi and Ana (2005)

Through the MDS method, the position of the sustainability point can be visualized through the horizontal and vertical axes. With the rotation process, the position of the point can be visualized on the horizontal axis with the sustainability index value given a score of 0% (bad) to 100% (good). The illustration of the results of the ordinance of the sustainability index values is shown in Figure 2.

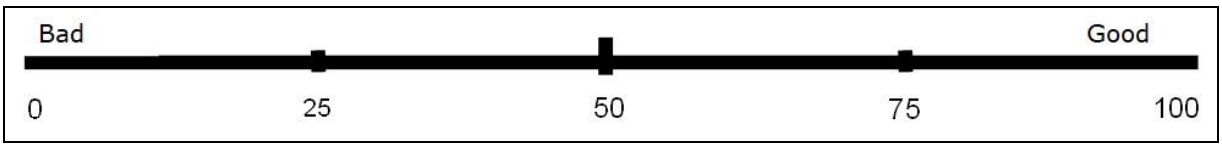

Figure 2. Illustration of sustainability index value in ordination scale.

In addition, the sustainability index value of each dimension can be visualized together in a kite diagram. The kite diagram is symmetrically determined by the index of each dimension (ecological, economic, sociocultural, and institutional). Besides, the index

value of each dimension can be displayed on the diagram. The sustainability kite diagram is presented in Figure 3.

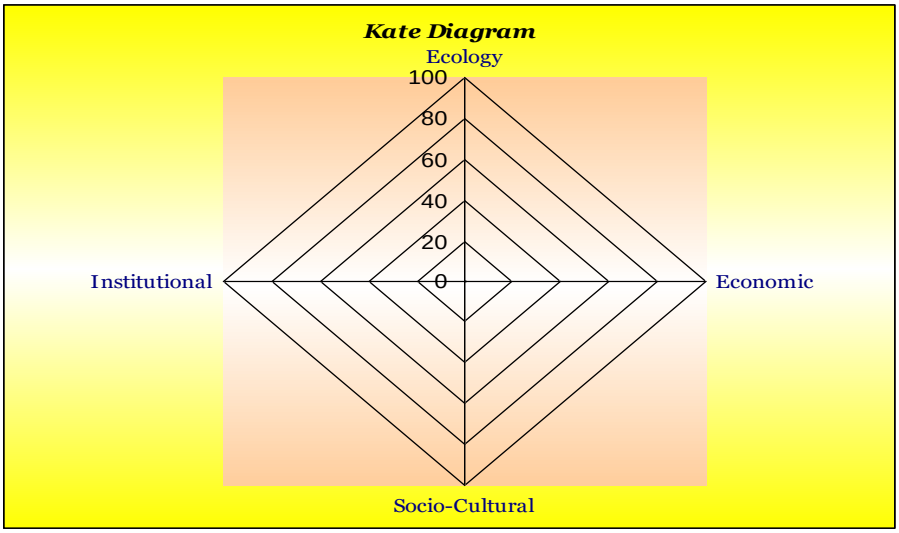

Figure 3. Illustration of the Sustainability index of each dimension.

Analysis to see which attributes are the most sensitive contributing to the sustainability index, a sensitivity analysis is carried out by looking at the shape of the change in the ordinary root mean square (RMS) on the X axis. The greater the change in the RMS value, the more sensitive the attribute.

Monte Carlo analysis was used to evaluate the effect of random error on estimating the ordinance value of Mangrove ecosystem management. According to Kavanagh and Pitcher (2004), the Monte Carlo analysis is also useful for studying:

1. The effect of attribute scoring errors is caused by an incomplete understanding of the research location conditions or a misunderstanding of attributes or how to make attribute scores.
2. The effect of variations in scoring due to differences in opinions or judgments by different researchers.
3. The stability of the MDS analysis process repeated (iterations).
4. Data entry errors or missing data.
5. The high value of "stress" from the analysis of Rap-Insus MMFAG (stress value is acceptable if < 25%).

The modified Rap-Insus MMFAG application process chart from Alder et al (2000) and Fauzi and Anna (2005) is presented in Figure 4.

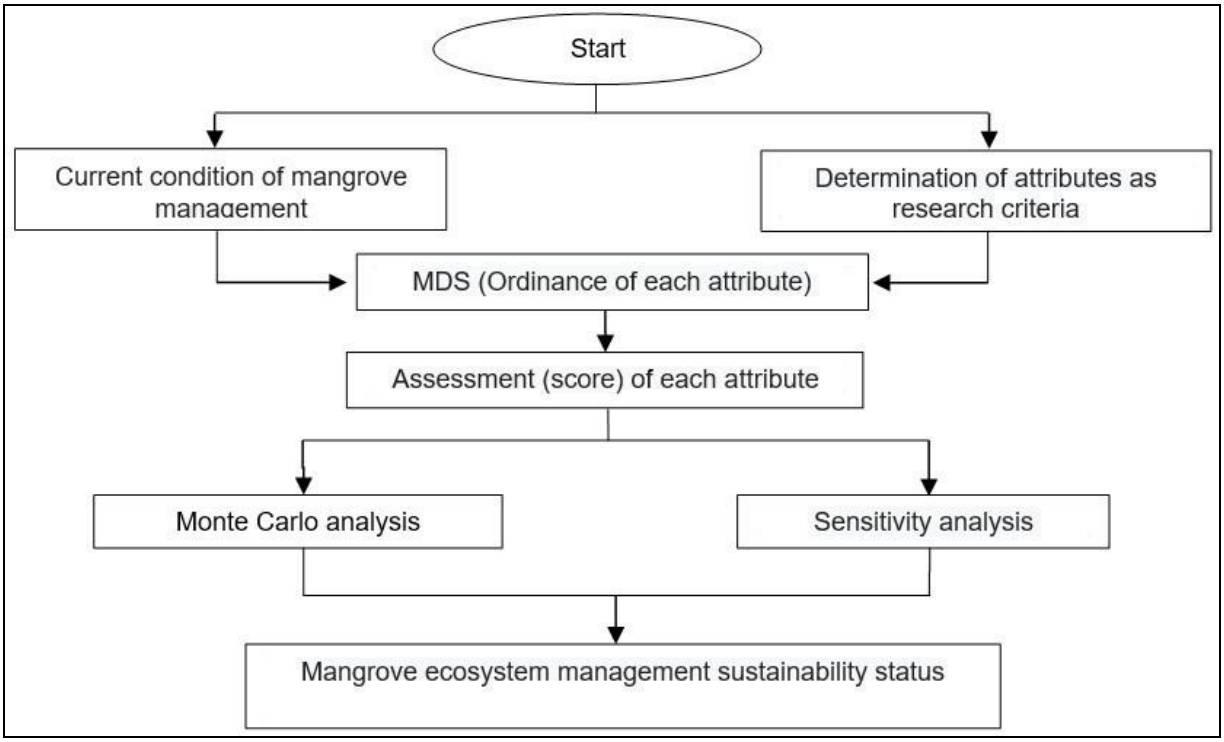

Figure 4. Rap-Insus MMFAG application process chart (modified from Alder et al 2000; Fauzi & Ana 2005).

Results. Sungai Apit Subdistrict is located in the Siak River watershed, and in some places, is a sloping beach facing Tebing Tinggi Island and Padang Island in the Bengkalis Regency. Sungai Apit District is between 1°14 – 0°34 N latitude and 102°03 – 102°53 E longitude. Sungai Apit Subdistrict is bordered by:

- North: Bengkalis Regency
- South: Pelalawan Regency
- West: Sabak Auh District, Pusako District, District Dayun
- East: Bengkalis Regency

Sungai Apit Subdistrict is the only Siak Regency sub-district with a reasonably extensive mangrove forest. It is estimated that the mangrove forest area in Sungai Apit District is around 511.4 hectares spread over 15 villages. Since 2014, the local community's awareness has been influential in the mangrove forest ecosystem. One form of public awareness is the emergence of mangrove conservation groups in each village. There are eight mangrove conservation groups in each village in Sungai Apit District. For example, the Mangrove Nursery and Conservation Group in Mengkap Village, the Mangrove Conservation Group in Rawa Mekar Jaya Village, the Sungai Kayu Ara Village Conservation Group, the Conservation Group in Belemen Village, Tanjung Kuras and other village conservation groups.

Ecological dimensions index and sustainability status. The results of the Rap-Insus MMFAG ordinance analysis on nine attributes that affect the ecological dimension show that the sustainability index value of the ecological dimension is 83.54. This value is in the range of 75.01 – 100 on the sustainability scale with good status (very sustainable), shown in Figure 5.

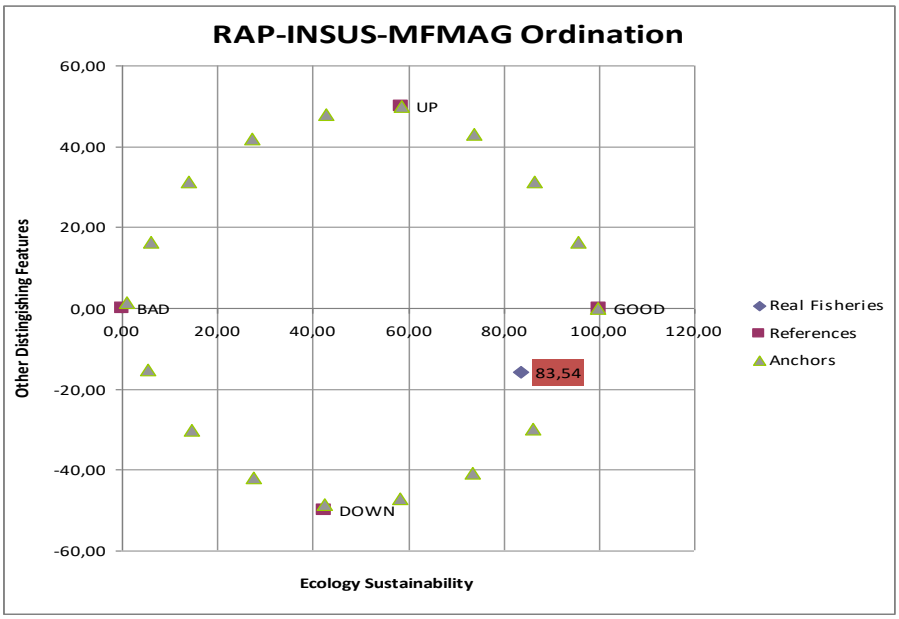

Figure 5. Index value and sustainability status of the ecological dimension.

Leverage analysis of 9 attributes of the ecological dimension obtained two sensitive attributes, namely the level of coastal abrasion and the dominant species. Changes to these two leverage factors will easily affect the increase or decrease in the value of the ecological dimension sustainability index. The results of the leverage analysis are presented in Figure 6.

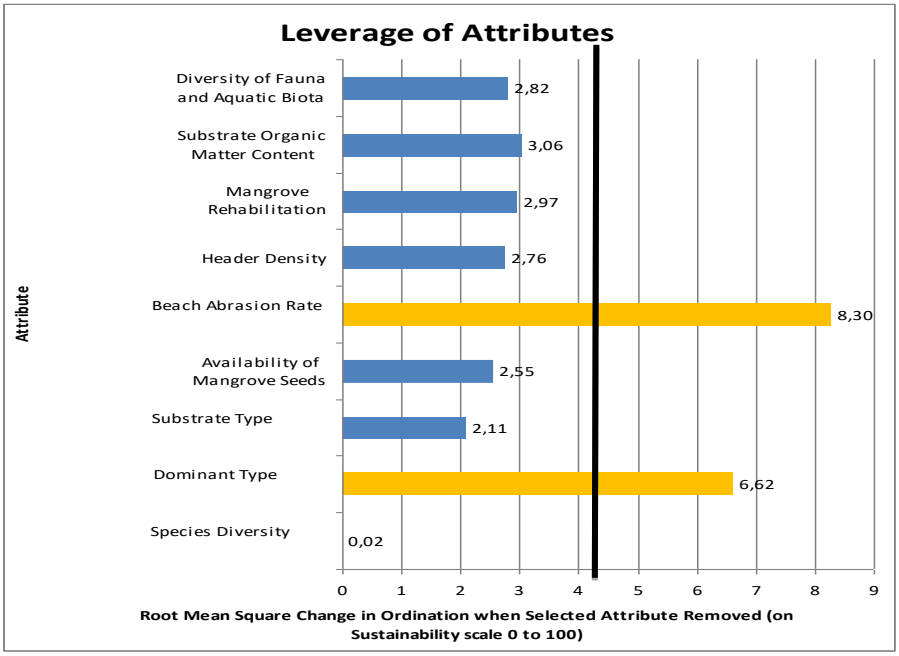

Figure 6. The sensitivity value of the ecological dimension attribute expressed in changes in root mean square (RMS) on a sustainability scale of 0 - 100.

Index and status of economic dimensions of sustainability. The results of the Rap-Insus MMFAG ordinance analysis on eight attributes that affect the economic dimension show that the value of the sustainability index of the economic dimension is 69.08. This value is in the range of 50 – 74.9 on the sustainability scale with moderately sustainable status, shown in Figure 7.

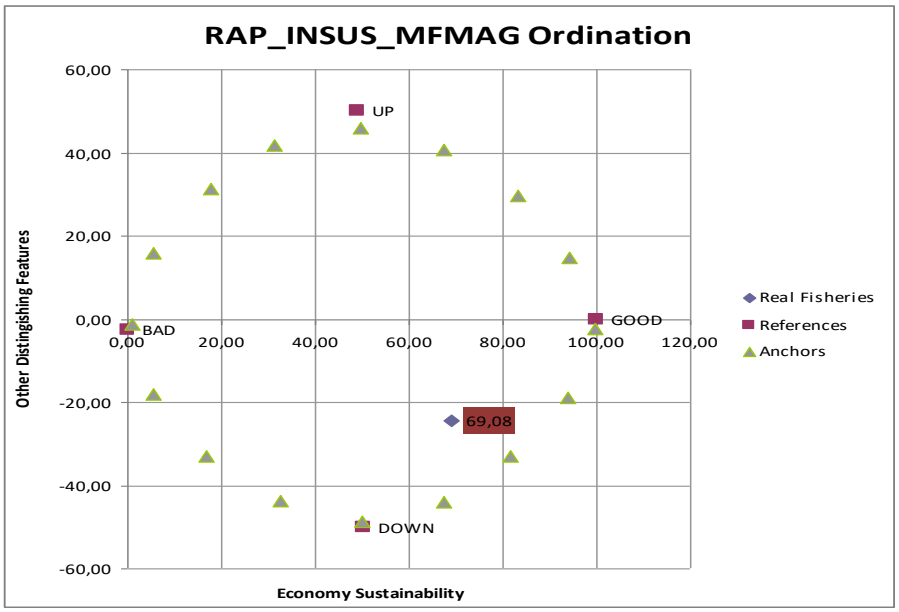

Figure 7. Index value and sustainability status of the economic dimension.

Leverage analysis of the eight attributes of the economic dimension obtained seven sensitive attributes, namely (1) the average income of the community from mangroves, (2) the average income of the community to the MSE, (3) the existence of a market for mangrove forest products, (4) dependence on livelihoods from mangroves, (5) accessibility of mangrove areas, (6) support for corporate social responsibility (CSR) funds, and (7) direct benefits from mangrove forests. Changes to these seven leverage factors will easily affect the increase or decrease in the value of the sustainability index of the economic dimension. The results of the leverage analysis are presented in Figure 8.

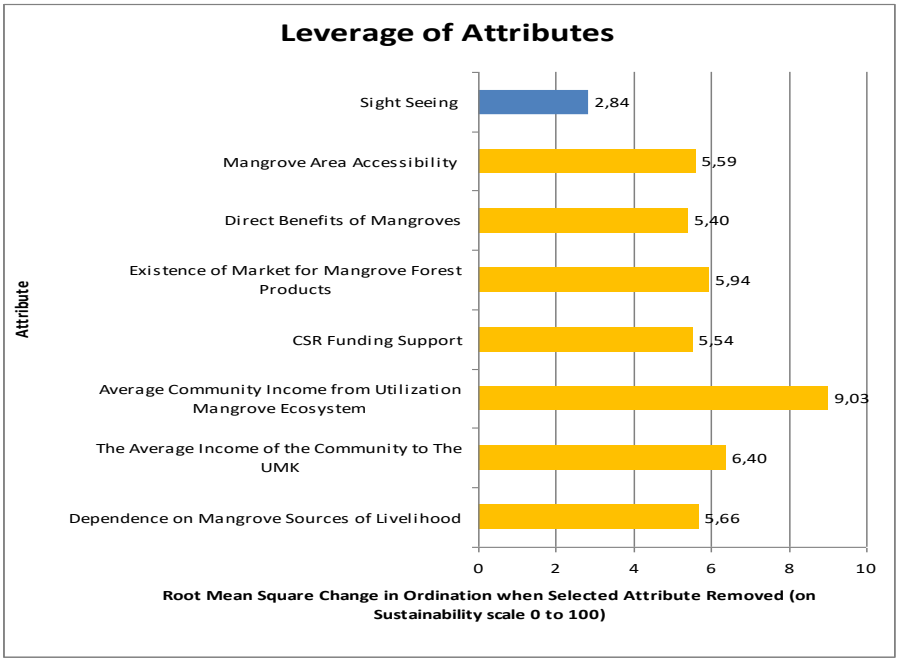

Figure 8. The sensitivity value of the economic dimension attribute expressed in the change in root mean square (RMS) on a sustainability scale of 0 – 100.

Socio-cultural dimension sustainability index and status. The results of the Rap-Insus MMFAG ordinance analysis of 7 attributes that affect the sociocultural dimension show that the value of the sustainability index of the sociocultural dimension is 57.25.

This value is in the range of 50 – 74.9 on the sustainability scale with moderately sustainable status, as seen in Figure 9.

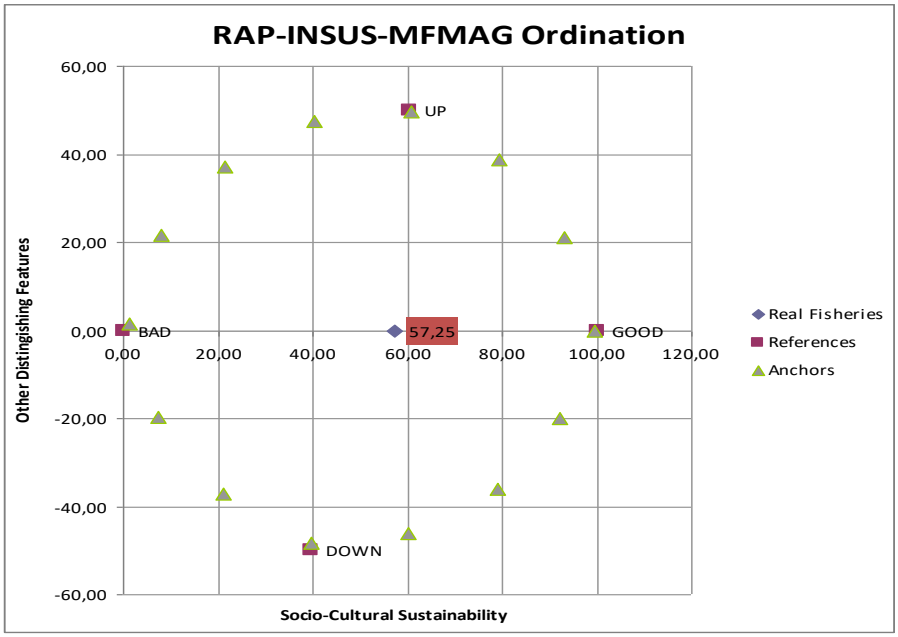

Figure 9. Index value and sustainability status of the sociocultural dimension.

Leverage analysis of the seven attributes of the sociocultural dimension obtained four sensitive attributes, namely (1) the social impact of mangroves on the community, (2) education about mangrove ecosystems by mangrove managers, (3) potential conflicts with other sectors, and (4) community knowledge about mangrove forests. Changes to these four leverage factors will easily affect the increase or decrease in the value of the sustainability index of the sociocultural dimension. The results of the leverage analysis are presented in Figure 10.

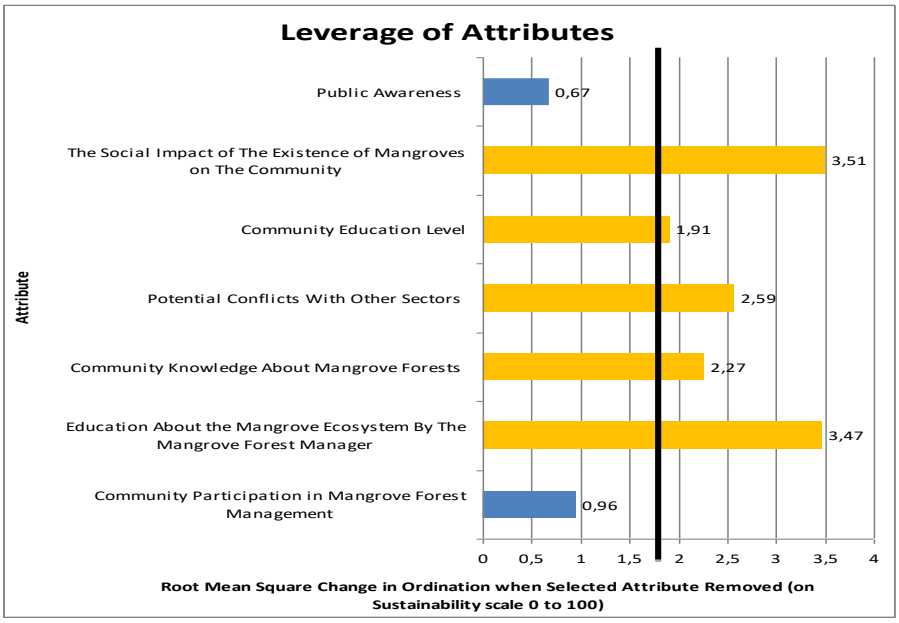

Figure 10. The sensitivity value of sociocultural dimension attributes expressed in changes in root mean square (RMS) on a sustainability scale of 0 – 100.

Status of sustainability of the institutional dimension. The results of the Rap-Insus MMFAG ordinance analysis on seven attributes that affect the institutional dimension show that the sustainability index value of the institutional dimension is 99.81. This value

is in the range of 75.01 – 100 on the sustainability scale, with a sustainable status, as seen in Figure 11.

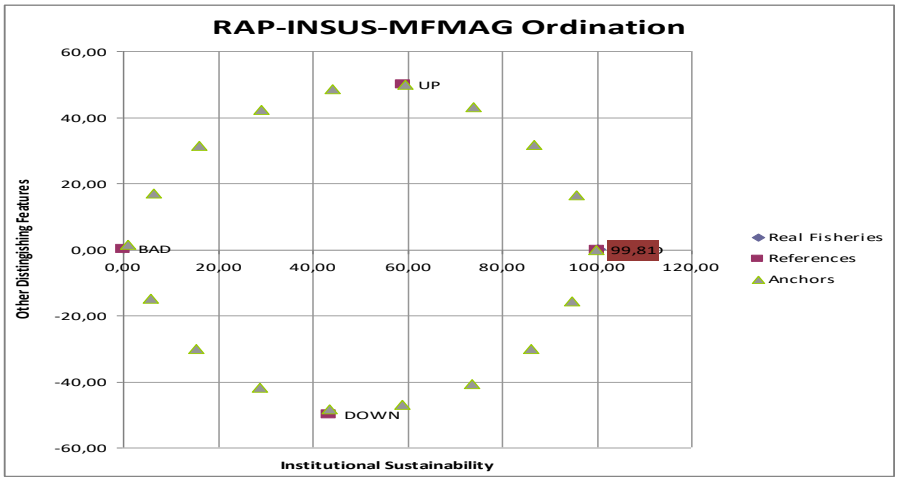

Figure 11. Index value and sustainability status of institutional dimension.

Leverage analysis of 9 attributes of the institutional dimension obtained only one sensitive attribute, namely "law enforcement." Changes to this leverage factor will easily affect the increase or decrease in the value of the sustainability index of the institutional dimension. The results of the leverage analysis are presented in Figure 12.

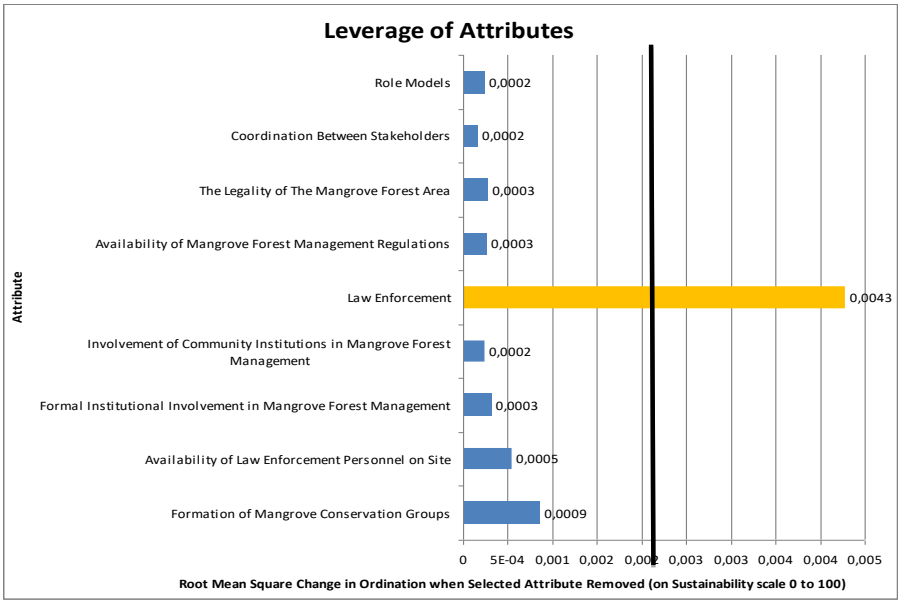

Figure 12. The sensitivity value of institutional dimension attributes expressed in changes in root mean square (RMS) on a sustainability scale of 0 – 100.

Index value and multi-dimensional sustainability status. The sustainability of mangrove forest ecosystem management in Sungai Apit Subdistrict from the economic and sociocultural dimensions has a sustainable status with index values of 69.08 and 57.25. Even from the ecological and institutional dimensions, with a sustainable status with index values of 83.54 and 99.84. The index value and sustainability status of the four dimensions of mangrove forest ecosystem management in Sungai Apit Subdistrict, Siak Regency, are visualized as a kite diagram in Figure 13 below.

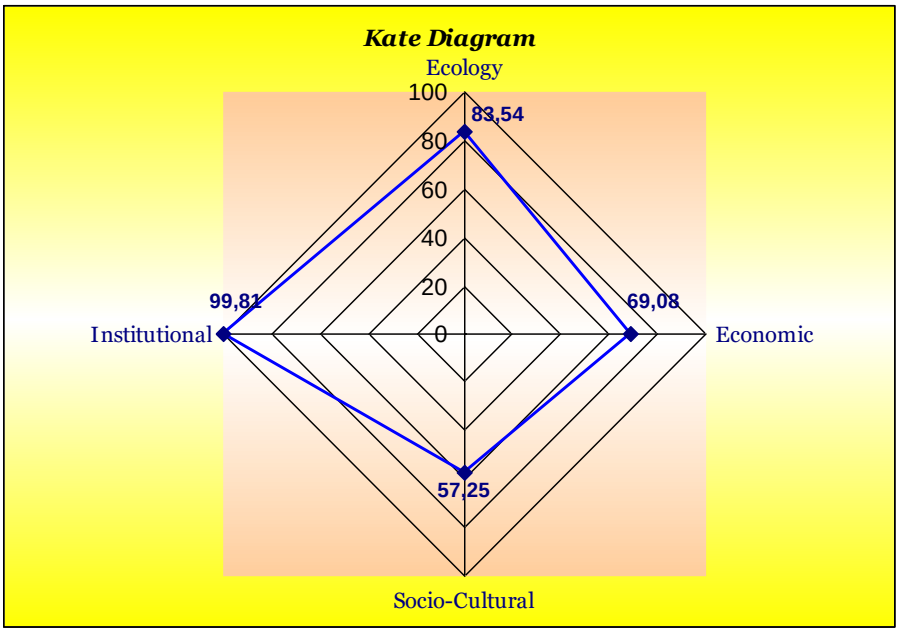

Figure 13. Kite diagram of multi-dimensional sustainability management of mangrove forest ecosystems in Sungai Apit Subdistrict, Siak Regency.

Improvements to attributes that give highly sensitive values and have a negative effect on the sustainability of mangrove forest ecosystem management in Sungai Apit District must be carried out and improved so the index value and sustainability status increase, especially in the economic and sociocultural dimensions. To justify whether the four dimensions are sustainable or not, according to Budiharsono (2007), it cannot be seen by averaging the index values of the four dimensions, but a pairwise comparison test must be carried out obtained from expert assessments in mangrove forest management. Thus, each index is verified by experts, so a weighted score is obtained. Determination of the index value and multi-dimensional sustainability status of mangrove forest ecosystem management performance is carried out by multiplying the index value of each dimension of the results of the Rap-Insus MFMAG analysis with the dimensional weight assessment by experts in Table 3.

Table 3

The multi-dimensional index value of mangrove forest ecosystem management in Sungai Apit Subdistrict

Dimension	*Dimensional weight (%)*	*Index value*	*Weighted result index value*
Ecology	30.77	83.54	25.71
Economic	22.45	69.08	15.51
Socio-cultural	27.75	57.25	15.89
Institutional	19.03	99.84	19.00
Total	100	309.71	76.11

Stress value and coefficient of determination. The accuracy of the configuration of a point that reflects the original data can be measured by looking at the stress value from the Rap-Insus MMFAG ordinance analysis results for each analyzed dimension. The ability of attributes to explain and contribute to the system's sustainability by looking at the coefficient of determination (R2) value for each dimension analyzed. The stress value and the coefficient of determination for each dimension are presented in Table 4.

Table 4

Stress values and multi-dimensional coefficient of determination

Dimension	*Sustainability index value*[*]	*Stress*[**]	*R^2*[***]	*Iteration*
Ecology	83.54	0.13	0.95	2
Economic	69.08	0.13	0.94	2
Socio-cultural	57.25	0.15	0.94	2
Institutional	99.84	0.13	0.95	2

Note: * The index value of 50.01 – 75 is categorized as sustainable and Index value of 75.01 – 100 is categorized as very sustainable.
** Stress value < 0.25 is a good value.
*** R^2 value of 94% or > 80% contribution is good.

Effect of error. Evaluation of the effect of random errors using Monte Carlo analysis aims to determine: (a) the effect of attribute scoring errors, (b) the effect variations, (c) the stability of the MDS analysis process repeated, (d) input errors or loss of data (missing data), and (e) the stress value is acceptable if <20%. The results of the Monte Carlo analysis for all dimensions are presented in Table 5.

Table 5

Results of multi-dimensional Monte Carlo analysis

Dimension	*MDS*	*Monte Carlo analysis*[*]	*Difference (MDS – MC)*
Ecology	83.54	80.83	2.71
Economic	69.08	67.21	1.87
Socio-cultural	57.25	56.60	0.65
Institutional	99.84	96.20	3.64

Note: * error at 95% confidence level.

Table 5 shows no significant difference between the MDS index value and the results of the Monte Carlo analysis, both the distribution value and the effect of the error are at the 95% confidence level. It can be ascertained that the error in scoring, the effect of score variations, the stability of the repeated MDS analysis process, and errors in entering or missing data (missing data) have no effect.

Key factors of MDS results. The results of the MDS analysis show that of the 33 attributes analyzed, 14 sensitive attributes affect the sustainability of the mangrove forest ecosystem management system in Sungai Apit Subdistrict, Siak Regency, with details of each dimension shown in Table 6.

Table 6

Multi-dimensional attributes sensitive to system sustainability of mangrove forest ecosystem management from MDS

Dimension	*No*	*Attributes*	*RMS*
Ecology	1	Abrasion rate	8.30
	2	Dominant species	6.62
Economic	1	Average community income from mangrove utilization	9.03
	2	Average community income to DMW	6.40
	3	The existence of a market for mangrove forest products	5.94
	4	Dependence on the source of livelihood from mangroves	5.66
	5	Mangrove area accessibility	5.59
	6	CSR funding support	5.54
	7	Direct benefits of the mangrove forest	5.40

Socio-cultural	1	The social impact of mangroves on the community	3.51
	2	Education regarding the mangrove ecosystem from the mangrove manager	3.47
	3	Potential conflicts with other sectors	2.59
	4	Community knowledge about mangrove forest	2.27
Institutional	1	Law enforcement	0.0043

Note: RMS = Root Mean Square

Table 6 shows that the number of attributes that affect the sustainability of the mangrove forest ecosystem management system based on the results of the MDS analysis is 14 attributes, which consist of an ecological dimension of two attributes, an economic dimension of seven attributes, a sociocultural dimension of four attributes and an institutional dimension of one attribute. To improve the sustainability status, each sensitive attribute needs to be intervened upon by improving the poor performance of the attribute.

Discussion. The results of the Rap-Insus MFMAG ordinance analysis on nine attributes that affect the ecological dimension show that the sustainability index value of the ecological dimension is 83.54 (Figure 5). This value is situated between 75.01 – 100 on the sustainability scale with good status (very sustainable). Based on the results of the leverage analysis above (Figure 6), the abrasion level has the highest RMS value, which is 8.30. It can be interpreted that the attribute "level of abrasion" has the greatest effect on the sustainability of mangrove forest ecosystem management from an ecological perspective. The level of abrasion at the research site is moderate, so it needs improvement. The level of abrasion is largely determined by land cover and the density of mangrove trees growing on the coast. From field observations, areas with low vegetation cover and tree density, such as some in Kayu Ara Permai Village, Lalang Village, Belemen Village, and MengKapan Village, have experienced abrasion, which is worrying. Changes to the abrasion level attribute will easily affect the increase or decrease in the ecological dimension sustainability index.

A stable ecosystem is characterized by the lack of dominant species and a high level of diversity. The dominant mangrove vegetation was found at the research site from the Rhizophoraceae family. This is due to reforestation (replanting), in which *Rhizophora* genus is widely used. De Santos (1978) says that species diversity has long been an indicator of environmental stability. Holling et al (1995) said that species diversity determines ecosystem resilience or sensitivity. Therefore, efforts should be made to replicate other species so the diversity of the mangrove ecosystem in the study area can increase.

Economic dimension sustainability status. The results of the Rap-Insus MFMAG ordinance analysis on eight attributes that affect the economic dimension show that the value of the sustainability index of the economic dimension is 69.08 (Figure 7). This value is between 50 – 74.9 on the sustainability scale, with a moderately sustainable status.

Based on the results of the leverage analysis above (Figure 8), the average level of community income from mangroves has the highest RMS value, which is 9.03. It can be interpreted that the attribute "average level of community income from the use of mangroves" has the greatest effect on the sustainability of mangrove forest ecosystem management from an economic perspective. The average community income from using mangroves in the study area is in a low category. The existence of conservation groups in each village in the study area and supported by the Village Regulation (Perdes), which prohibits community members from using mangroves, such as collecting wood. Even in Kayu Ara Permai Village, it is strictly forbidden to enter the conservation area without permission from the manager. However, in conservation areas in other villages, entrance is still possible, especially to look for honey and lokan (*Geloina erosa*). The people whose

livelihood is fishermen are only 3.28%. Most (20.14%) of the people in the study location are farmers, with palm oil as the main commodity.

The next lever that is no less important to the sustainability of mangrove forest ecosystem management from an economic perspective is the average income of the community towards the Siak Regency DMW, the existence of a mangrove forest market, dependence on livelihoods from mangroves, the accessibility of mangrove areas, and support for CSR funds. All these attributes will determine the sustainability of mangrove forest ecosystem management from an economic perspective. For example, the attribute of community income to the minimum regional wage (UMK) of Siak Regency in 2021 (Governor of Riau Decree Number 1581/XI/2020 2020) is still in the medium category, and there must be an effort to increase it.

Especially for the attribute of tourist visits, although it is not a sensitive attribute, it is still a concern. This is related to the tourist facilities in each conservation area being in a very alarming state. For example, in the Conservation Area of Kayu Ara Permai Village, Meng Kapan Village, and Rawa Mekar Jaya Village, most tracks are obsolete and cannot be passed anymore. Likewise, other facilities are no longer functioning. Therefore, so the sustainability of tourist visits can be maintained and improved, attention and assistance from the government (district and province) is highly required.

Socio-cultural dimension sustainability status. The results of the Rap-Insus MFMAG ordinance analysis on seven attributes that affect the sociocultural dimension show that the sustainability index value of the sociocultural dimension is 57.25 (Figure 9). This value is 50 – 74.9 on the sustainability scale, with a moderately sustainable status.

Based on the results of the leverage analysis above (Figure 10), the "social impact of the existence of mangroves on the community" has the highest RMS value, which is 3.51. It can be interpreted that the attribute "social impact of the existence of mangroves on the community" influences the sustainability of mangrove forest ecosystem management from a sociocultural perspective. The attributes of the social impact of mangroves on the community are in a good category, so they need to be maintained.

The next lever that is no less important to the sustainability of mangrove forest ecosystem management from a sociocultural perspective is education about mangrove ecosystems by mangrove managers, potential conflicts with other sectors, and community knowledge about mangrove forests. All these attributes will determine the sustainability of mangrove forest ecosystem management from a sociocultural perspective.

Attributes of education about mangrove ecosystems by the management are in good condition and need to be maintained. Meanwhile, the attributes of potential conflicts and attributes of community knowledge about mangrove forests are in a good position and need to be improved to be good.

Institutional sustainability status. The results of the Rap-Insus MFMAG ordinance analysis on seven attributes that affect the institutional dimension show that the value of the sustainability index of the institutional dimension is 99.81 (Figure 11). This value is between 75.01 – 100 on the sustainability scale with a sustainable status.

Based on the leverage analysis above (Figure 12), law enforcement has the highest RMS value, which is 0.0043. It can be interpreted that the attribute law enforcement has the most significant influence on the sustainability of mangrove forest ecosystem management from an institutional perspective. The attributes of law enforcement are in good condition and need to be maintained.

Multi-dimensional sustainability status. The combined index value (multi-dimensional) obtained is 76.11. This value is between 75.01 – 100, indicating that the sustainable management of mangrove forest ecosystems in Sungai Apit Subdistrict is sustainable. The ecological and institutional dimensions have the highest weight, with a score of 25.71 and a weighted value of 30.77. Next is the institutional dimension with a

score of 19.00 or a weighted value of 19.03, followed by the sociocultural dimension with a score of 15.89 and a weighted value of 27.75, and lastly, the economic dimension with a score of 15.51 and a weighted value of 22.45 (Table 3).

Based on these weights, it can be predicted that the sustainability of mangrove forest ecosystem management in Sungai Apit Subdistrict, Siak Regency, is determined by the success of increasing the sustainability status of the economic and sociocultural dimensions without ignoring the importance of the ecological and institutional dimensions. Schaduw (2015) says that the improvement of every sensitive attribute or indicator in each dimension needs to be done seriously so sustainability can be improved.

Stress value and coefficient of determination. The results of the Rap-Insus MFMAG ordinance analysis for each of the analyzed dimensions (Table 4) show that the average stress value of the dimensions is 0.135, and the average R^2 value is 0.945. In RAPFISH, the tress value is said to be good if the value is below 0.25 (Malhotra 2010), meaning that the goodness of fit value in MDS can reflect the original data in the attribute configuration. The R^2 value of 0.945 indicates that the attributes or factors assessed in each dimension can explain and contribute 94% to the sustainability of the system under study. According to Kavanagh and Pitcher (2004), a good R^2 value is greater than 80% or close to 100%.

Effect of error. Monte Carlo analysis was used to test the confidence level of the total index value and each management dimension. This analysis helps to see the effect errors on each attribute in each dimension caused by procedural errors or understanding of attributes, variations in scoring due to differences of opinion, stability of the MDS analysis process, data entry errors or missing data, and stress values that are too high. The results of the multi-dimensional Monte Carlo analysis (Table 5) show no significant difference between the MDS index value and the results of the Monte Carlo analysis, both the distribution value and the effect of the error analyzed at 95% confidence level. It can be ascertained that the error in scoring, the effect of score variations, the stability of the repeated MDS analysis process, and errors in entering or missing data have no effect.

Key factors of MDS results. The results of the MDS analysis show that of the 33 attributes analyzed, 14 sensitive attributes affect the sustainability of the mangrove forest ecosystem management system in Sungai Apit Subdistrict, Siak Regency (Table 6). The 14 sensitive attributes consist of an ecological dimension of two attributes (abrasion level and dominant type), an economic dimension of seven attributes, a sociocultural dimension of four attributes, and an institutional dimension of one attribute. The 14 sensitive attributes are (1) the level of coastal abrasion, (2) the dominant species, (3) the average income of the community from mangroves, (4) the average income of the community to DMW, (5) the existence of a market. Mangrove forest products, (6) dependence on mangroves for livelihoods, (7) the accessibility of mangrove areas, (8) CSR funding support, (9) direct benefits from mangrove forests, (10) the social impact of mangroves on the community, (11) education about mangrove ecosystems by mangrove managers, (12) potential conflicts with other sectors, (13) community knowledge about mangrove forests, and (14) law enforcement. To improve the sustainability status, every sensitive attribute needs to be intervened by maintaining the attribute performance of good attributes and improving the attribute performance of sensitive attributes.

Conclusions. The sustainability status of mangrove forest ecosystem management in Sungai Apit Subdistrict according to each dimension are the ecological dimension is sustainable (83.54), the socio-economic dimension is sustainable (69.08), the sociocultural dimension is sustainable (57.25), and the institutional dimension is highly sustainable (99.81). Likewise, multi-dimensionally, it is included in the very sustainable category (76.11). This study revealed 14 sensitive attributes that affect the sustainability of the mangrove forest ecosystem management system in Sungai Apit Subdistrict, Siak Regency, which consists of two factors of ecological dimension, seven factors of economic

dimension, four factors of sociocultural dimension, and one factor of institutional dimension. The 14 sensitive attributes are (1) the level of coastal abrasion, (2) the dominant species, (3) the average income of the community from mangroves, (4) the average income of the community to DMW, (5) the existence of a market for mangrove forest products, (6) dependence on mangroves for livelihoods, (7) the accessibility of mangrove areas, (8) CSR funding support, (9) direct benefits from mangrove forests, (10) the social impact of mangroves on the community, (11) education about mangrove ecosystems by mangrove managers, (12) potential conflicts with other sectors, (13) community knowledge about mangrove forests, and (14) law enforcement.

Recommendations. It is necessary to pay attention and prioritize improving the sustainability dimensions with a lower sustainability index value, namely the economic and sociocultural dimensions. Support from local governments (districts and provinces) and various parties is needed to help renovate damaged conservation area facilities and infrastructure.

Conflict of interest. The authors declare that there is no conflict of interest.

References

Adriman, Prianto E., Fauzi M., Fajri N. E., 2022 Adaptation capacity of the mangrove ecosystem located in the Rawa Mekar Jaya Village, Siak Regency, Riau Province, Indonesia. AACL Bioflux 15(1):126-135.

Adriman, Prianto E., Fauzi M., Fajri N. E., 2020 Community structure and adaptive capacity of mangrove forest ecosystems in Meng Kapan Village, Siak Regency. Institute for Research and Community Service, University of Riau, 37 pp.

Adriman, 2012 [Design of sustainable coral reef ecosystem management in marine protected areas in East Bintan Region, Riau Archipelago]. Dissertation. Graduate School. Bogor Agricultural University. 196 pp. [in Indonesian].

Alder J., Pitcher T. J., Preikshot D., Kaschner K., Ferris B., 2000 How good is good? A rapid appraisal technique for evaluation of the sustainability status of fisheries of the North Atlantic. In: Methods for evaluation the impact of fisheries on North Atlantic ecosystems. Pauly D., Pitcher T. J. (eds), Fisheries Centre, University of British Columbia, Vancouver, Canada, 136-182 p.

Bengen D. G., 2001 Technical guidelines for the introduction and management of mangrove ecosystems. Center for the Study of Coastal Ocean Resources, Bogor Agricultural University, Bogor, 60 pp.

Budiharsono S., 2007 [Manual of determining the status and leveraging factors of PEL]. Direktorat Perekonomian Daerah. Badan Perencanaan Pembangunan Nasional (Bapenas). Jakarta. 50 pp. [in Indonesian].

Damai A. A., Boer M., Marimin, Damar A., Rustiadi E., 2011 [Participatory prospective analysis in coastal management area of Lampung Bay]. Graduate Forum, 34(4):281-296 [in Indonesian].

De Santos R. S., 1978 Concepts of applied ecology. Springer-Verlag. New York. 310 pp.

Fauzi A., Anna S., 2005 [Fisheries and marine resources modeling for policy analysis]. Gramedia Pustaka, Jakarta, 343 pp. [in Indonesian].

Fauzi A., 2004 [Economics of natural resources and environment: theory and applications]. Gramedia Pustaka Utama, Jakarta. 237 pp. [in Indonesian].

Fauzi A., Anna S., 2002 [Evaluation of the sustainability status of fisheries development: application of the Rapfish approach]. Jurnal Pesisir dan Lautan, 4(3):43–55 [in Indonesian].

Heal G., 1998 Valuing the future. Economic theory and sustainability. Columbia University Press, New York. 298 pp.

Holling C., Schindler D., Walker B., Roughgarden J., 1995 Biodiversity in the functioning of ecosystems: an ecological synthesis. In C. Perrings, K. Maler, C. Folke, C. Holling, & B. Jansson (Eds.), Biodiversity Loss: Economic and Ecological Issues. Cambridge: Cambridge University Press. 44-83 p. doi:10.1017/CBO9781139174329.005.

Kavanagh P., Pitcher T. J., 2004 Implementing Microsoft Excel software for Rapfish: a technique for the rapid appraisal of fisheries status. University of British Columbia. Fisheries Centre Research Reports 12(2) ISSN: 1198-672. Canada. 74 pp.
Kuvaini A., Hidayat A., Kusmana C., Basuni S., 2019 [Multi-dimensional assessment techniques to evaluate the sustainability of mangrove forest management on Kangean Island, East Java]. Jurnal Wilayah dan Lingkungan 7(3):137-152 [in Indonesian].
Malhotra N. K., 2010 Marketing research: an applied orientation. Sixth Edition. Prantice Hall. 897 pp.
Pattimahu D. V., Kusmana C., Harjomidjoyo H., Darusman D., 2010 [Analysis of the value of sustainability of mangrove forest ecosystem management in West Seram District, Maluku]. Jurnal Geografi 11(1):239-249 [in Indonesian].
Rusila Y., Mkhazali, Suryadiputra I. N., 2006 [Guide to introduction of mangroves in Indonesia]. Wetlands, Bogor. 219 pp. [in Indonesian].
Samekto A. F. X., 2005 [Sustainable development in a changing social order]. Jurnal Hukum Progresif 1(2):15-30 [in Indonesian].
Schaduw J. N. W., 2015 [Sustainability of mangrove ecosystem management on Mantehage Island, Wori Subdistrict, Minahasa Utara Regency, North Sulawesi]. Jurnal LPPM Bidang Sains dan Teknologi, 2(2):60-70 [in Indonesian].
Walpole R. E., 1995 [Introduction to statistics. Translator: Bambang Sumantri. Third edition]. Jakarta: PT Gramedia Pustaka Utama. 381-397 p. [in Indonesian].
Warningsih T., Kusai, Bathara L., Zulkarnain Z., Ramadona T., Deviasari D., 2021 Management strategy of mangrove ecosystem in Siak Regency, Riau Province, Indonesia. ECSOFiM: Journal of Economic and Social of Fisheries and Marine 9(1):60-71.
*** Governor of Riau Decree Number 1581/XI/2020, 2020 [Kpts. 1581/XI/2020 concerning the Minimum Wage for Regencies/Cities in Riau Province for the Year 2021]. www. jdih.riau.go.id [in Indonesian].
*** World Commision on Environmment and Development (WCED), 1987 Our common future. United Nations World Commission on Environment and Development. London: Oxford University Press. 374 pp.

Received: 31 October 2022. Accepted: 03 December 2022. Published online: 23 August 2023.
Authors:
Adriman, Aquatic Resource Management Department, Faculty of Fisheries and Marine in Riau University, St. HR Subrantas, KM 12.5 Panam Pekanbaru, Riau, Indonesia, e-mail: adriman@lecturer.unri.ac.id
Eko Prianto, Aquatic Resources Management Department, Faculty of Fisheries and Marine Science, Universitas Riau, Jl. Raya Pekanbaru-Bangkinang km. 12.5 Sp. Baru, Pekanbaru, 28293 Riau, Indonesia, e-mail: eko.prianto@lecturer.unri.ac.id
Romie Jhonnerie, Fisheries Resources Utilization Department, Faculty of Fisheries and Marine Science, Universitas Riau, Jl. Raya Pekanbaru-Bangkinang km. 12.5 Sp. Baru, Pekanbaru, 28293 Riau, Indonesia, e-mail: romie.jhonnerie@gmail.com
Nur El Fajri, Aquatic Resource Management Department, Faculty of Fisheries and Marine in Riau University, St. HR Subrantas, KM 12.5 Panam Pekanbaru, Riau, Indonesia, e-mail: nur.elfajri@lecturer.unri.ac.id

How to cite this article:
Adriman, Prianto E., Jhonnerie R., El Fajri N., 2023 Sustainability status of mangrove ecosystem management in Sungai Apit Subdistrict, Siak Regency, Indonesia. AACL Bioflux 16(4):2313-2330.