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Regional Case Study

Sustainability Status Analysis of Urban Mangrove Management Using Multidimensional Scaling (MDS) Rapfish

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Abstract

Kebun Raya Mangrove Surabaya is an is an urban mangrove conservation ecotourism area. However, the rise in tourism activities, institutional limitations, and lack of proper facilities have become major issues in the area. This study aims to examine the status of discontinuation in the management of ecotourism areas using the multidimensional scaling (MDS) method within a rap-tourism framework. The analysis will cover 43 assessment attributes for five dimensions of tourism: ecology, economy, social, institutions, and infrastructure and technology. The findings of the study revealed that the sustainability index values are as follows: ecological (86.25), economic (63.52), social (89.13), institutional (84.51), and infrastructure and technology (88.07), all indicating high sustainability. The study found that this area has a sustainability index result with an overall average value of 82.30, which falls into the highly sustainable category. The findings suggest that Surabaya mangrove ecotourism is in good condition; however, improvements are needed, particularly in the economic dimension, which requires the most strengthening to maintain long-term sustainability.

Keywords: Mangrove ecotourism; multidimensional assessment; rap-tourism; Surabaya; sustainability status

1. Introduction

Mangrove ecosystems are coastal resources that have ecological, economic, and social functions, namely coastal protection, carbon sequestration, and habitat for various coastal biota (Efani et al., 2024; Bunting et al., 2022). However, mangrove forest areas are constantly declining globally due to clear-cutting, coastal development, and climate change, which inevitably cause ecosystem degradation (Blanton et al., 2024). Indonesia has the largest mangrove area in the world, contributing approximately 20% of the global total, and has a high risk of damage and land conversion. Surabaya is one of the coastal

areas in East Java with a quite extensive mangrove ecosystem of about 1,099.21 hectares, and most of the area is located in the eastern coastal area or east coast of Surabaya (Putri et al., 2024). Meanwhile, there is potential land for mangrove rehabilitation of 2,621.73 ha. Sadly, 97% of this potential land has been converted into fishponds (Aziz, 2023).

The Surabaya government has developed protection policies through Mayoral Regulation Number 65 of 2011 concerning the supervision and control of mangrove areas and the 2025–2045 RTRW, which designates the east coast of Surabaya (Pamurbaya) as a protected and conservation zone (Prasita et al., 2019). The realization of these policies includes the establishment of the Kebun Raya Mangrove Surabaya, the first Indonesian thematic botanical garden based on the mangrove ecosystem, which serves as a conservation, education, and ecotourism destination under the management of the Kebun Raya Mangrove Surabaya Technical Implementation Unit (UPT) (Karnanta et al., 2025). This place in Medokan Sawah-Gunung Anyar is not only ecologically important but also brings economic benefits to the community through conservation-driven tourism activities (Putri et al., 2024).

A detailed sustainability study is required to ensure the continuation of the management of this ecotourism area. The multidimensional scaling (MDS) method with the Rapfish model can adequately fulfill this role because it is capable of depicting sustainability levels by combining five dimensions: ecological, economic, social, institutional, infrastructure, and technology (Hasna et al., 2025; Mardianton et al., 2024). MDS is a statistical method used to assess sustainability status by reducing multidimensional indicators into an ordination space for comparative analysis (Purwaningsih et al., 2021). This approach has evolved from Rapfish to Rap-tourism because of its flexible structure and suitability for tourism sustainability assessment (Mukhlisin and Trimarstuti, 2023). Recent studies have applied MDS-based Rap-tourism to evaluate the ecological, economic, social, and institutional dimensions of ecotourism destinations, including mangrove tourism systems (Sadad et al., 2022).

This study reveals the extent to which the management system has realized sustainability and identifies the factors that facilitate or hinder it (Rachmawati, 2024). Setiawati (2019) conducted a sustainability assessment at the Surabaya Mangrove Botanical Gardens in the Wonorejo area using three dimensions: ecology, economics, and social aspects. The study found that the sustainability level was in the moderately sustainable category at 50.14%. This study expands the analytical framework to five dimensions: ecology, economics, social aspects, institutions, infrastructure, and technology, resulting in a more comprehensive sustainability assessment relevant to the complexities of the current area management system.

2. Methods

This descriptive analytical study used an integrated quantitative and qualitative approach. The main data for this study are survey data and assessments of the five dimensions of sustainability: ecological, economic, social, institutional, and infrastructural, in the Kebun Raya Mangrove Surabaya. Secondary data consisted of spatial data of the locations, data of the management institutions, and supporting data from the respective agencies. The materials used were stationery, questionnaires, a digital camera for documentation, and *Microsoft Excel* for statistical analysis. The research materials were the data obtained through interviews, field observations, and the supporting documents related to mangrove ecotourism management. The research materials comprised data obtained through interviews, field observations, and supporting documents related to mangrove ecotourism management.

2.1. Location and research period

This research focuses on Kebun Raya Mangrove Surabaya, which is located in Medokan Sawah and in Gunung Anyar districts (Figure 1). The research site covers only a few fragments of the total area of Kebun Raya Mangrove Surabaya (34 ha), located at 7°19'52.15" S latitude and 112°49'02.00" E longitude in the Gunung Anyar district, Surabaya City. Several reasons led to the choice of two regions (Medokan Sawah and Gunung Anyar) as the research area. The reasons for selecting Anyar include its proximity to a mangrove conservation area; second, because Anyar is a rapidly developing ecotourism destination;

third, because Anyar has a high number of visitors; and fourth, because Anyar serves as the management headquarters. This research will be conducted from October to November 2025.

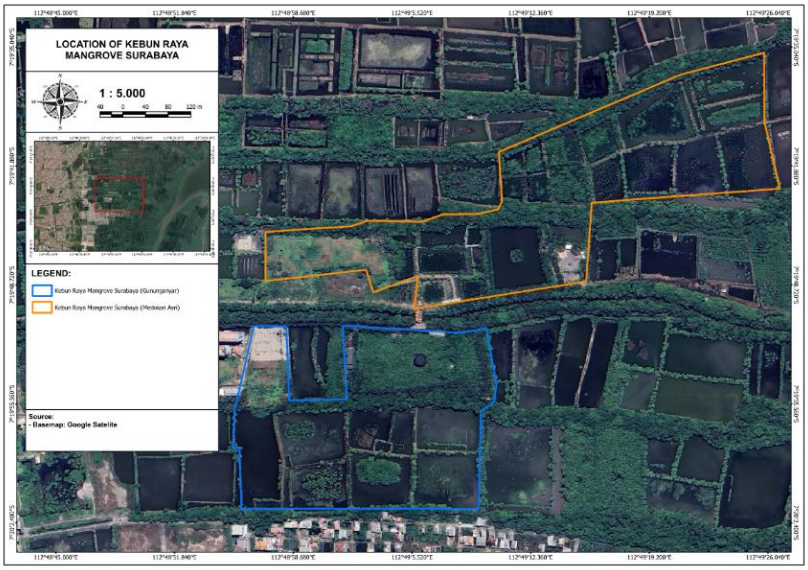

Figure 1. Map location of Kebun Raya Mangrove Surabaya

2.2. Sustainability dimensions and attributes

Multidimensional scaling (MDS) was used to evaluate the sustainability status of managing mangrove ecotourism. Five fundamental factors were integrated into this framework: ecology (eight attributes), economy (10 attributes), social (seven attributes), institutional (10 attributes), and infrastructure and technology (eight attributes). These five dimensions were represented by 43 attributes. All attributes included the availability of physical facilities and digital promotion tools, as well as biophysical conditions, financial contributions, participation levels, and the efficacy of policies. The respondents used an ordinal scoring scale ranging from 0 (poor) to 2 (good) to evaluate each important quality, which was then processed in the data analysis. Table 1 presents the sustainability dimensions and attributes. All these attributes are important because they simultaneously represent key factors that determine the sustainability of the management system (Sukuryadi, 2026).

Table 1. Sustainability dimensions and attributes

Dimensions	Attributes
Ecology	(1) Coastal abrasion level[(b;c)]; (2) pressure on the mangrove ecosystem[(b;d)]; (3) mangrove species diversity[(b;d)]; (4) mangrove fauna diversity[(b;d)]; (5) mangrove density[(b;c;d)]; (6) mangrove cover[(b;c;d)]; (7) mangrove rehabilitation[(c;d)]; (8) availability of mangrove seedlings[(c)].
Economy	(1) Utilization of the economic value of the mangrove ecosystem[(b, c, d)]; (2) average income of local communities[(a, b, c, d)]; (3) stakeholder involvement[(b, d)]; (4) contribution to regional GDP[(b, d)]; (5) ticketing and retribution management system[(g)]; (6) price affordability for visitors [(g)]; (7) development of mangrove-based enterprises [(c)]; (8) absorption of local workers [(b, d)]; (9) CSR funding support[(c)]; and (10) diversification of tourism attractions [(g)].
Social	(1) social impacts of mangrove presence[(c)]; (2) community participation[(b, c, d)]; (3) education level of the surrounding community[(a, b, c, d)]; (4) community access to mangrove ecosystems[(b, d)]; (5) conflicts regarding the use of mangrove resources[(b, c,

Dimensions	Attributes
	[d]; (6) mangrove ecosystem damage by the community[b, d]; and (7) public awareness of the importance of mangrove ecosystems[b, d].
Institutional	(1) Policies and management planning for the area[a;b;d]; (2) availability of formal/non-formal regulations for area management[a;b;d]; (3) government support[a]; existence of farmer groups/fishermen groups/community institutions[d]; (5) coordination of related stakeholders[b;d]; (6) compliance with management regulations[d]; (7) enforcement of sanctions on violators[b]; (8) supervision and monitoring[a;b;c;d]; (9) legality of the mangrove botanical garden area[c]; and (10) performance of formal institutions in ecotourism management[c].
Technology and Infrastructure	(1) Accessibility of roads and transportation to ecotourism locations[a, e]; (2) completeness of tourism facilities[e]; (3) availability of supporting facilities[a, e]; (4) information and promotion systems[e]; (5) education and interpretation facilities[f]; (6) research infrastructure[f]; (7) waste management and cleanliness systems[e, f]; and (8) availability of Internet and communication networks for management and visitors[e, f].

Sources : [a](Lestari et al., 2024); [b](Haris et al., 2021); [c](Kuvaini et al., 2019); [d](Muhsimin et al., 2018); [e](Hasna et al., 2025); [f](BRIN, 2024); [g](Putri et al., 2024).

2.3. Respondent and data collection

Sampling was conducted using purposive sampling (expert judgment), which aims to obtain an accurate and relevant assessment based on the respondents' competence and experience with the research object (Lestari et al., 2024). Expert respondents were selected from various stakeholder groups possessing a strategic role and an in-depth understanding of the conditions and management of the Kebun Raya Mangrove Surabaya. The target stakeholder groups included government representatives (relevant agencies/offices), academics, area managers, non-governmental organizations or conservation communities, business actors, and local community members (Haris et al., 2021). The total number of respondents in this study was 60, who were selectively chosen based on their direct involvement or experience in the management and development activities of the mangrove area. Primary data were collected through structured questionnaires containing score assessments for the 43 sustainability attributes, which were subsequently supplemented and validated using qualitative data from in-depth interviews with key informants and field observations to reinforce the accuracy of the analysis results.

2.4. Analysis of data

A sustainability analysis of the ecotourism area was conducted quantitatively using the multidimensional MDS Rapfish ordination technique. This approach is designed to comprehensively measure the sustainability status by integrating five crucial dimensions. The process commenced with data collection, which involved the assessment of attributes by experts (expert judgment) and field observations, wherein each attribute was evaluated using an ordinal score ranging from 0 (poor) to 2 (good). The validated ordinal data were subsequently processed using the MDS Rapfish system. The main output of this analysis is a 0–100 index value (Fauzi and Anna, 2005), with the sustainability status classified into four categories, ranging from unsustainable (0.00–25.00), less sustainable (25.01–50.00), moderately sustainable (50.01–75.00), to highly sustainable (75.01–100.00). This provides a clear depiction of the area's position. The categories resulting from the MDS analysis are presented in Table 2.

Table 2. Classification of multidimensional scaling (MDS) analysis result categories

No.	Index Value	Category
1.	0.00-25.00	Poor (unsustainable)
2.	25.01-50.00	Low (less sustainable)

No.	Index Value	Category
3.	50.01-75.00	Moderate (moderately sustainable)
4.	75.01-100.00	Good (Highly sustainable)

Sources: Zulkifli et al. (2025)

To ensure the quality and integrity of the results, data validity was tested using Monte Carlo analysis and the *goodness-of-fit* test. Monte Carlo analysis is a simulation-based statistical method used to test the stability and reliability of analysis results by repeating calculations using random variations in the input data. This method is carried out at a 95% confidence interval or a 5% error rate (Setiacahyandari and Hizbaron, 2023). The stress value test was used to assess the level of accuracy and suitability of the MDS ordination results to the original data, whereas the coefficient of determination (R^2) was used to indicate the proportion of data variation that can be explained by the MDS model. The stress value must be below 0.25 (ideally <0.15), and the coefficient of determination (R^2) must be close to 1 (one) (Citation). Finally, leverage analysis was used to identify the most sensitive attributes with the greatest impact on the sustainability index resulting from changes (Parmawati and Hardyansah, 2020).

3. Result and Discussion

3.1. Multidimensional scaling (MDS) analytic result

3.1.1 Ecology dimension

The ecological sustainability status of the Kebun Raya Mangrove Surabaya, was determined from MDS analytic have an index value of 86.25 (figure 2), which is classified as highly sustainable, based on the Haris et al., (2021) classification and 0-100 scale. Through these findings, mangrove ecosystems have been identified as the main pillars of ecological sustainability via various natural mechanisms that make environmental recovery and resilience possible (Sulastri et al. 2022). Nevertheless, this perfect score still demands that managers, stakeholders, and the government maintain regular management, monitoring, and evaluation to ensure that ecological pressure resulting from a large number of tourists does not lower the area's environmental carrying capacity (Hamit et al. 2025).

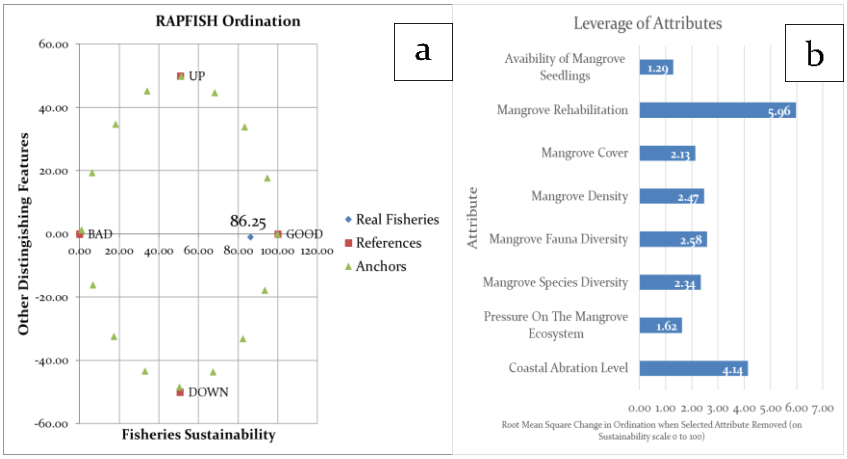

Figure 2. (a) Rapfish result on ecology dimension, (b) Leverage analysis of ecology dimension

Based on the Rapfish leverage analysis, the ecological dimension's sustainability score was mostly influenced by several leverage attributes. Three single attributes with the highest root mean square (RMS) values were mangrove rehabilitation (RMS = 5.96), coastal abrasion level (RMS = 4.14), and mangrove fauna diversity (RMS = 2.58) (Figure 2). Mangrove rehabilitation is the main leverage for ecological sustainability, with the highest RMS value of 5.96, showing the successful restoration of coastal ecosystems affected by human activities and natural causes (Rahadian et al., 2022). Intentionally carried out rehabilitation can expand vegetation cover, improve coastal soil quality, and return mangroves to

their role as coastal protectors and biota habitats (Amalo et al., 2025). Hence, the success of this program is largely determined by the overall condition of the ecosystem (Handayani et al., 2024). The coastal abrasion factor, which has an RMS value of 4.14, is equally important because severe abrasion can lead to the destruction of crucial mangrove habitats, which not only provide natural protection of the coast but also help solve climate change problems. In addition, mangrove fauna diversity, with an RMS value of 2.58, continues to be a vital indicator of an ecosystem's well-being, as it reflects that the food chain is stable and that the ecosystem is productive (Sari et al., 2023). The three factors are mutually interrelated in supporting the ecological stability of the area not only by increasing vegetation cover but also by strengthening coastal structures and preserving biota habitats.

3.1.2 Economic Dimension

The economic sustainability status of the Kebun Raya Mangrove Surabaya, indicated an index value of 63.52 (Figure 3), which denotes moderate sustainability. This situation shows that ecotourism activities have been a source of positive economic inflows through revenue from levies, employment of local communities, and increased economic activities in the area.

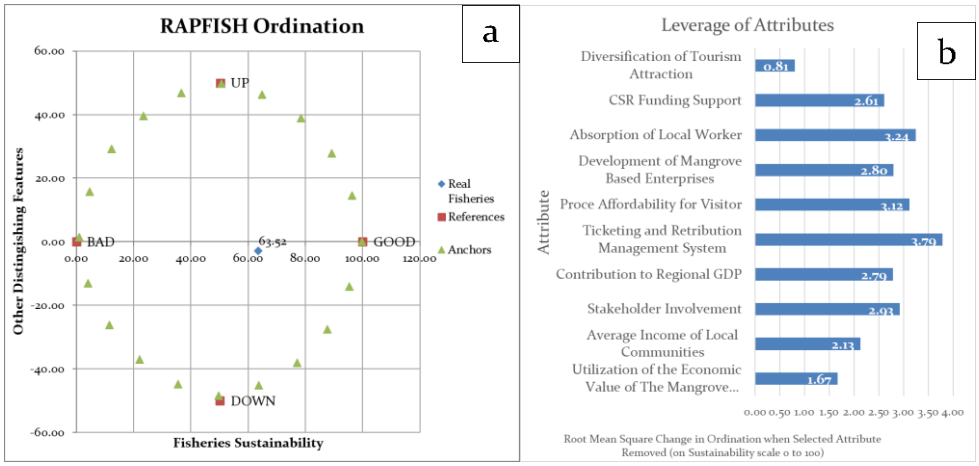

Figure 3. (a) Rapfish result on economic dimension, (b) Leverage analysis of economic dimension

The leverage analysis results using the RAPFISH method (Figure 3) revealed that several attributes were the most sensitive factors influencing economic sustainability. The Top three attributes with the highest RMS values were the ticketing and retribution management system (RMS = 3.79), the absorption of local worker (RMS = 3.24), and price affordability for visitors (RMS = 3.12). The ticket and retribution management system is the main leverage for economic sustainability, with a high RMS value of 3.79 indicating the effectiveness of the financial management mechanisms of an area, which leads to the generation of revenues from ticketing and tourism levies. Good management will attract more people and visitors, and will guarantee that the monies collected can be used to support conservation and the extension of tourism facilities (Phondetparinya & Seenprachawong, 2019). In addition, the absorption of local workers is another way in which economic sustainability can be achieved, as shown by an RMS value of 3.24. The involvement of the local community in tourism management and the provision of services will not only lead to their well-being but also help develop a sense of ownership of the area (Kia, 2021). Additionally, visitor affordability, reflected by an RMS of 3.12, is the main factor determining tourism attractiveness and contributing to a steady tourism income. Thus, it is necessary to maintain a balance between economic rates and proper management of the area for sustainability. In general, the economic dimension of the Surabaya Mangrove Botanical Gardens is considered quite sustainable, indicating that economic activity in the area is running well but still has room for further growth.

3.1.3 Social Dimension

Results from the MDS analysis with the Rapfish approach reveal that the social dimension of the Kebun Raya Mangrove Surabaya obtains a sustainability index of 89.13 (Figure 4), which is equivalent to a highly sustainable category on a 0–100 scale. The social aspects of ecotourism management represented by this score are those that are running smoothly and contributing to the system's long-term viability. These circumstances find expression in the active participation of the local community in environmental conservation, rising environmental awareness, and the establishment of friendly relationships among managers, residents, and visitors.

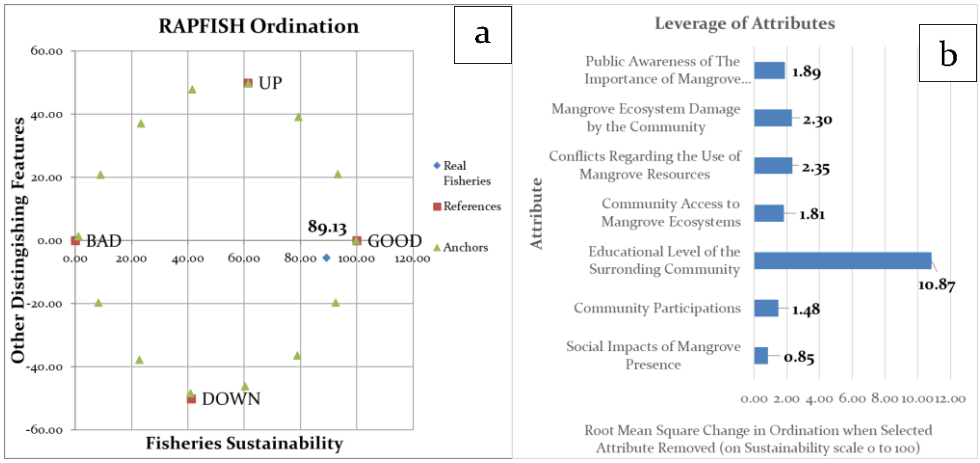

Figure 4. (a) Rapfish result on social dimension, (b) Leverage analysis of social dimension

According to the leverage analysis results (Figure 4), the main factors with the highest RMS values are those that indicate the most sensitive changes in the social dimension of sustainability in the area. The three attributes with the highest RMS values are the education level of the surrounding community (RMS = 10.87), conflicts regarding the use of mangrove resources (RMS = 2.35), and mangrove ecosystem damage by the community (RMS = 2.30). These three attributes are the mainstay for maintaining social equilibrium and providing the foundation for the successful, long-term implementation of sustainable ecotourism management. The level of education of the people living around the area is the biggest factor in the social dimension, with the highest RMS of 10.87, and it has a profound effect on people's understanding of the need for the preservation of nature and their involvement in ecotourism management (Achyani et al., 2025). People with a higher level of education are generally more environmentally conscious, implement good conservation mechanisms, and are usually very active in ecotourism-based activities (Itfan, 2023). Therefore, increased access to environmental education and training is an effective strategy for strengthening an area's social sustainability. In addition, disputes over mangrove resource utilization have an RMS value of 2.35 and are also influential factors behind social stability, as the involvement of different people, such as fishermen, tourism managers, and local community members in the conflict can cause them to become entangled and hence hinder conservation programs (Bidayani et al., 2024). The community attribute of mangrove ecosystem damage, with an RMS of 2.30, is also a factor that affects the social side of the community. Participating in environmentally unfriendly activities, such as illegal logging or waste disposal, could degrade the ecosystem (which in turn reduces the socioeconomic benefits that the community can gain), while the community may not even be aware of this (Sind et al., 2024). Overall, the social aspect of the Kebun Raya Mangrove Surabaya is in good shape and can be regarded as highly sustainable. Nevertheless, maintaining such a sustainable condition requires constant efforts to enhance community capacity through environmental education, joint conflict resolution, and the application of a reward scheme for communities that are actively engaged in mangrove ecosystem conservation (Sri et al., 2025).

3.1.4 Institutional Dimension

The results of the MDS analysis using the RAPFISH method show that the institutional dimension of Kebun Raya Mangrove Surabaya has a sustainability index of 84.51 (Figure 5), which is highly sustainable based on the category under the 0–100 scale. This signifies that the mangrove ecosystem is supported by a well-functioning institutional framework that has the capacity to sustain it for a long time. Besides, it portrays that the governance system, stakeholder coordination, and regulatory enforcement within the ecotourism area are operating at a good level of stability and efficiency.

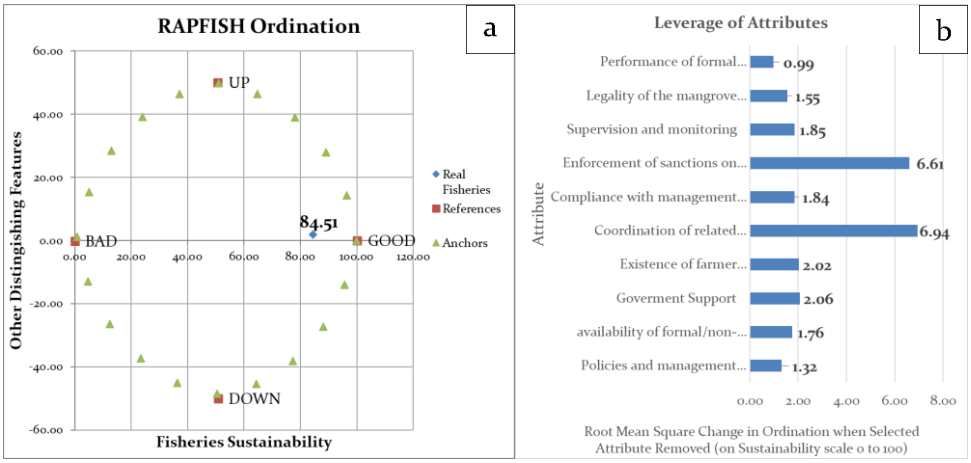

Figure 5. (a) Rapfish result on institutional dimension, (b) leverage analysis of institutional dimension

According to the leverage analysis (see Figure 5), the changes in the number of attributes of different types that had the highest RMS values. Thus, these attributes are the most sensitive factors that can bring about changes in the area 'sinstitutional sustainability status. The top three attributes with the highest RMS values were: coordination of related stakeholders (RMS = 6.94), enforcement of sanctions on violators (RMS = 6.61), and government support (RMS = 2.06). In fact, these three attributes are the main ones that lead to target-oriented, ecologically sound management, and in the end, the management of ecotourism areas will become self-sustainable.

Coordination of related stakeholders is the attribute that has the most significant influence on the institutional dimension, with the highest RMS value of 6.94. The effectiveness of ecotourism management is mostly caused by the synergy between local governments, area managers, local communities, academics, and the private sector (Landoni et al., 2024). Strong coordination not only ensures that conservation programs, tourism management, and community economic activities can be conducted in harmony without conflicts of interest arising (Habel et al., 2023). In addition, the enforcement of sanctions on violators, with an RMS of 6.61, is an institutional aspect that substantially influences enforcement, which is at the core of compliance in ecotourism area management, as violation of rules should be met with firm and consistent sanctions (Smith, 2022). Government support, with an RMS of 2.06, is moreover, a very important factor, especially when it is materialized in the form of pro-ecological policies, financing, as well as the facilitation of training and mentoring activities for communities, which, as a whole, lead to the strengthening of the area's institutional capacity (Aqilah and Islam, 2024). The institutional dimension of Kebun Raya Mangrove Surabaya generally exhibits a highly sustainable state. The three elements form a network of an effective and adaptive governance system to the region's dynamics. Nevertheless, to maintain this sustainable status, the institutional sector must not only enhance its capacity through deepened cross-sectoral coordination but also more law enforcement that is consistent and a government commitment to promoting sustainable mangrove ecosystem-based management policies (Mulyani et al., 2021).

3.1.5 Infrastructure and Technology Dimension

The outcomes of the MDS analysis indicate that the sustainability index for the infrastructure and technology dimension of the Kebun Raya Mangrove Surabaya is 88.07 (Figure 6), which means that

it is a highly sustainable category on a scale from 0 to 100. This number reflects that the infrastructure and technology in the area are in perfect condition and are a source of sustainability for mangrove ecotourism management in the long run. This implies that the fundamental infrastructure, accessibility, and technological means that are available in the area and support conservation, tourism, and environmental education activities are functioning successfully.

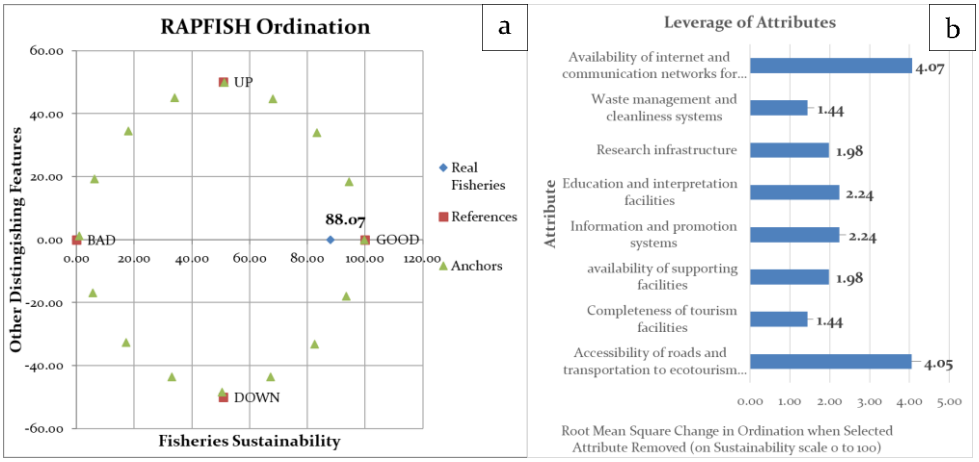

Figure 6. (a) Rapfish result on infrastructure and technology dimension, (b) Leverage analysis of infrastructure and technology dimension

Based on the findings of the leverage analysis (Figure 11), several attributes show the highest RMS values, indicating the most sensitive factors with regard to changes in the sustainability situation of the infrastructure and technology dimensions. The top three attributes with the highest RMS values are the availability of Internet and communication networks for management and visitors (RMS = 4.07), accessibility of roads and transportation to ecotourism locations (RMS = 4.05), and education and interpretation facilities (RMS = 2.24). The availability of Internet and communication networks for management and visitors was identified as the most significant lever, with a highest RMS value of 4.07. This is because adequate digital connectivity not only greatly facilitates the efficiency of the area management system but also makes tourism information more accessible to visitors (Ji and Deng, 2025). In addition, the accessibility of roads and transportation to ecotourism locations (RMS = 4.05) is heavily implicated in the continuance of the area's viability, as easy access not only beckons more visitors but also supports the economic activities of local communities (Iamtrakul et al., 2025). The attribute of education and interpretation facilities (RMS = 2.24) plays a major role in the process of strengthening ecotourism as a medium of environmental learning, which in turn helps visitors comprehend the ecological value of the mangrove based on an educational approach that is quite effective in raising people's awareness of the importance of the conservation of the coastal ecosystem (Verawati and Idrus, 2023). In summary, the infrastructure and technology dimensions at Kebun Raya Mangrove Surabaya are in a highly sustainable condition. The three attributes therefore interact with each other, leading to a stronger effect of the area as a conservation-based ecotourism destination. Although the achievement of such an ecological milestone level calls for a persistent effort remaining of digital infrastructure, the continuity of sustainable transportation facilities, and the growth of interactive educational facilities that would foster community and tourist participation in the mangrove ecosystem conservation are absolutely necessary (Mendoza, 2025).

3.2. Validity of multidimensional scaling (MDS) analysis result

Monte Carlo analysis is a method of function that is used by Fauzi (2019) to identify error sources that result from the variability of data. Various errors may arise in Rapfish because of (1) the effect on the attribute scoring caused by insufficiency of the information, misunderstanding of the attributes, or the method of attribute scoring;(2) the influence of scoring differences due to different opinions or different

assessments by the researchers;(3) the stability of the repeated multidimensional scaling (MDS) analysis process (unstable anchor positions); (4) mistakes in the data entry or missing data; and (5) high "stress" values in the analysis results. Errors were identified through a comparison between the MDS index value and the Monte Carlo value. Table 3 presents a comparison of the sustainability indices of the MDS and Monte Carlo results.

Table 3. Results of validity analysis using the Monte Carlo method

Dimensions	Analysis Result		
	MDS Value (%)	*Monte Carlo* (%)	Difference (%)
Ecology	86.25	83.15	3.10
Economy	63.52	62.32	1.20
Social	89.13	85.59	3.54
Institution	84.51	81.36	3.15
Infrastructure & Technology	88.07	84.63	3.44

The results of the Monte Carlo analysis can be used to determine the reliability and stability of the research data. The difference between the sustainability index values from the MDS and the simulated index values for all five dimensions is less than the relative error threshold, which is 5% (ranging from 1.20% to 3.54%). This tiny difference indicates that the analysis process was stable, that the variation in scoring among respondents was low, and that the model was successful in avoiding missing-data errors. Therefore, the findings on the sustainability status of the Kebun Raya Mangrove Surabaya are highly sustainable. The validity of the MDS analysis results can also be estimated through the goodness-of-fit method using the stress value and the coefficient of determination (R^2). Fauzi (2019) provided the following criteria for a good MDS model: the stress value should be less than 25%, and the coefficient of determination (R^2) should be more than 80%. The results of the validity test are presented in Table 4.

Table 4. Goodness of fit value result

Dimension	Stress value	R^2
Ecology	13.77	94.88
Economy	14.01	94.98
Social	13.90	94.39
Institution	13.37	94.92
Infrastructure & Technology	13.85	94.93

The results of the goodness-of-fit analysis indicated that the stress values for the five dimensions varied from 13.37% to 14.01%, which was far below the required 25% threshold. In line with this, the determination coefficient (R^2) was very close to 1 for all cases, being more than 94% (exceeding the 80% threshold) in each dimension. This excellent goodness-of-fit criterion verifies that the attributes in the five dimensions are statistically valid and reliable representatives of the sustainability conditions of the area (Parmawati and Hardyansah, 2020).

3.3. Sustainability status of mangrove ecotourism areas based on dimensions

Leverage analysis (Table 5) identified a number of attributes as the most sensitive and influential contributors to the change in the sustainability index value of the Kebun Raya Mangrove Surabaya for all dimensions of sustainability. These attributes are the main factors that most strongly determine the management direction and overall sustainability of the ecotourism area.

Table 5. Sensitive attributes in each dimension

Dimension	Attributes
Ecology	(1) mangrove rehabilitation
	(2) coastal abrasion level
	(3) mangrove fauna density
Economy	(1) ticketing and retribution management system
	(2) absorption of local worker
	(3) price affordability for visitor
Social	(1) education level of the surrounding community
	(2) conflicts regarding the use of mangrove resources
	(3) mangrove ecosystem damage by the community
Institution	(1) coordination of related stakeholders
	(2) enforcement of sanctions on violators
	(3) government support
Infrastructure & Technology	(1) availability of internet and communication networks for management and visitors
	(2) accessibility of roads and transportation to ecotourism locations
	(3) education and interpretation facilities

The sensitive attributes for each dimension largely illustrate the ecological, economic, social, institutional, and technological factors interplay in the formation of an adaptive and sustainable ecotourism management system. Therefore, to enhance regional sustainability, it is necessary to concentrate on optimizing these attributes through heightened cross-sectoral coordination, community empowerment, and the employment of conservation-based and locally usable technologies that not only solve socioeconomic problems but also improve the standard of living of the local people. This is particularly important given that Setiawati 's(2019) research showed that low levels of community participation, a poor quality of the coastal environment, and decreasing mangrove density are the factors that lead to a sustainability score that is only in the moderately sustainable category (50.14%). Thus, the higher result obtained in this study confirms that social, ecological, and institutional integration at a higher level is the main factor that has led to the sustainability status moving up compared to previous research.

Moreover, the findings of the MDS analysis (Table 6) reveal that the sustainability condition of the Kebun Raya Mangrove Surabaya reached an index of 83.20. This index value, which was measured through the integration of the five dimensions of ecology, economy, social, institutional, and infrastructure and technology, places the management of the area in the highly sustainable category. The soundness of this result is in line with the strong statistical parameters of the model, as evidenced by the Stress and R^2 values, which meet the criteria of model accuracy and reliability. This is indicative of good management performance in the ecotourism area, which is in line with sustainability principles across sectors.

Table 6. Multidimensional scaling (MDS) values and sustainability status

Dimensions	MDS Value	Status
Ecology	86.25	Highly Sustainable
Economy	63.52	Moderate Sustainable
Social	89.13	Highly Sustainable
Institution	84.51	Highly Sustainable
Infrastructure & Technology	88.07	Highly Sustainable
Average	83.20	Highly Sustainable

From these findings, the sustainability index values of the five dimensions were used to create a sustainability diagram (Figure 7) that shows that overall, the management of the Kebun Raya Mangrove Surabaya is very sustainable. To maintain and improve the index value in the future, continuous maintenance and strengthening efforts are needed for the sensitive attributes that influence each dimension.

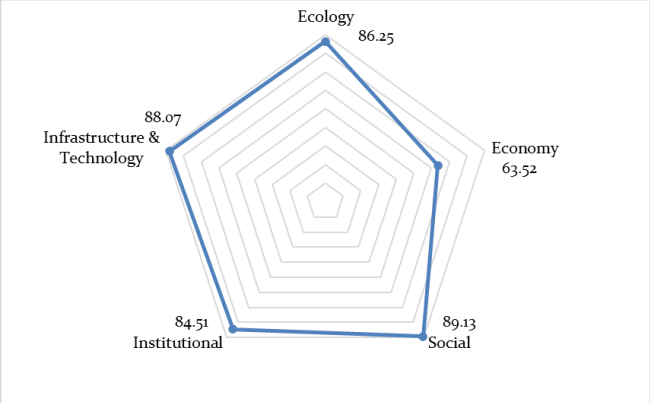

Figure 7. Five-dimensional sustainability index diagram

In general, the analysis findings reveal that Kebun Raya Mangrove Surabaya has a high level of sustainability, as reflected by the average index of 83.20, which is a good indication of management performance across all dimensions. However, the leverage analysis results signal that some attributes are still very important and demanding attention, particularly the economic dimension, which is at the lowest point among the other dimensions. This indicates the need to optimize community-based economic management in such a way that the benefits arising from ecotourism are distributed fairly without sacrificing the area's ecological functions. Some of the major recommendations consistent with the results are the establishment of a more transparent, efficient, and equitable ticketing policy and the enhancement of conservation-based training and community empowerment programs (Khambali et al., 2020). In addition, stakeholder coordination should be a continuous process, and mangrove rehabilitation activities should be the main drivers (Aqilah and Islam, 2024). Moreover, regular checking of these vulnerable points is a significant step in avoiding the decline in the area's sustainability status in the coming years (Singgalen and Manongga, 2022).

4. Conclusions

The results of the MDS analysis using the RAPFISH approach show that the management of the Kebun Raya Mangrove Surabaya in aggregate is in the highly sustainable category, with an average index value of 82.30. There are four out of five dimensions at the highly sustainable level: ecology (86.25), social (89.13), institutional (84.51), and infrastructure and technology (88.07); thus, implying that the overall management of the area is excellent. However, the economic dimension is the only one that is at a moderately sustainable level, with an index value of 63.52, thereby suggesting that the economy should be given special attention to reach the optimal level of sustainability.

To maintain its highly sustainable status and encourage the economic dimension to reach the same level, strategic and integrated steps are required from management and the local government. Among the major recommendations are the formulation of a transparent, efficient, and equitable ticketing policy and the empowerment of conservation-based community training programs through the provision of local community skills. Additionally, stakeholder collaboration involving relevant partners and mangrove restoration activities should be consistently carried out as driving factors. Keeping track of these crucial attributes on a regular basis is a decisive step in averting postponements in the area's sustainability status (Kia, 2021).

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Ethics Statement

This study did not involve human participants, animals, or sensitive data; therefore no ethical approval was required.

Credit Author Statement

Yunita Suci Amalia: Conceptualization, Research Design, Data Analysis, Spatial Distribution Assessment, Manuscript Preparation, Wrote Paper. **Mohammad Khusaini:** Review of Technical Approval, Policy Document, Support Effectiveness Analysis. **Dini Atikawati:** Compilation and Processing Secondary Data, Spatial Data Support, Asisstance Data Interpretation. **Bunga Hidayati:** Proofreading and Language Editing, Consistency Cecking Manuscript. **Gita Prismadianto:** Methodological Supervision and Critical Review, Scientific Validation to Strengthen the Analytical Framework.

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