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Sustainability Status of the Mangrove Ecosystem on the North Coast of West Java

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ABSTRACT

The mangrove forests across five districts in West Java—Bekasi, Karawang, Subang, Indramayu, and Cirebon—cover over 43,000 hectares but are severely degraded, with about 90% damaged. This decline is driven by land conversion and poor water quality which also threatens coral reefs and increases flooding risks. Current efforts by communities, private sectors, and government lack effective coordination, leading to prolonged environmental problems. Mangroves offer high economic potential, but sustainable and innovative management is critical. The study aimed to assess the sustainability status using the multidimensional scaling (MDS) method with Rapfish. Results show that all surveyed areas score below 50 on the sustainability index, with an overall score of 46.74%, indicating a "less sustainable" classification.

INTRODUCTION

Mangrove ecosystems are highly productive coastal systems that provide essential ecological benefits, such as nutrient provision, marine biota habitat, coastal protection, and natural disaster buffering **(Kuenzer *et al.*, 2011; Sasidhar *et al.*, 2013; Giri *et al.*, 2015; Masood *et al.*, 2015; Abadi, 2023)**. Economically, mangroves provide food, forest products, and support the economic and ecotourism activities of coastal communities. Therefore, the existence and sustainability of mangrove ecosystems must be maintained in terms of both quality and quantity **(Kusmana, 2014; Saiful *et al.*, 2023)**.

According to **Open Jabar (2022)** data, mangrove forests on the north coast of West Java cover an area of 43,362.09 ha spreading across five districts, but around 90% (39,138.54 ha) are in damaged condition. This damage is caused by land-use change and declining water quality, which increase the risk of tidal flooding. The carrying capacity of the environment in this region has exceeded its threshold, while collaboration between

the community, private sector, and government remains suboptimal. As a result, proper and sustainable management is urgently needed **(West Java Provincial Environment Office, 2022)**.

The decline of mangrove ecosystems is not proportional to population growth and increased economic activity. Although some northern coastal areas of West Java have been developed as ecotourism sites, utilization remains suboptimal because communities do not fully harness mangrove resources. In fact, the potential of mangrove tourism is very large and can support the local economy. Therefore, sustainable and collaborative management between stakeholders is essential **(Harahap *et al.*, 2018)**.

According to **Nuitja (1987)** and **Kartamihardja *et al.* (2009)**, Indonesia's marine resource potential is enormous and supports the national vision as a maritime axis, with rich biodiversity and an extensive coastline. Mangrove forests play a crucial ecological and economic role, but many are degraded due to land-use change and pollution. On the North Coast of West Java, around 90% of mangrove forests are damaged, heightening the risks of abrasion and tidal flooding. To address this, in 2022 the Ministry of Environment and Forestry (KLHK) undertook rehabilitation efforts, successfully planting 1,210 hectares of mangroves—exceeding the target of 1,100 hectares. However, in West Java's North Coast (Pantura) region, the condition of mangrove forests remains very concerning. Out of approximately 43,000 hectares, 90% (around 38,700 hectares) are damaged. The most affected areas include Indramayu, Subang, Karawang, and Cirebon **(Ministry of Environment and Forestry, 2021)**. Effective restoration requires strong collaboration among government, communities, and other stakeholders.

Indonesia contains about 25% of the world's mangrove area, hosting remarkable biodiversity: 48 species of mangroves, 74 species of mollusks, 5 species of crabs, 34 species of shrimp, 60 species of fish, 8 species of reptiles, more than 200 species of birds, and 12 species of mammals living in mangrove ecosystems **(Malik, 2019; Efriyeldi *et al.*, 2023)**. Supported by 108,800km of coastline and thousands of rivers, mangrove tourism management must be integrated with protection efforts. This aligns with Presidential Decree No. 32 of 1990 on Protected Area Management and Minister of Home Affairs Instruction No. 26 of 1997 on the implementation of forest green belts, which are applied in the context of mangrove forests across Indonesia. Proper mangrove management is also crucial for achieving the sustainable development goals (SDGs), particularly in the economic, environmental, and social domains. However, mangrove ecosystems continue to face threats from land conversion for aquaculture, reclamation, and plantations. Therefore, mangrove area management must adopt a collaborative governance approach to ensure that mangrove ecotourism development is sustainable and effective **(Ansell & Gash, 2007)**.

Studies in Karangsong, Indramayu, show that mangrove ecosystems have strong potential for ecotourism development but require sustainable management to prevent environmental damage **(Priadi, 2018)**. Meanwhile, in Tangkolak, Karawang,

communities support mangrove conservation and marine tourism, but obstacles such as lack of government and corporate support, along with sanitation issues, hinder progress **(Abadi, 2021)**. In Tangerang Regency, the sustainability status of mangrove ecosystem management was assessed using the Rapfish method with a multidimensional scaling (MDS) approach. The results indicated that mangrove ecosystem management across four dimensions was categorized as moderately sustainable **(Rani *et al.*, 2022)**.

MATERIALS AND METHODS

The method used in this study relates to assessing the status and sustainable management of mangrove ecosystems through a multidimensional scaling (MDS) approach using the Rapfish method. The research was conducted in mangrove areas along the north coast of West Java, including Bekasi, Karawang, Subang, and Indramayu, with five sampling locations. The study was carried out over 12 months, and data were collected through questionnaires, focus group discussions (FGDs), and direct interviews with respondents. Additional data were obtained from related agencies, literature reviews, and relevant research.

The sample size was determined using the Lemeshow formula, as the total population size was unknown. Based on the calculation, 500 respondents were selected across the five study locations. FGDs and interviews were conducted to explore management and development strategies, with resource persons including managers, NGOs, extension workers, government representatives, and academics from the northern part of West Java.

The analytical method for determining sustainability status and leverage attributes employed the Rapfish method with an MDS approach. According to **Yudhari (2022)**, this analysis covers four dimensions of mangrove ecosystem management: ecological, economic, social, and institutional. The basic concept of the MDS method involves mapping objects or points in a space, where similar objects or points are located close together, while dissimilar ones are placed further apart. The results of the MDS analysis are presented as an index value (0–100) that reflects the sustainability status of the study object based on actual conditions and ordination across each dimension.

According to the **Ministry of State for the Environment (2004)**, sustainability analysis with the Rapfish method consists of three stages:

1. Determining attributes or indicators for each sustainability dimension.
2. Assessing attributes/indicators in each dimension through research questionnaires.
3. Evaluating sustainability index and status through ordination analysis using MDS, sensitivity analysis (leverage analysis), and anomaly analysis (Monte Carlo analysis).

In this study, 34 indicators were used to assess the sustainability of mangrove ecosystem management on the north coast of West Java. These consisted of seven

ecological indicators, eight economic indicators, eight social indicators, and eleven legal and institutional indicators (Table 1). The determination of these indicators was based on modifications from **Barbour *et al.* (1987)**, **Pitcher and Preikshot (2001)**, and previous studies **(Pattimahu *et al.*, 2010; Santoso, 2012; Theresia *et al.*, 2015)**, as well as considerations from field observations.

Table 1. Dimension attributes

Dimension	Attribute
Ecology	Mangrove land use zoning division
	Mangrove density conditions
	Mangrove diversity
	Mangrove ecosystem rehabilitation activities
	Diversity of fauna (animals) in mangroves
	The mangrove ecosystem here protects from abrasion/robbing floods
	The mangrove ecosystem does not change function to become another land
Economy	This mangrove ecosystem increases the contribution to regional income
	The mangrove ecosystem can be utilized by the community
	The mangrove ecosystem increases the average income of the surrounding community (tourism)
	Results of mangrove forest utilization inventory
	The existence of mangrove ecosystems increases employment opportunities
	Mangrove ecosystems can attract tourist visits
	Mangrove ecosystems increase business opportunities
	Mangrove ecosystems receive subsidies/assistance from private and state parties
Social	Knowledge about mangroves
	Easy public access to mangrove ecosystems
	Mangrove damage here is caused by the community
	Public awareness is important for mangrove resources
	Community participation is important in managing mangrove ecosystems
	Local wisdom is present in managing mangrove ecosystems
	Social conflicts
	Cooperation between stakeholders/communities
Legal and institutional	Mangrove ecotourism management policies and planning
	Role of management institutions

	Mangrove management regulations
	Involvement of village officials in managing mangrove ecotourism
	Cooperation between institutions/stakeholders
	Involvement of community institutions in management
	Legality of mangrove ecotourism areas
	Mangrove ecotourism management performance
	Transparency/openness to the ecotourism management system
	Monitoring and supervision
	Imposition of sanctions for violators

Source : **Primary Data (2024)**.

This attribute was assessed based on a score of 1-4, namely with a value of 1 = Not Good, 2 = Quite Good, 3 = Good, and 4 = Very Good. From the score assessment on each of these attributes, sustainability was then analyzed based on the **Pitcher and Preikshot (2001)** assessment index with the following criteria:

Table 2. Sustainability index

Index Value	Category
<25	Unsustainable
26-50	Less Sustainable
51-75	Quite Sustainable
76-100	Sustainable

Source : **Pitcher and Preikshot (2001)**.

RESULTS

The potential area of mangrove forests on the north coast of West Java reaches 43,362.09 ha, distributed across several districts, including Bekasi, Karawang, Subang, Indramayu, and Cirebon. However, approximately 90% (39,138.54 ha) of these mangrove forests are currently degraded (Fig. 1).

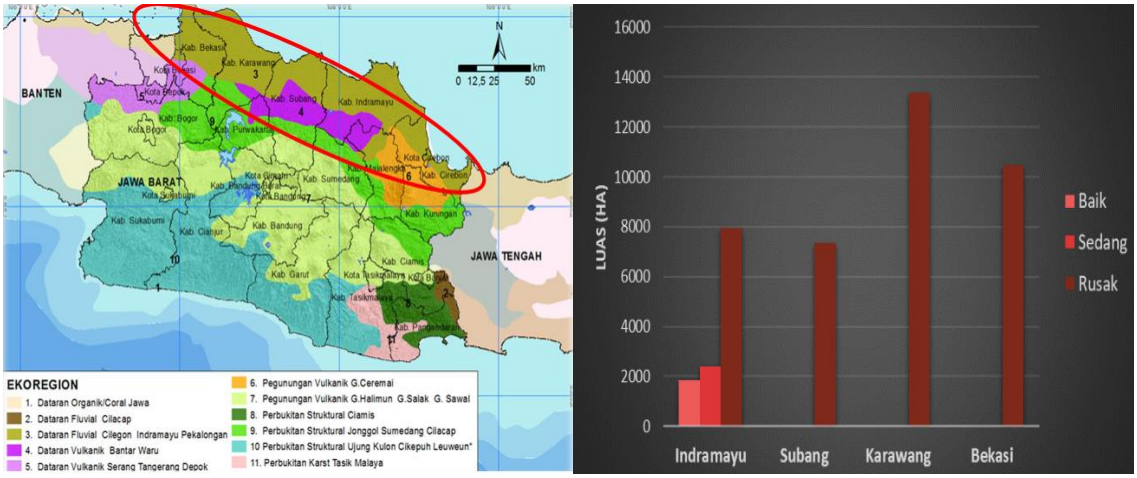


Fig. 1. Area of mangrove in North West Java

This damage is caused by land-use change, which leads to declining water quality, degradation of mangroves and coral reefs, and an increased risk of tidal flooding (Fig. 2). The decline of mangrove ecosystems is not proportional to the rate of population growth and economic activity. However, efforts to utilize mangrove ecosystems for ecotourism and mangrove-based products remain suboptimal. Many communities have not yet developed mangrove-derived products, making mangrove ecotourism less attractive. In fact, the development of mangrove tourism on the north coast of West Java represents a highly productive opportunity for economic activities. Nevertheless, its management must be carried out properly and collaboratively by relevant stakeholders.

Fig. 2. Mangrove damage in north West Java

The study was conducted in the coastal mangrove areas of north Java, including Bekasi, Karawang, Subang, and Indramayu, from August to October 2024. The analysis method used to determine sustainability status and leverage attributes was the Rapfish method with a multidimensional scaling (MDS) approach. The results are presented as follows:

1. Ecological dimension

Ecological attributes were selected based on their relevance to environmental health, namely: zoning of mangrove land use, mangrove density conditions, mangrove diversity, mangrove ecosystem rehabilitation activities, diversity of fauna in mangroves, the role of mangrove ecosystems as protection against abrasion/tidal floods, and land-use change. Based on the results of MDS analysis using Rapfish, the sustainability index value of the ecological dimension in mangroves was 44.17, which falls under the "less sustainable" category.

Zoning of mangrove utilization on the north coast of West Java (Indramayu, Subang, Karawang, Bekasi) has not been optimally organized. Most mangrove areas lack a clear zoning plan, resulting in overlapping functions between conservation, aquaculture ponds, and settlements. Based on the study of **Priadi (2018)** in Karangsong, Indramayu, mangrove tree density ranges from 200–400 trees/ha, classified as moderate to low. This density is influenced by plant age, mangrove type, and human activities such as logging and pond expansion.

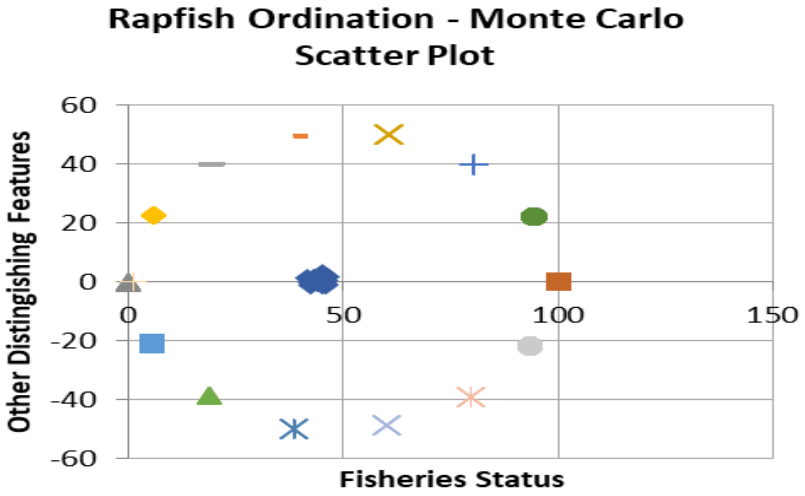
Mangroves in West Java are dominated by *Rhizophora mucronata*, *Avicennia marina*, and *Sonneratia alba*. A study by **Rahardi and Suhardi (2016)** in Subang recorded 8–12 species of true and associated mangroves in the region. However, land-use change and habitat degradation have reduced this diversity. Areas with lower diversity are more vulnerable to climate change and the loss of ecological functions. Despite relatively low density, West Java's coastal mangrove ecosystem is noted for its species richness. According to **Harahap *et al.* (2018)**, Indramayu's mangrove area serves as a habitat for various fish species, mangrove crabs (*Scylla* spp.), and shrimp such as *Penaeus merguiensis*.

Similarly, a study in the Muara Gembong (Bekasi) mangrove area by **Rahim *et al.* (2023)** recorded 20 fish species and 8 mollusk species, highlighting the significant biodiversity supported by mangrove ecosystems. However, mangrove conversion and pollution have contributed to declining diversity. **Faqih and Jumarang (2023)** found that species diversity in degraded mangrove areas was lower than in pristine sites.

This situation has important implications for surrounding ecosystems and communities. Rehabilitation efforts have been undertaken by the government, such as the Karangsong Village (Indramayu) project led by DLH Provinsi and the Wanadri Foundation (190 ha), and community-based rehabilitation in Mayangan Village (Subang). According to the **Ministry of Environment and Forestry (2021)**, West Java has a rehabilitation target of 1,000 ha per year. However, the success of these efforts depends heavily on the types of seedlings used, planting methods, and local community participation. Persistent challenges include mangrove conversion, lack of clear zoning, and limited effectiveness of rehabilitation efforts.

Rapfish ordination results of the sustainability status and leverage analysis on the ecological dimension (Fig. 3) highlight four indicators that are most sensitive to the sustainability index of this dimension:

1. Diversity of mangrove fauna.
2. Mangrove ecosystem rehabilitation.
3. Mangrove protection against tidal flooding.
4. Zoning of mangrove utilization.



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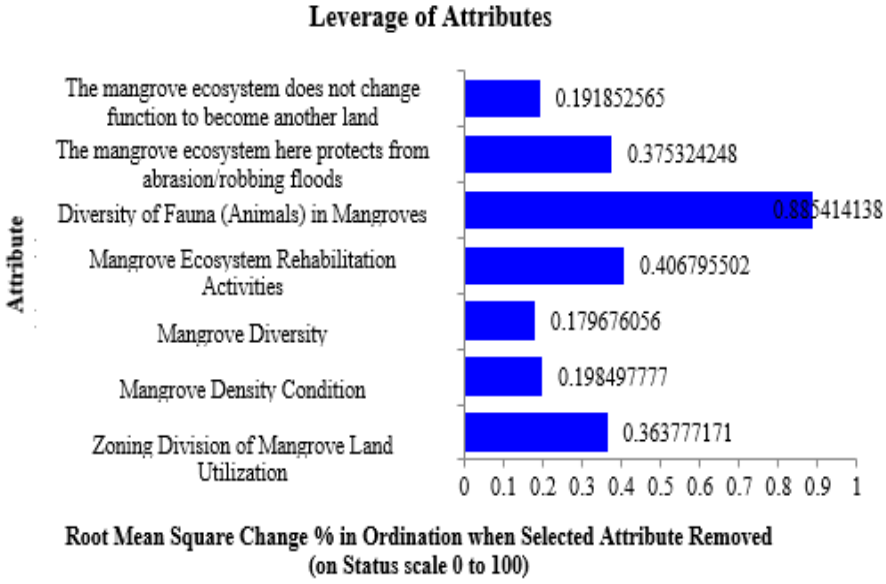

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Fig. 3. Rapfish ordination and leverage (Sensitivity) analysis of ecological dimension

1. Economic dimension

The attributes used in the economic dimension include: (1) the contribution of mangrove ecosystems to regional income, (2) community utilization of mangrove ecosystems, (3) the role of mangroves in increasing average community income (tourism), (4) inventory of mangrove forest utilization, (5) employment opportunities generated by mangrove ecosystems, (6) attraction of tourist visits, (7) business opportunities supported by mangrove ecosystems, and (8) subsidies/assistance from private and public sectors. The Rapfish analysis on the economic dimension produced a sustainability index value of 46.64, indicating that the economic dimension of the mangrove ecosystem is categorized as "less sustainable."

Mangrove ecosystems in coastal areas of West Java, such as Karangsong (Indramayu), Blanakan (Subang), and Muara Gembong (Bekasi), contribute to improving community livelihoods through fisheries, mangrove crab cultivation, and ecotourism. According to **Priadi (2018)**, the Karangsong mangrove area has significant ecotourism potential, capable of increasing community income by 25–40% compared to previous levels. Businesses related to mangrove crab cultivation and mangrove-derived products (e.g., mangrove syrup, *dodol*) also yield high profit margins, particularly when supported by effective marketing. However, profitability remains highly dependent on seasonality, market conditions, and community business management capacity.

Many small business owners in coastal communities lack knowledge of strategies to enhance the added value of their products. Limited market access is a key barrier, with mangrove catches and processed products often sold through middlemen at unfavorable prices. **Rahman *et al.* (2021)** found that in coastal Cirebon, more than 60% of fishermen and mangrove product processors rely on middlemen due to the lack of access to modern or digital markets. Other challenges include limited capital, inadequate distribution infrastructure, and insufficient technology and promotion. Some communities, such as those in Karawang and Indramayu, have begun to leverage BUMDes (village-owned enterprises) and cooperatives to reduce dependence on intermediaries, but the scale remains limited.

Mangrove ecosystems also generate employment opportunities in fisheries, aquaculture, mangrove forestry, and ecotourism. These activities absorb significant labor, particularly among productive-age groups. Data from the **West Java Provincial Environment Office (2022)** show that more than 20% of coastal communities in Indramayu and Subang depend on mangrove-related sectors. In Karangsong, rehabilitation programs and ecotourism development have created new jobs, especially for youth and women's groups. However, most of these jobs remain informal and seasonal, providing limited income security. Workforce training and capacity building are therefore urgently required.

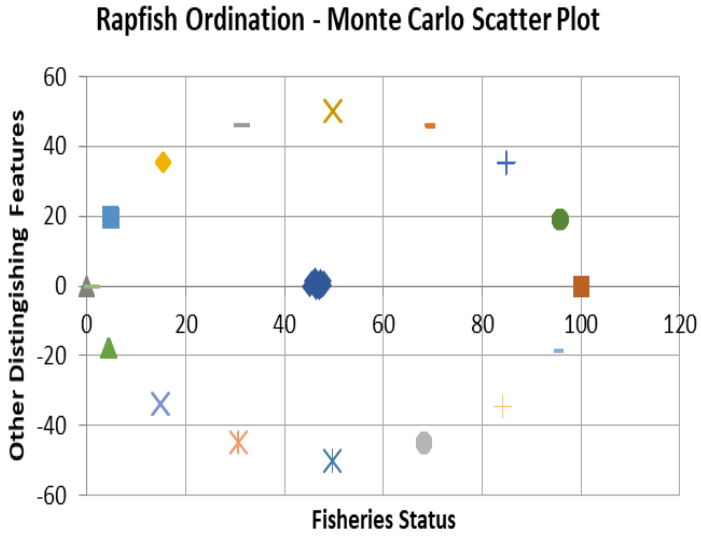
Another major challenge is the high dependence of coastal communities on government subsidies. While assistance programs—such as boats, nets, mangrove seedlings, and business training—are valuable, they are often unsustainable. **Pathony *et al.* (2020)** reported that in coastal Subang and Bekasi, government aid has not always improved long-term economic independence due to limited follow-up support. In many cases, fishing gear or business capital was not used effectively because of insufficient technical and managerial capacity. This highlights the need to transition from a subsidy-based model to a community empowerment approach, focusing on training, business incubation, and sustainable mentoring.

Income distribution among coastal communities utilizing mangrove resources remains uneven. Households with assets such as land, boats, or strong market connections earn significantly more than laborers or small-scale fishers. **Abadi (2021)** reported that the Gini ratio in Karawang's coastal area reached 0.44, indicating moderate to high inequality. Community-managed ecotourism initiatives demonstrate potential for reducing inequality through profit-sharing and participatory management systems. However, in many areas, mangrove-based enterprises are still dominated by a few actors, preventing equitable distribution of economic benefits.

To achieve sustainable and inclusive mangrove-based economic development, strengthening community institutions, digitizing micro-enterprises, fostering cross-sector collaboration, and implementing locally tailored skills training are essential. The findings of this study show that the current economic contribution of mangrove ecosystems remains insufficient. With widespread ecosystem degradation, mangrove resources are underutilized, leading many community members to seek alternative livelihoods such as fishing or industrial jobs in urban areas.

Rapfish ordination results for the economic dimension (Fig. 4) identified three indicators most sensitive to the sustainability index:

1. Mangrove ecosystems attract tourist visits.
2. Mangrove ecosystems contribute to income.
3. Proper inventory of mangrove utilization.



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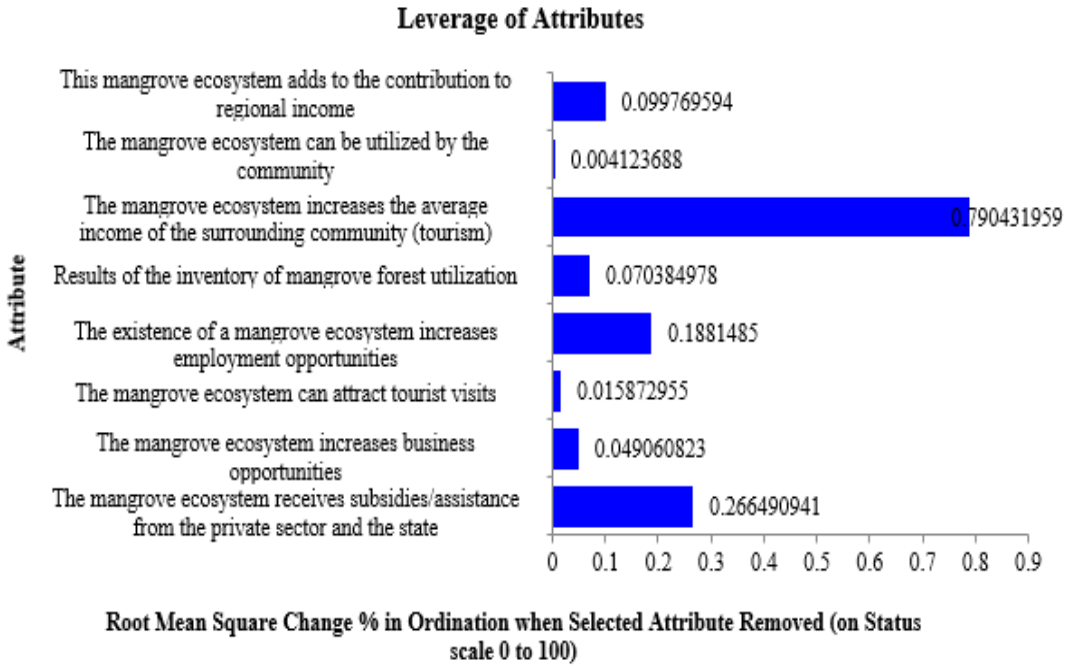

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Fig. 4. Rapfish ordination and leverage (Sensitivity) analysis of economic dimension

2. Social dimension

The attributes used in the social dimension include: (1) knowledge about mangroves, (2) community access to mangrove ecosystems, (3) human-induced mangrove damage, (4) community awareness of mangrove resources, (5) community participation in mangrove ecosystem management, (6) the existence of local wisdom in mangrove

management, (7) frequency of social conflicts, and (8) coordination between stakeholders and communities. The Rapfish analysis for the social dimension produced a sustainability index value of 48.37, indicating that the social dimension of mangrove ecosystems in northern West Java is "less sustainable."

This result suggests that the social situation around mangrove areas still requires serious attention. Frequent social conflicts and low awareness of mangrove management contribute to ongoing ecosystem degradation. Community participation in mangrove resource management in Indramayu, Subang, Karawang, and Bekasi is still partial and not comprehensive. In some areas, such as Karangsong (Indramayu), community involvement in rehabilitation and ecotourism initiatives is relatively strong, largely due to facilitation by local governments and NGOs. According to **Priadi (2018)**, high participation occurs when communities are involved from the planning stage through implementation. However, in many other areas, participation remains instructional rather than participatory.

Most fishermen and coastal residents have a basic level of education (elementary to junior high school), which limits their understanding of environmental issues, sustainability, and science-based management. This affects the quality of decision-making in business groups and conservation communities. **Larasati *et al.* (2024)** noted that low environmental literacy in Subang's coastal areas has led to minimal adoption of environmentally friendly technologies and sustainable fisheries practices.

Conflicts in northern coastal West Java generally stem from mangrove land conversion, competition over fishing grounds, and the use of illegal fishing gear. Horizontal conflicts also occur between traditional fishing communities and pond operators or industrial developers. **KIARA (2013)** reported rising agrarian conflicts in Bekasi and Karawang due to reclamation and industrial projects. Awareness of mangrove ecosystem sustainability also varies: areas with conservation and educational programs (e.g., Karangsong) tend to show high awareness, while other areas such as Muara Gembong and Blanakan exhibit low awareness. **Abadi (2021)** found that awareness is strongly influenced by the intensity of extension programs and the presence of local leaders engaged in environmental advocacy.

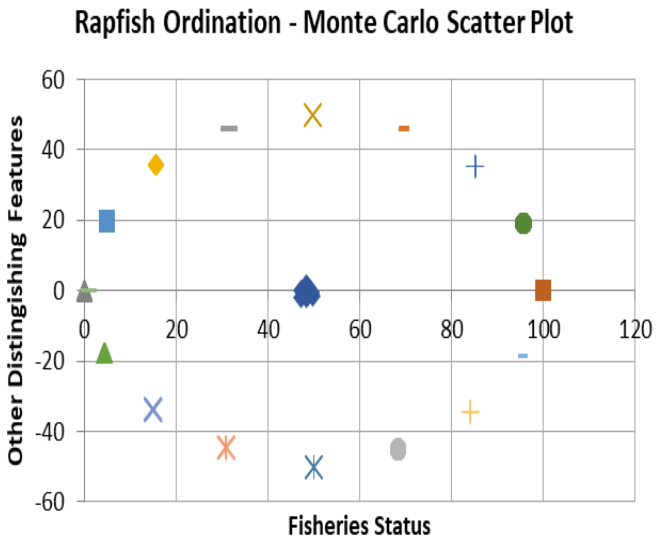
Government and NGO communication and extension efforts in northern West Java are often inconsistent and unsustainable. Messages are usually delivered in a top-down manner, limiting community understanding and ownership. **Waluyo and Chandra (2023)** showed that community-based approaches are more effective, especially when they use local media, local languages, and participatory formats such as community dialogues and field schools. Some cultural practices support conservation, such as prohibitions on cutting certain tree species or traditions of collective efforts to protect estuaries. However, modernization and economic pressures have eroded many of these values.

In Cirebon and Indramayu, rituals such as sedekah laut serve as expressions of local wisdom that can be integrated into culture-based conservation approaches. Nevertheless, access to coastal resources remains unequal. Small-scale fishers, women, and indigenous groups often face barriers to land, equipment, or market access, while pond ownership and conservation areas are frequently controlled by large investors. **Rahman *et al.* (2021)** observed unequal access to pond land in Bekasi and Karawang, which exacerbates social exclusion of vulnerable groups.

While social cohesion within small groups (e.g., among fishers) is generally strong, relationships between stakeholder groups—government, NGOs, businesses, and communities—are often characterized by mistrust. This lack of transparency in decision-making and benefit-sharing weakens collaboration. A study by **Rani *et al.* (2022)** in Tangerang Regency emphasized that the success of mangrove management programs is largely determined by the degree of trust and cross-sectoral collaboration.

Rapfish ordination of the social dimension (Fig. 5) and its leverage analysis identified four indicators most sensitive to the sustainability index value:

1. Human-induced mangrove damage.
2. Public awareness of mangrove ecosystems.
3. Community participation in mangrove management.
4. Frequency of social conflicts.



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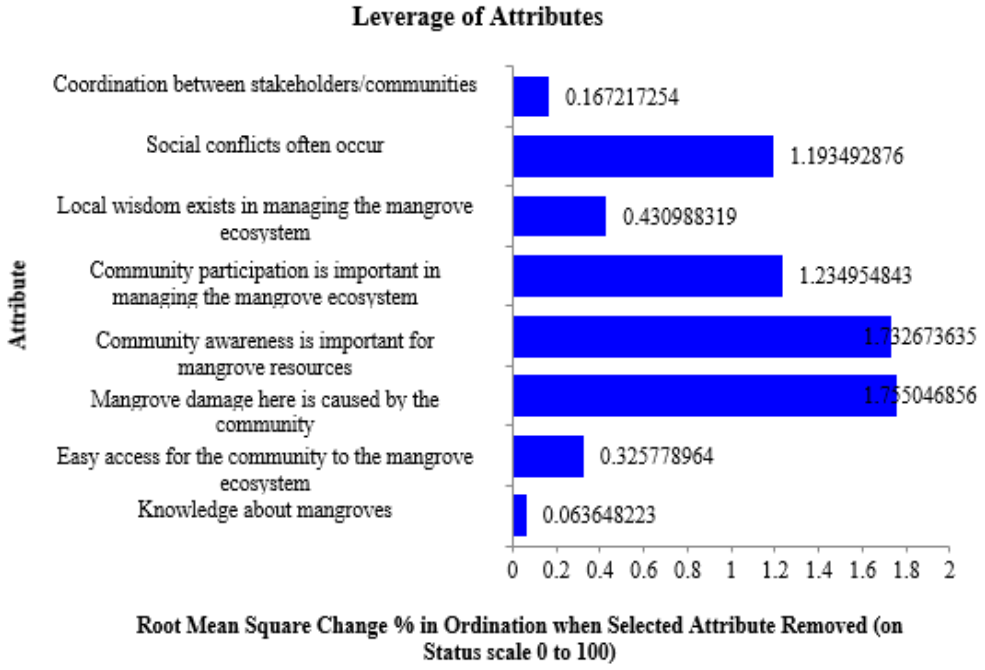

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Fig. 5. Rapfish ordination and leverage (Sensitivity) analysis of social dimension

3. Legal and institutional dimension

The attributes used in the legal and institutional dimension include: (1) policies and management planning for mangrove ecotourism, (2) rules and roles of management institutions, (3) mangrove management regulations, (4) involvement of village officials in mangrove ecotourism, (5) coordination between institutions/stakeholders, (6) involvement of community institutions, (7) legality of mangrove ecotourism areas, (8) performance of mangrove ecotourism management, (9) transparency and openness of management systems, (10) monitoring and supervision, and (11) sanctions for violators. The Rapfish analysis for this dimension produced a sustainability index value of 47.79, indicating that the legal and institutional aspects of mangrove ecosystem management are "less sustainable."

This result highlights persistent weaknesses in law enforcement and institutional governance. Although mangrove ecosystems in Indonesia are legally protected by several regulations—such as Law No. 32 of 2009 on Environmental Protection and Management, Presidential Decree No. 32 of 1990 on Protected Area Management, and Minister of Environment and Forestry Regulation No. P.105/MENLHK/SETJEN/KUM.1/12/2018 on Mangrove Rehabilitation—implementation remains problematic. Field interviews revealed that mangrove management policies are often unclear, particularly regarding which agency holds authority, leading to overlapping responsibilities and weak

enforcement. In many areas, no specific or binding regulations exist, further complicating governance.

Rule enforcement is especially weak in cases of mangrove land conversion for aquaculture or industrial development. Many violations go unpunished due to limited supervision and enforcement capacity. A study by **Ridlo and Arsali (2024)** in Subang showed that only 18% of mangrove conversion violations were legally processed, while the rest were either ignored or informally resolved.

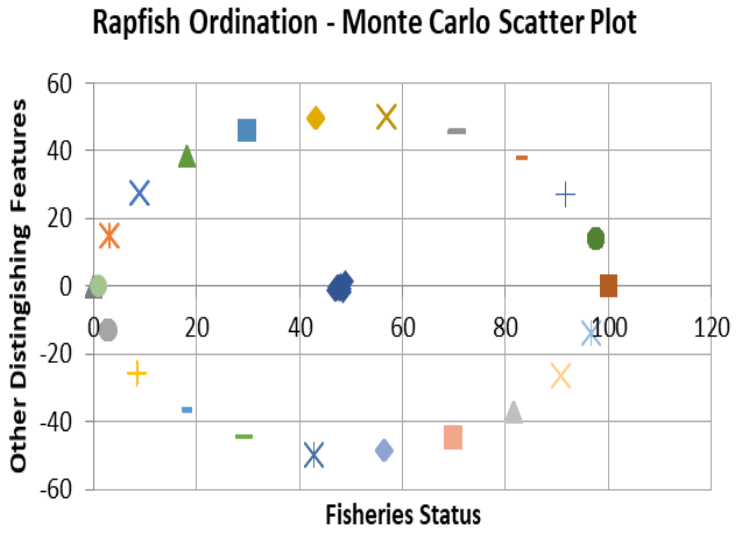
Stakeholder involvement in mangrove management decision-making—particularly communities, NGOs, and the private sector—remains limited. Some positive steps toward collaborative governance have emerged, such as in Karangsong (Indramayu), where the community participates in zoning and ecotourism management **(Priadi, 2018)**. However, many conservation programs still lack transparency in budgeting and implementation, causing distrust among communities. **Pratama *et al.* (2022)** emphasized the need for annual reports on mangrove programs to enhance accountability and community engagement.

Customary laws related to mangroves still exist in certain fishing communities, such as prohibitions on cutting mangroves near estuaries or beliefs in spiritual guardians of mangrove forests. However, these customary practices are rarely recognized in formal governance. Conflicts often arise over mangrove use between communities and companies, or among fishing groups themselves. Such disputes are usually resolved informally through village heads or traditional leaders rather than legal mechanisms. **Rani *et al.* (2022)** reported that most conflicts on the north coast of West Java are settled outside formal legal channels.

Local institutions—such as mangrove farmer groups and tourism awareness groups—play important roles in management. However, they often lack training, technical assistance, and operational funding. Strengthening these institutions through capacity building in management, marketing, and conservation is crucial to improving their effectiveness and impact.

Rapfish ordination of the legal and institutional dimension (Fig. 6) and leverage analysis identified four indicators most sensitive to the sustainability index value:

1. Transparency and openness in mangrove ecotourism management systems.
2. Legality of mangrove areas.
3. Involvement of community institutions.
4. Coordination between stakeholders.



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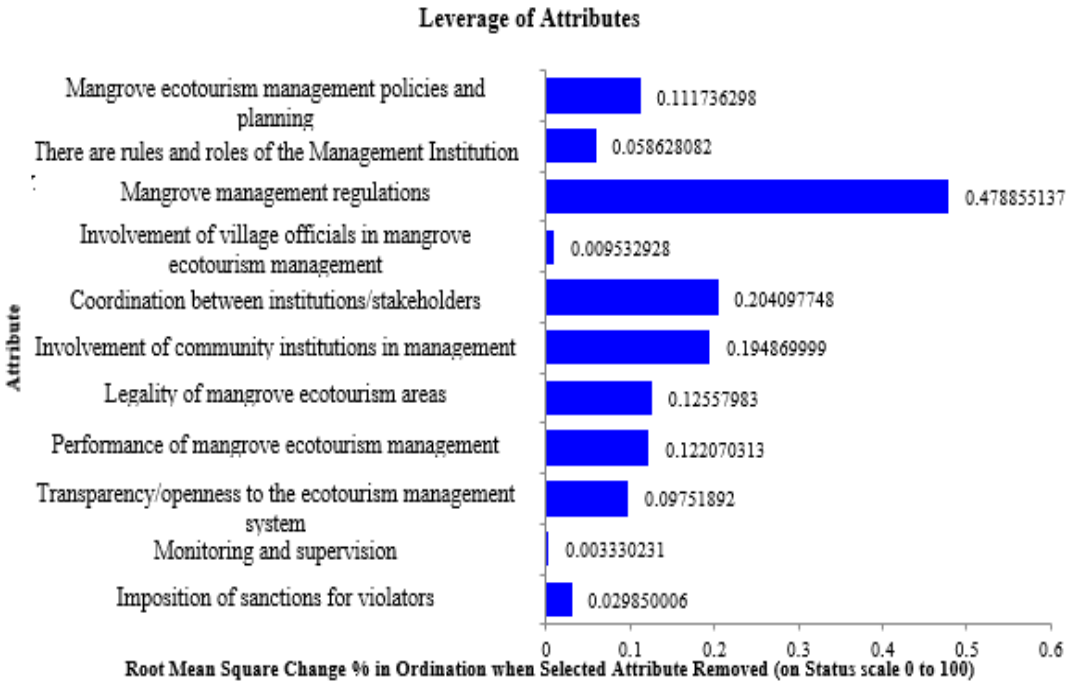

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Fig. 6. Rapfish ordination and leverage (Sensitivity) analysis of law and institutional dimension

DISCUSSION

The sustainability status of mangrove ecosystem management on the north coast of West Java is classified as **less sustainable**, as indicated by the multidimensional (combined dimension) index value of **46.74%**. A comparison of the sustainability analysis results across dimensions is visualized in a kite diagram **(Fig. 7)**. This finding

implies that mangrove ecosystem management in the region requires strengthened governance that ensures balanced performance across all sensitive key indicators in order to enhance the overall sustainability status.

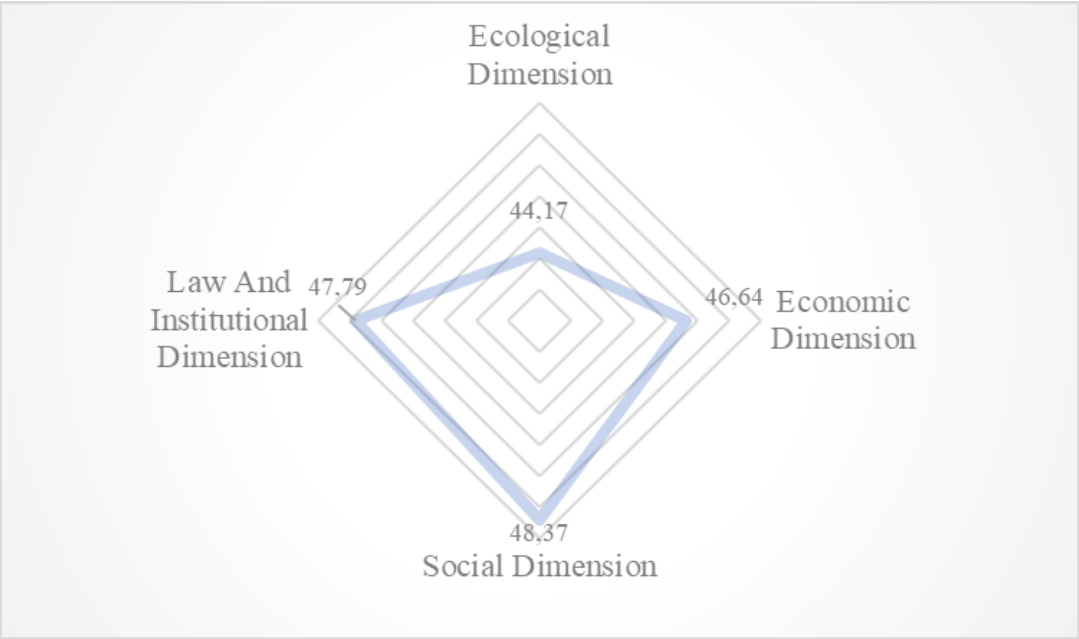

Fig. 7. Mangrove management dimensional flyover diagram

Monte Carlo analysis was used to test the level of confidence in the total index value and each management dimension. This analysis assesses the effect of possible errors in each indicator—such as procedural mistakes, differences in interpretation, variations in scoring due to differing opinions, instability in the MDS analysis, data entry errors, missing data, or high stress values. The small differences between the Monte Carlo and MDS analysis results demonstrate that the use of the RAPFISH method in determining the sustainability status of mangrove ecosystem management on the north coast of West Java has a high level of confidence. Validation of RAPFISH analysis by **Fauzi and Anna (2005)** showed a coefficient of determination of 0.94, indicating that the dimension indicators analyzed play a substantial role in explaining the variation of sustainability index values. The stress value ranged between 15–16%, which is below the 25% threshold, signifying that the model has a good goodness-of-fit in representing the sustainability status of the mangrove ecosystem.

Despite this, the ecosystem remains under serious threat due to land conversion, particularly for aquaculture ponds, which significantly contributes to mangrove loss **(Bambang *et al.*, 2024)**. Although mangroves provide crucial ecological and social benefits, they are experiencing deforestation and degradation at an alarming rate. Across Indonesia, mangroves categorized as being in critical condition cover approximately 476,192 ha in forest areas and 161,432 ha outside forest areas. Research indicates that oil palm plantations and aquaculture ponds are the leading drivers of mangrove loss **(Richards & Friess, 2016)**.

The decline is not limited to the north coast of West Java. On the east coast of North Sumatra, most mangrove ecosystems have been converted into aquaculture ponds. In 1990, mangrove ecosystems in this region covered 59,645.79 ha, but by 2015, the area had decreased to 37,132.62 ha **(Basyuni *et al.*, 2018; Siswoyo *et al.*, 2024)**. Similarly, in eastern Indonesia, such as South Konawe Regency, environmental quality has also deteriorated due to anthropogenic activities **(Muhsimin *et al.*, 2018)**.

On the north coast of West Java, mangroves hold significant potential as sustainable ecotourism resources. Ecological, economic, social, and legal-institutional approaches are all essential to supporting their management. As productive wetland ecosystems, mangroves provide multiple benefits—from ecological functions such as coastal protection and biodiversity support to social and economic contributions. Importantly, mangroves in Indonesia are estimated to contribute to **reducing up to 30% of national emissions from the land sector (Murdiyarso *et al.*, 2015)**.

Sustainable mangrove ecosystem management is complex and requires accommodative, collaborative mechanisms among diverse stakeholders. A bottom-up, participatory approach involving relevant institutions is essential to prevent conflicts of interest and ensure effective implementation. This includes the active involvement of communities, local institutions, and key stakeholders such as the Fisheries and Marine Service, Tourism Service, Perum Perhutani, Regency/City Governments, Village Governments, Tourism Awareness Groups, community organizations, Village-Owned Enterprises, and local leaders.

Particular attention is needed to strengthen sensitive indicators in the legal and institutional dimension, which recorded the lowest sustainability index value compared to the ecological, economic, and social dimensions. Weakness in this dimension poses a serious threat to both current and future mangrove ecosystem sustainability **(Schaduw, 2015)**. Relationships among stakeholders present both opportunities for cooperation and risks of conflict—particularly regarding overlapping claims to mangrove areas. Given these challenges, mangrove management and development must be community-centered, with local communities positioned as the primary actors in ensuring sustainability.

CONCLUSION

The sustainability status of mangrove ecosystem management on the north coast of West Java obtained a multidimensional index value of 46.74%, which falls into the “less sustainable” category. The sustainability index values for each dimension were as follows: ecological 44.17% (less sustainable), economic 46.64% (less sustainable), social 48.37% (less sustainable), and legal–institutional 47.79% (less sustainable). Each dimension has sensitive indicators that serve as references for improving and developing management performance to raise the overall sustainability status of the region.

Given that all dimensions are currently classified as less sustainable, this condition requires serious attention. Mangroves provide critical ecological functions—particularly in protecting coastal areas from abrasion—while also supporting biodiversity, livelihoods, and local economies. Therefore, improving sustainability demands not only technical and ecological measures but also strengthened collaboration among stakeholders. Strong, coordinated, and participatory management involving government agencies, local institutions, communities, and the private sector is essential to ensure that the mangrove ecosystem on the north coast of West Java can be managed sustainably into the future.

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