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Fish Diversity Level and Sustainability of Mangrove Ecosystem in West Aceh Coast, Aceh Province, Indonesia

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ABSTRACT

Mangrove ecosystems play a crucial ecological role in supporting the survival of various aquatic organisms, particularly fish. In the coastal area of West Aceh District, mangroves are distributed across several sub-districts, covering a total area of approximately 394.96 hectares. This ecosystem experienced significant degradation following the 2004 tsunami and continues to face anthropogenic pressures, including land clearing and infrastructure development. This study aimed to assess fish diversity and the ecological sustainability of mangrove ecosystems in the coastal region of West Aceh. The research was conducted from October 2024 to March 2025. Data were collected using a quantitative descriptive approach. Analyses were performed using Microsoft Excel and the Rapfish (Rapid Appraisal for Fisheries) software. Based on the diversity index analysis, the average index in the Samatiga waters was 2.03, while in the Lamnaga waters it was 1.63, indicating a moderate level of fish diversity in both locations. Using the Multidimensional Scaling (MDS) method, the ecological sustainability index for mangroves in the Samatiga region was found to be 80.17, while the index for the Lamnaga region was 77.14. These results classify both areas as having good or very sustainable ecological conditions.

INTRODUCTION

Mangrove ecosystems have a vital ecological role in the survival of various aquatic organisms, especially fish. Mangrove areas provide complex and productive habitats such as shelter, feeding grounds, and spawning and rearing areas for fish and other marine life **(Belinda *et al.*, 2022)**. The root structure of mangroves creates an ideal nursery ground environment as it provides protection from predators, reduces the strength of currents and waves **(Mutmainah *et al.*, 2022)**, and provides shelter for fish larvae and juveniles. This supports the survival of the early phase of fish life, which is the stage most vulnerable to mortality **(Akbar *et al.*, 2024)**.

In addition to shelter, mangrove ecosystems provide an abundant food source in organic detritus from fallen and decomposed leaves, which form the basis of the food chain for various aquatic organisms including fish **(Selviani *et al.*, 2024)**. Thus, mangroves act as primary production centres that support fisheries productivity in coastal areas **(Edwarsyah & Gazali, 2015)**. The connectivity of mangroves with other coastal ecosystems, such as coral reefs and seagrass beds, also allows fish to move between habitats throughout their life cycle. Juvenile fishes grow and develop in mangrove areas before migrating to open waters as adults **(Belinda *et al.*, 2022)**.

The decline in mangrove area and cover directly impacts the decline in fish diversity and abundance, ultimately affecting the catch and welfare of local fishermen. Mangrove conservation and protection efforts are essential to ensure the sustainability of ecological functions, and the economic benefits generated by mangrove ecosystems not only maintain the sustainability of habitat and fish stocks but also support food security and the economy of coastal communities **(Rani *et al.*, 2022)**.

Coastal West Aceh Regency is geographically one of the areas located in West Aceh Regency, as a whole mangrove ecosystem has an area of 394.96 Ha, which is situated and spread in Arongan Lambalek District, Samatiga, Johan Pahlawan and Meureubo District. The dominance and diversity of mangrove species include (*Rhizophora apiculata, R. mucronata, R. stylusa, Sonneratia alba, Sonneratia caseolaris* and *Avicennia marina*) **(Wintah *et al.*, 2023)**.

In 2004, this mangrove ecosystem area suffered severe damage due to the tsunami natural disaster, which massively changed the coastline. Fish diversity is one of the leading indicators of aquatic ecosystem health and has a strategic role in maintaining the sustainability of fisheries resources. Fish diversity also supports the sustainability of catches in quantity and quality.

On the other hand, anthropogenic pressures continue to occur, especially from land clearing activities and coastal infrastructure development that pay little attention to environmental sustainability. Mangrove degradation in West Aceh impacts ecological functions and threatens coastal communities' socio-economic sustainability. The disruption of fish diversity caused by habitat exploitation and degradation can disrupt ecological functions, leading to a decline in fisheries yields. Therefore, efforts to conserve and protect mangroves are essential to ensure the sustainability of environmental functions in maintaining habitat and fish diversity in the Coastal Aceh Barat District.

MATERIALS AND METHODS

The research was conducted from October 2024 to March 2025 in the coastal area of West Aceh, namely in the mangrove ecosystem area in Samatiga District and Meureubo District of West Aceh Regency. The research location is shown in Fig. (1).

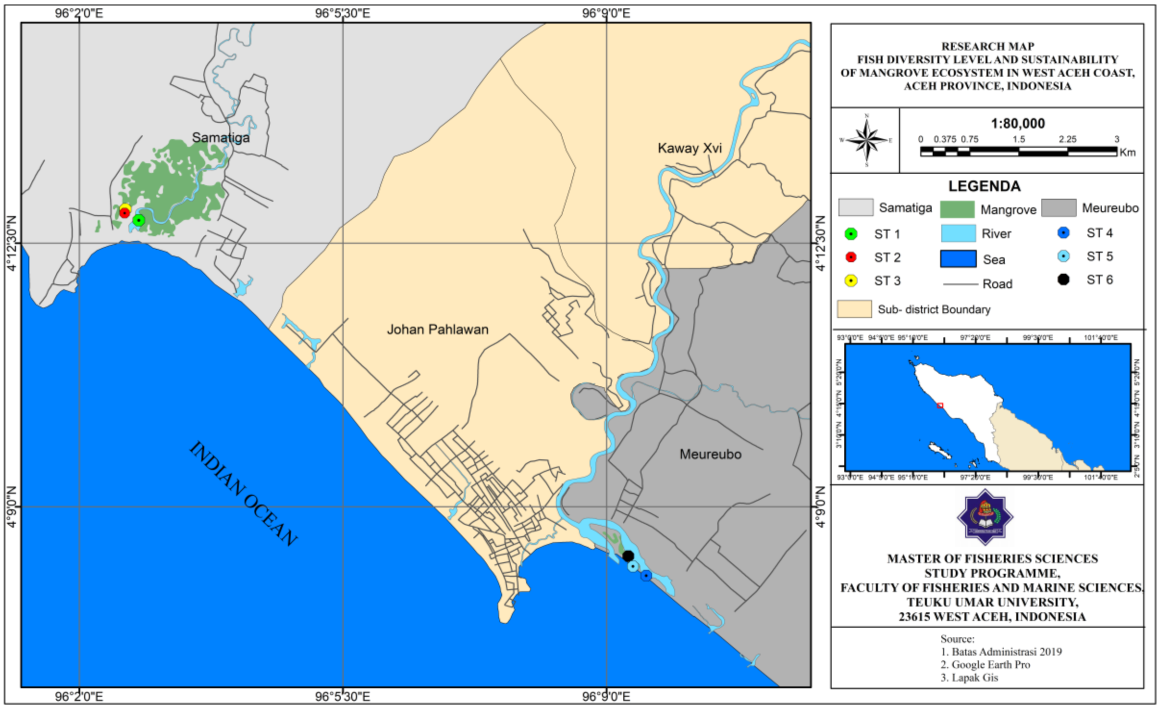

Fig. 1. Research location

Research design

Data collection in this study was conducted using a quantitative descriptive approach. Quantitative descriptive research is a method that aims to objectively describe a situation using numerical data **(Hardani *et al.*, 2020)**. The selection of observation stations and fish diversity assessment was carried out using a purposive sampling method—sampling based on specific criteria and considerations aligned with the research objectives **(Budiman *et al.*, 2021)**.

Additionally, in-depth interviews were conducted to explore mangrove ecosystem sustainability and fish diversity in the coastal area of West Aceh District, Aceh Province. Environmental parameters observed included salinity, temperature, and pH, all of which were measured *in situ* at the designated observation stations **(Mutmainah *et al.*, 2022)**.

Data analysis

Data analysis in this study was conducted to assess fish diversity levels and the sustainability status of mangrove ecosystems in the study area. The analysis included the following components:

a. fish species diversity

To determine the diversity of fish species in the waters, the Shannon-Wiener diversity index was used, following the formula outlined by **Aprilia *et al.* (2023)**. This index is a widely used ecological method for measuring biodiversity, as it accounts for both the abundance and evenness of species in a community.

the Shannon-Wiener Index formula is as follows:

$$H' = -\sum_{i=1}^{n} pi \ln pi$$

Description:
H'= Shanon-Wiener diversity index
N = Total Number of individuals of all species
ni= Number of individuals of the i-th species
Pi= Proportion of individuals of the i-th species

The value obtained was then included in the criteria for fish species diversity **(Aprilia *et al.*, 2023)**, including:
Value H' > 3: High species diversity
Value H' 1-3: Medium Species Diversity
Value H' < 1: Low Species Diversity

b. Mangrove ecosystem sustainability

The data used to assess the sustainability status of mangrove ecosystems and the level of fish diversity were descriptive quantitative, comprising both primary and secondary data. Primary data were collected through field observations and in-depth interviews with respondents or informants selected using a purposive sampling method—where respondents are deliberately chosen based on specific criteria relevant to the research objectives **(Burhanis *et al.*, 2024)**.

Data analysis was conducted using the Multidimensional Scaling (MDS) approach, a mapping technique that simplifies the relationships between variables by positioning them in a spatial configuration based on the similarity of their characteristics

$$d = \sqrt{(|x_1 - x_2|^2 + |y_1 - y_2|^2 + |z_1 - z_2|^2 + \dots \dots)}$$

Then, the point is applied and regressed the Euclidian difference (dij) from point i to point j with the equation:

$$d_{ij} = a + bd_{ij} + e$$

An Alternating Least Squares (ALS) technique based on the root of the Euclidean distance (squared distance) was employed, known as the ALSCAL algorithm. This method aims to optimize the spatial configuration of data points by minimizing the differences between the observed and estimated distances in a multidimensional space. The ALSCAL algorithm seeks to make the intercept of the equation equal to zero (*a* = 0) **(Tony & Preikshot, 2001)**. It operates by minimizing the squared distance (origin = 0ijk) between data points in three-dimensional space (i, j, k), producing a goodness-of-fit measure known as S-stress with the equation:

$$s = \sqrt{\frac{1}{m}\sum\left[\frac{\sum\sum(d^2 i\ jk - O^2 i\ jk)^2}{\sum\sum O^4 i\ jk}\right]}$$

The most sensitive attributes showed changes to the index and sustainability status based on the highest root mean square (RMS) value. Rapfish analysis sustainability status values were grouped into four sections: (1) 0-25 (poor or unsustainable), (2) 26-50 (less sustainable), (3) 51-75 (moderately sustainable), and (3) 76-100 (good/very sustainable) **(Burhanis *et al.*, 2021)**. The quantitative and qualitative data that have been obtained were then tabulated and analyzed. The analysis process was carried out with the help of Microsoft Excel software and the Rapfish (Rapid Appraisal of Fisheries) programme to assess conditions quickly and thoroughly.

RESULTS AND DISCUSSION

The results showed that the mangrove ecosystems in Samatiga and Lamnaga waters provide relatively favorable environmental conditions for the optimal growth and development of mangrove vegetation. Measurements of environmental parameters indicated that salinity in both areas ranged from 20 to 31ppt. Water temperature ranged between 27 and 30°C, which falls within the optimal range for the physiological processes of mangrove plants. Additionally, the pH values ranged from 7.5 to 8.5, indicating neutral to slightly alkaline conditions that support microorganism activity and biochemical stability in the ecosystem **(Latuconsina, 2019)**.

This parameter range is characteristic of estuarine environments, which serve as ideal habitats for various mangrove species. The combination of salinity, temperature, and pH reflects good water quality and contributes to the sustainability of the mangrove ecosystems in both regions **(Tabalessy, 2023)**.

Fish diversity in Samatiga and Lamnaga

Analysis of fish species diversity in Samatiga waters, based on data from three observation stations, showed an average Shannon-Wiener diversity index (H') of 2.03. This value reflects a moderate level of diversity, suggesting a relatively stable ecological condition and a fairly even distribution of fish individuals among species. In contrast, the diversity index in Lamnaga waters was slightly lower, at 1.63, though still within the moderate category.

According to the Shannon-Wiener classification, values of H' < 1 indicate low diversity, values between 1 and 3 reflect moderate diversity, and values >3 signify high diversity **(Setiawan *et al.*, 2019)**. The moderate diversity in both areas indicates that the ecosystems are functional, though some differences in ecological pressures may influence species richness and evenness.

Higher fish diversity is typically associated with healthy coastal vegetation such as mangroves and seagrass beds, which serve as spawning grounds, nursery areas, and shelters for juvenile fish **(Wintah *et al.*, 2023)**. Conversely, lower diversity may suggest species dominance or ecological imbalance. Studies have shown that mangroves with higher density support greater fish diversity and abundance **(Faruk *et al.*, 2019)**.

The lower diversity in Lamnaga may reflect greater environmental pressures, including more intensive fishing activity, domestic and agricultural waste, and degradation of mangrove habitats. Such pressures can reduce ecosystem structural diversity and resilience **(Ramadhani *et al.*, 2015)**. While small-scale fisheries tend to be more sustainable due to their adaptability and local governance **(Said & Chuenpagdee, 2019)**, unmanaged resource use can lead to long-term ecological degradation. High species diversity generally supports better ecosystem functioning, including effective fish recruitment, balanced trophic interactions, and resilience to disturbances **(Gusmawati *et al.*, 2023)**.

Mangrove ecosystem sustainability

The Rapfish (Rapid Appraisal for Fisheries) analysis evaluated eight sustainability attributes: fish stock availability, fish species diversity, environmental impact, exploitation pressure, mangrove density, mangrove land use types, habitat condition, and availability of mangrove seedlings.

Using Multidimensional Scaling (MDS), the ecological sustainability index for the Samatiga mangrove ecosystem was 80.17 (Fig. 2), indicating a very sustainable condition. In Lamnaga, the ecological dimension showed a slightly lower but still sustainable index value of 77.14 (Fig. 3).

The difference in sustainability scores between the two locations can be attributed to several factors, including the intensity of land use, differences in mangrove vegetation density, variations in water quality, and differences in local coastal resource management policies **(Muhsimin *et al.*, 2018)**. Samatiga's higher index suggests more effective management and conservation efforts, as well as better environmental support for ecosystem stability.

Overall, both Samatiga and Lamnaga research sites show that the ecological condition of mangroves is good or very sustainable, which is in the interval 76-100.

However, it is necessary to strengthen adaptive management strategies to maintain and improve these conditions, especially in Lamnaga waters.

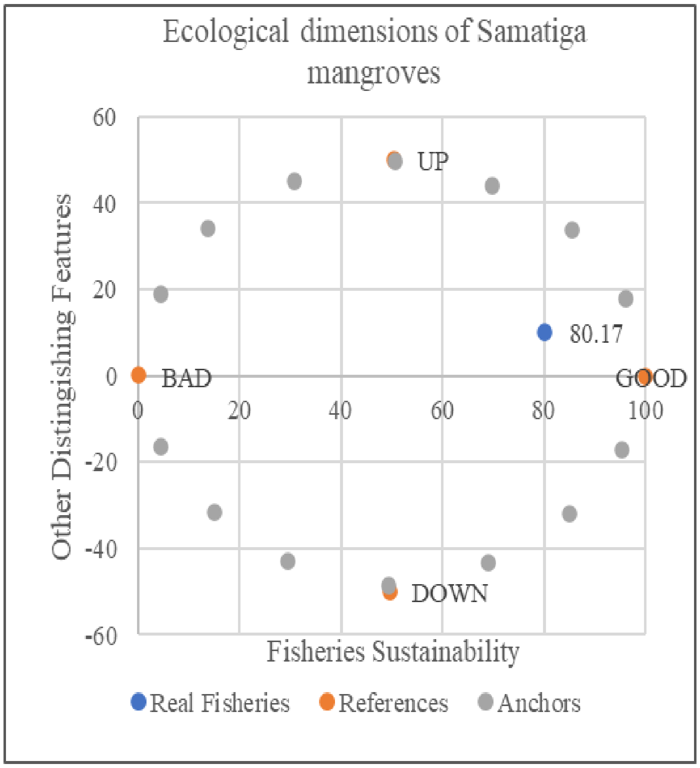

Fig. 2. Index analysis and sustainability status of mangrove ecosystem in Samatiga Waters

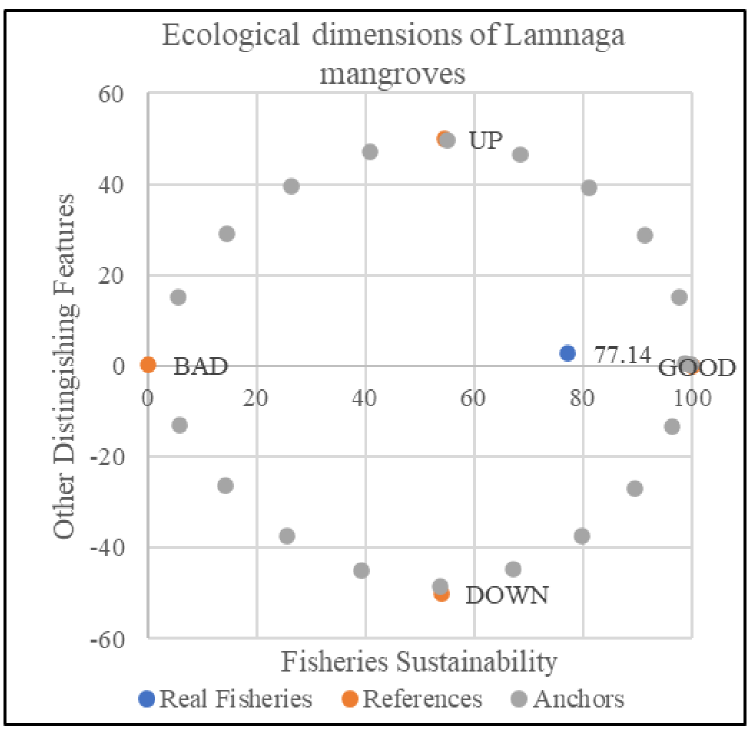

Fig. 3. Index analysis and sustainability status of mangrove ecosystem in Lamnaga waters

This condition shows that the mangrove ecosystems in the Samatiga and Lamnaga areas can still perform their ecological functions optimally. The mangrove area in the Samatiga area is relatively well preserved, both in terms of vegetation structure and ecological function as an essential habitat. Environmental protection efforts are significant in maintaining the sustainability of marine resources and biodiversity **(Burhanis *et al.*, 2024)**. While the Lamnaga area has ecological pressures or constraints, in addition to inefficiencies in mangrove area management, including the lack of rehabilitation programs, weak supervision, and low community participation in conservation activities, the existence of healthy mangroves plays a vital role as a spawning ground, enlargement, and protection for aquatic organisms. It is a natural buffer against abrasion and seawater intrusion.

Based on the results of leverage analysis using the Root Mean Square Change (RMS) approach in the Multi-Dimensional Scaling (MDS) method (Fig. 4), information was obtained regarding the influence of each attribute on the value of the mangrove ecological sustainability index in Samatiga waters.

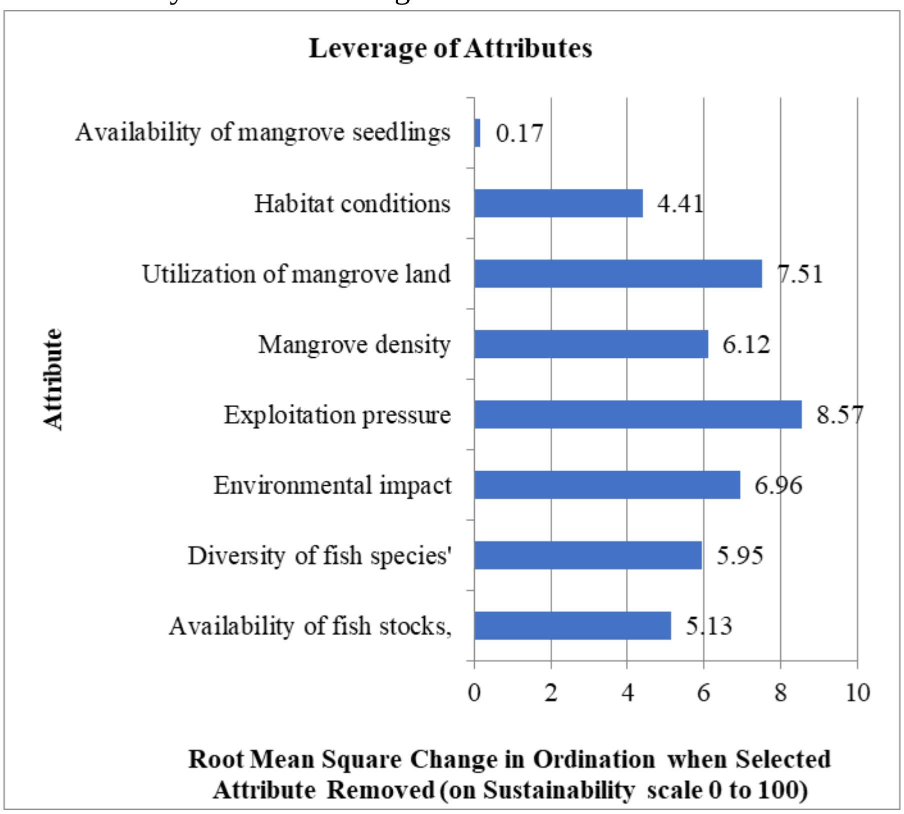

Fig. 4. Leverage analysis of the ecological dimensions of the Samatiga Mangrove ecosystem

Fig. (4) shows that several attributes are sensitive to the mangrove ecosystem sustainability index, including exploitation pressure; this indicates that ecological sustainability is very sensitive to the pressure of human activities, such as illegal logging, land conversion, and other anthropogenic pressures that cause mangrove ecosystem degradation. Another essential attribute is the type of mangrove land use. Land use changes and mangrove vegetation density have a direct impact on the productivity and ecological sustainability of mangrove ecosystems **(Rani *et al.*, 2022)**. In contrast to Samatiga, the attribute leverage analysis for ecological sustainability in the Lamnaga region reveals different dominant factors (Fig. 5). In Lamnaga, the most influential attributes affecting ecological sustainability are the type of mangrove land use and habitat condition.

The strong influence of habitat condition as a leverage factor suggests that substrate quality, tidal patterns, and local water dynamics are critical in determining the carrying capacity of the habitat for natural mangrove regeneration and the diversity of associated biota. This highlights the importance of site-specific management strategies to ensure long-term sustainability of the ecosystem **(Burhanis *et al.*, 2021)**. Properly addressing these site-specific factors is crucial for effective conservation and rehabilitation efforts **(Rusdi *et al.*, 2020)**.

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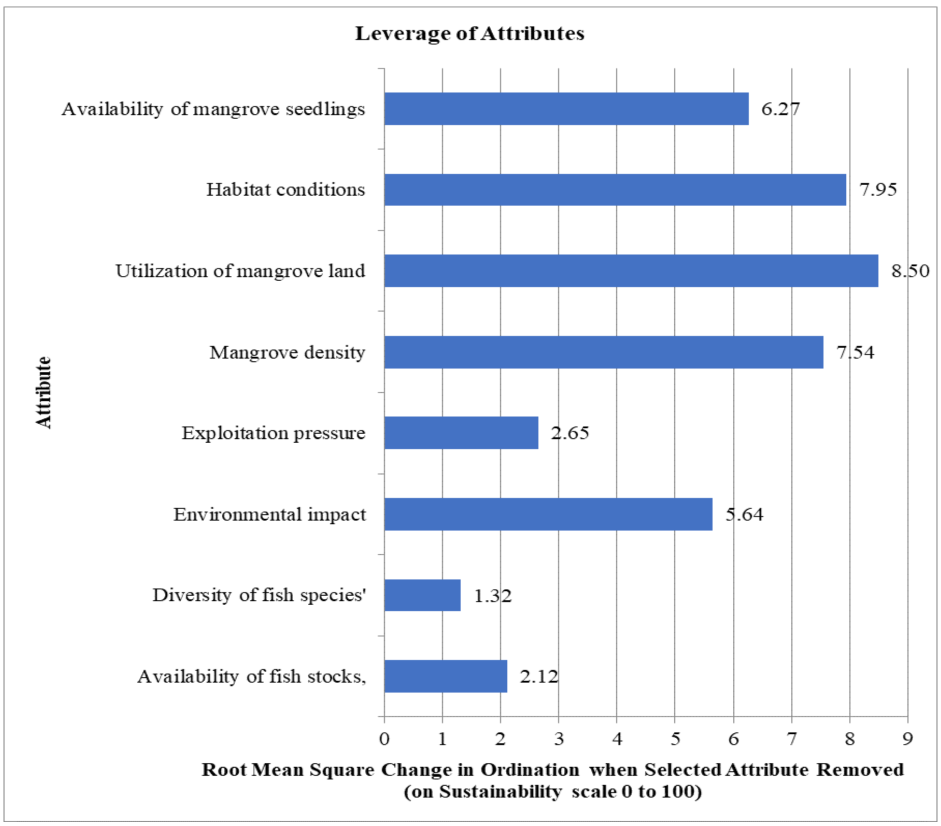

Fig. 5. Leverage analysis of the ecological dimensions of the Lamnaga mangrove ecosystem

The results of the analysis show that the sustainability of mangrove ecosystems in two coastal areas, namely the mangrove ecosystem in Samatiga and the mangrove ecosystem in Lamnaga, shows that each location has different determinants of ecological sustainability, reflecting the unique biophysical conditions and specific levels of environmental pressure in each area. Overall, the analytical results from this study indicate the importance of a site-based management approach that considers each area's dominant characteristics and ecological pressures to ensure the long-term sustainability of mangrove ecosystems in West Coast Aceh. Decision-making is based on local data so interventions can be more effective, efficient, and sustainable **(Rusdi *et al.*, 2020)**.

CONCLUSION

The results of the study indicate that the fish species diversity in both Samatiga and Lamnaga falls within the moderate category, with Shannon-Wiener diversity index (H') values of 2.03 in Samatiga and 1.63 in Lamnaga. Additionally, analysis using the Multidimensional Scaling (MDS) method revealed that the ecological sustainability index for the Samatiga mangrove ecosystem is 80.17, while the Lamnaga region scored 77.14. These values place both regions in the "good" to "very sustainable" category, indicating that the mangrove ecosystems in these coastal areas are functioning effectively and remain ecologically viable.

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