Multidimensional Sustainability of Floating Net Cage Cultivation System: Comparison in Three Locations of Lampung Bay, Sumatra, Indonesia

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Abstract
The sustainability of the Floating Net Cage (FNC) cultivation system in Indonesia, including in Lampung Bay, Sumatra, remains largely unknown, even though this fish farming system has become an important source of livelihood for coastal communities. This study aims to evaluate the sustainability of the Floating Net Cage (FNC) cultivation system in three main locations of Lampung Bay, namely Pasaran Island, Hurun Bay, and Labuhan Sawah. The approach used is Rapid Appraisal for Fisheries (Rapfish) with five dimensions of sustainability: ecological, economic, social, institutional, and technological. Leverage analysis is used to identify the attributes that most influence sustainability positions, while Monte Carlo simulations are performed to assess the stability of the analysis results. The results show that Hurun Bay performs best in the institutional and technological dimensions, while Pasaran Island is highly sensitive in the economic and technological dimensions. The robust error value of the Monte Carlo simulation indicated that most dimensions had good yield stability, but some, such as technology in Hurun Bay (0.152) and economics in Pasaran Island (0.117), were highly sensitive. These findings provide a scientific basis for sustainable aquaculture management policies and support the achievement of the Sustainable Development Goals (SDGs), specifically goal 2 (No Hunger) and goal 14 (Ocean Ecosystems).
Keywords: FNC, Rapfish, Lampung Bay, Sustainability, Monte Carlo, SDGs

INTRODUCTION

Aquaculture with the Floating Net Cage (FNC) system has become one of the main sources of livelihood for coastal communities in Indonesia, including in Lampung Bay. According to FAO (2020), aquaculture contributes more than 50% to global fish production, with Asia accounting for around 89% of total production. In Indonesia, aquaculture production increased from 14.7 million tons in 2019 to 15.4 million tons in 2021. This shows the important role of FNC in supporting food security and the local economy.

Lampung Bay has great potential for the development of FNC due to the relatively calm water conditions and close to the market center. Recent studies show that Lampung accounts for more than 7% of the national marine fish production. However, the sustainability of this system is still questionable due to economic and institutional pressures. According to Hardian et al. (2020), the policy of banning certain fishing gear in Lampung Bay raises pros and cons that affect the dynamics of coastal communities.

The sustainability of FNC cultivation must be seen from various dimensions. Pitcher & Preikshot (2001) introduced the Rapfish method for assessing fisheries sustainability in a multidimensional way, encompassing ecological, economic, social, technological, and institutional levels. A recent study by Zhang et al. (2021) shows that a multidimensional approach can identify critical factors for the sustainability of mariculture in the Southeast Asian region.

The ecological dimension is a major concern because FNC cultivation often coexists with sensitive ecosystems such as coral reefs and seagrass beds. According to Chen et al. (2022), intensive cultivation can increase nutrient load by up to 30% in coastal waters. On Pasaran Island, the existence of FNC coexists with the cultivation of green shellfish and seaweed, where, on the one hand, it creates potential for spatial competition, but, on the other hand, it plays a role in maintaining water quality.

The economic dimension is also crucial because FNC is the main source of income for thousands of coastal households. KKP data (2021) show that the aquaculture subsector contributes 45% to Indonesia's fisheries GDP. However, a study by Liu et al. (2020) emphasizes that dependence on a single commodity increases economic risks for cultivators.

The social dimension includes aspects of welfare, space utilization conflicts, and community acceptance. According to research by Rahman et al. (2021), social conflicts in coastal areas increase by 20% when cultivation is not properly regulated. In Lampung Bay, the existence of beach tourism in Hurun Bay, side by side with FNC, raises potential conflicts of interest.

The institutional dimension relates to regulations, guidelines, and implementing organizations. A study by Nurhayati et al. (2022) shows that strong local institutions can increase the sustainability of aquaculture by up to 25%. The Lampung BKIPM Strategic Plan 2020–2024 emphasizes the importance of quality control and safety of fishery products as part of the institutional strategy.

The technology dimension includes innovations in feed, seeds, and monitoring systems. According to the BBPBL Lampung report (2020), the distribution of superior seeds has increased by 15% per year, supporting FNC's productivity. A study by Gao et al. (2021) emphasizes that the application of IoT technology in aquaculture can increase feed efficiency by up to 20%.

The Rapfish method based on Multi-Dimensional Scaling (MDS) is used to assess sustainability quickly. Sensitivity analysis helps identify the most influential attributes, while Monte Carlo simulations improve the reliability of the results. According to Pitcher & Ainsworth (2008), the combination of MDS and Monte Carlo was able to reduce bias by up to 10%. A recent study by Wang et al. (2022) also supports the use of MDS for aquaculture sustainability evaluation.

This research was conducted in three locations: Pasaran Island, Hurun Bay, and Labuhan Sawah. All three have different characteristics: Pasaran with multi-commodity cultivation, Hurun with institutional support from BBPBL-KKP, and Labuhan Sawah with a relatively healthy coral reef ecosystem. These differences allow for richer comparative analysis.

Preliminary results show that the technology dimension in Hurun Bay has the highest sustainability score (89.91), while the ecological dimension in Pasaran Island has the lowest (59.53). This is in line with a study by Li et al. (2021), which found that modern technology increases the sustainability of aquaculture in Asia by up to 30%. On the contrary, ecological degradation is the main factor in the decline in the sustainability index.

This research supports several pillars of **the Sustainable Development Goals (SDGs),** in particular: SDG 2 (*Zero Hunger*), SDG 8 (*Decent Work and Economic Growth*), SDG 12 (*Responsible Consumption and Production*), and SDG 14 (*Life Below Water*). Thus, the results of the research are not only relevant to Lampung Bay but also contribute to the global sustainability agenda.

METHODOLOGY

Research Location

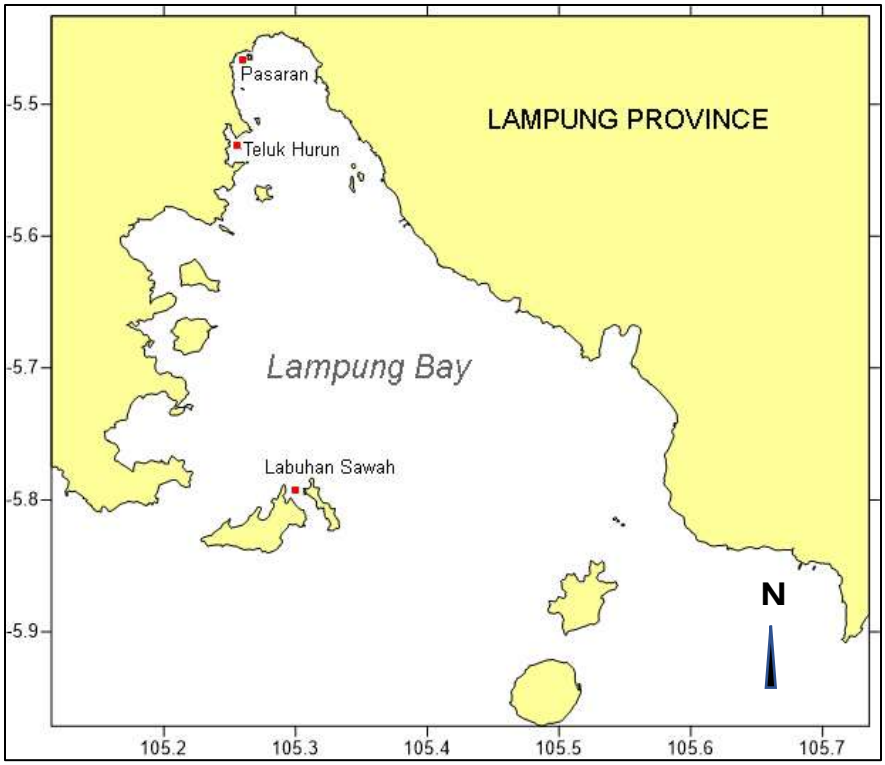

Figure 1. Map of the Research Location

This research was carried out in **Lampung Bay, Sumatra, Indonesia**, which is one of the coastal areas with a fairly high intensity of **Floating Net Cage (FNC)** cultivation . Three locations were purposively chosen to represent different ecological, social, and institutional conditions, namely **Pasaran Island**, **Hurun Bay**, and **Labuhan Sawah**. Pasaran Island was chosen because FNC cultivation in this location coexists with green clam and seaweed cultivation, thus creating ecological pressure and space competition. Hurun Bay was chosen because of the institutional support from the Lampung Marine Aquaculture Fisheries Center (BBPBL) and its proximity to the beach tourism area. Meanwhile, Labuhan Sawah was chosen because of the relatively healthy condition of the coral reef ecosystem and minimal anthropogenic pressure, so it can be an interesting comparison. The selection of locations with these different characteristics allows for richer and more in-depth comparative analysis.

Research Design

This study uses a **descriptive quantitative** approach with **the Rapfish (Rapid Appraisal for Fisheries)** method based on **Multi-Dimensional Scaling (MDS).** Rapfish was chosen because it is able to assess the sustainability of fisheries systems in a multidimensional manner with limited data, and has been widely used in aquaculture sustainability research in various countries (Vatria, 2020). The analysis was carried out on five dimensions of sustainability, namely **ecological, economic, social, institutional, and technological**, each of which consists of seven attributes.

Table 1. Attributes in each dimension

1	**DIMENSIONS**				
	Ecology	**Social**	**Economy**	**Institutional**	**Technology**

1	Carrying capacity of the waters	Cultivator's human resource level	Source of capital	Availability of formal regulations	The level of application of the recommended technology
2	Threats to the waters	Number of aquaculture household	Access to production infrastructure	Cultivator institutions	Consistency of GAP implementation
3	Aquatic ecosystem conditions	Social interaction	Market absorption rate	Seeding institutions	Feed management
4	Suitability of the waters	Social infrastructure	Increased production	Government support	IT Utilization
5	Aquatic fertility	Frequency of conflicts of interest	Revenue level	Research & Extension Institutions	Use of superior seeds
6	Sedimentation rate	Labour availability	Contribution to Aquaculture	Community participation in policies	Integrated Aquaculture
7	Frequency of pest and disease attacks	Social conditions of thecommunity	Asset ownership	Effectiveness of stakeholder cooperation	FNC design and construction

Data Collection

The research data consists of **primary data** and **secondary data**. Primary data was obtained through field surveys, interviews with cultivators, village officials, and related stakeholders. Secondary data was obtained from the official report of the Lampung Marine and Fisheries Service (DKP), BBPBL, and academic publications. Attribute scoring is carried out on an ordinal scale (0–10) based on real conditions in the field. This scale was chosen because it is simple, easy for respondents to understand, and in accordance with perception-based sustainability evaluation practices (Hartati et al, 2021).

Rapfish Analysis

Rapfish analysis is carried out in several stages:

1. **Multi-Dimensional Scaling (MDS):** used to map the sustainability position of each location in a multidimensional space. The output is a sustainability index (0–100) for each dimension.
2. **Leverage Analysis:** used to identify the attributes that have the most impact on sustainability value. Attributes with high leverage values are considered key factors that need to be strengthened.
3. **Monte Carlo Simulation:** 500 iterations **were performed** to test the resilience of the results to data variations and biases. Robust error results (Bahdad, 2020).

Sustainability Categories

According to Akhmad Fauzi (2019), the sustainability index is interpreted in the following categories:

- 0–25 = unsustainable
- 26–50 = less sustainable
- 51–75 = moderately sustainable
- 76–100 = sustainable.

Data Validation

Validation is carried out through several mechanisms:

- **Source triangulation:** comparing primary data (interviews) with secondary data (official reports).
- **Consistency test:** done with Monte Carlo to ensure unbiased results.
- **Expert discussion:** engaging academics and Lampung fisheries practitioners to validate the interpretation of the results.

Analysis Tools

The analysis was conducted using **R version 4.5.0 (2025)** with *vegan packages* for MDS. Visualization of results in the form of **kite diagrams** and **radar charts** to show comparisons between dimensions. The use of R software provides high flexibility in data processing and visualization, and has become the standard in Rapfish-based sustainability research (Hartati 2021).

Linkage with the SDGs

This methodology supports the achievement of several pillars **of the Sustainable Development Goals (SDGs):**

- **SDG 2:** Zero Hunger (through increasing food production for fisheries).
- **SDG 8:** Decent Work and Economic Growth (through increasing farmers' incomes).
- **SDG 12:** Responsible Consumption and Production (through sustainable cultivation practices).
- **SDG 14:** Life Below Water (through the protection of coastal and marine ecosystems).

RESULTS AND DISCUSSION

The analysis of the sustainability of the Floating Net Cage (FNC) cultivation system in Lampung Bay was carried out at three research locations, namely Pasaran Island, Hurun Bay, and Labuhan Sawah. The results of Rapfish's analysis based on Multi-Dimensional Scaling (MDS) show variations in sustainability scores between dimensions and locations. In general, the value of the sustainability index is in the category **of moderately sustainable to sustainable**, with scores ranging from 59.53 to 89.81. This shows that the FNC system in Lampung Bay has the potential to be further developed, but there are certain dimensions that still need to be strengthened so that sustainability can be achieved comprehensively.

Table 2. FNC sustainability index in three locations of Lampung Bay

	Ecology	Economy	Social	Institutional	Technology
Pasaran Island	59.53	70.65	67.40	66.22	59.99
Hurun Bay	71.05	60.28	72.97	83.58	89.81
Labuhan Sawah	75.84	70.14	66.15	65.08	77.71

In the **ecological dimension**, Pasaran Island received the lowest score of 59.53, which shows that conditions are quite sustainable but close to the less sustainable category. This can be explained by the ecological pressures due to multi-commodity cultivation in the same location, namely green mussels and seaweed, which has the potential to increase nutrient load and reduce the quality of the waters. On the other hand, Labuhan Sawah obtained the highest score on the ecological dimension of 75.84, which indicates better conditions because the coral reef ecosystem is still relatively healthy and has minimal anthropogenic pressure. Hurun Bay is in the middle position with a score of 71.05, which shows that despite the existence of beach

tourism activities and research institutions, the ecological condition is still quite well maintained (Figure 2).

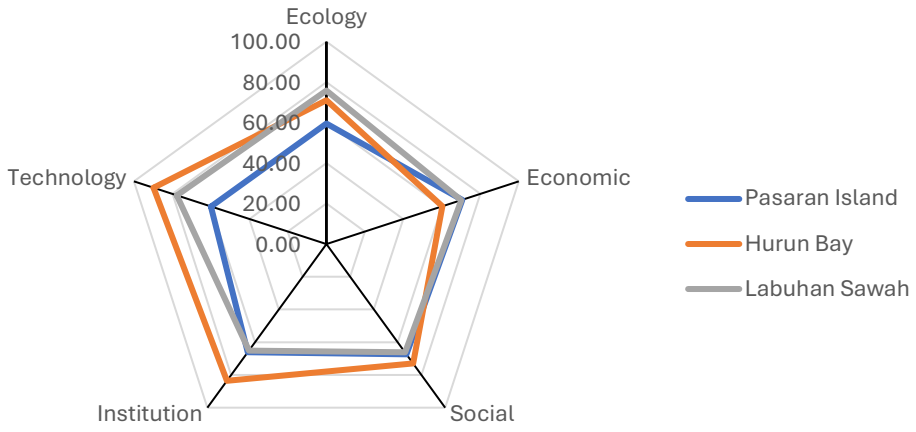

Figure 2. A hover diagram of Rapfish's analysis results for ecological, economic, social, institutional, and technological dimensions.

Leverage analysis showed that the most influential attributes on the ecological dimension were **aquatic fertility (4.20)** and **aquatic ecosystem conditions (3.48).** This means that water quality management and ecosystem protection are key factors in maintaining the ecological sustainability of FNC (Figure 3).

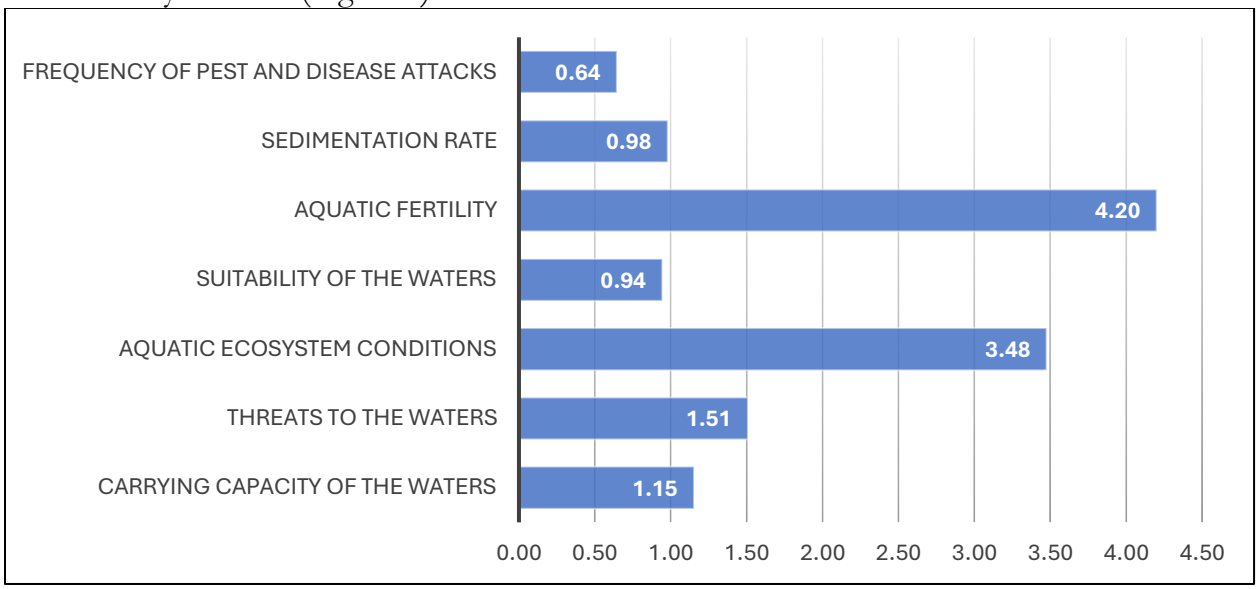

Figure 3. Ecological Leverage Value

The **economic** dimension shows interesting variations. Pasaran Island obtained the highest score of 70.65, which can be attributed to closer market access to Bandar Lampung City so that FNC products are easier to absorb. Labuhan Sawah is also relatively high with a score of 70.14, showing a significant economic contribution to the local community. On the other hand, Hurun Bay only obtained a score of 60.28, which shows that the orientation of activities in this location is more related to research and tourism, so the direct economic contribution

from FNC is relatively lower. Leverage analysis shows that the most influential attributes are **the contribution to aquaculture (8.87), the market absorption rate (5.55),** and **the income and production level (5.41)** (see Figure 4). This confirms that the economic sustainability of FNC is highly dependent on the system's ability to increase production, farmers' income, and contribution to the aquaculture sector as a whole.

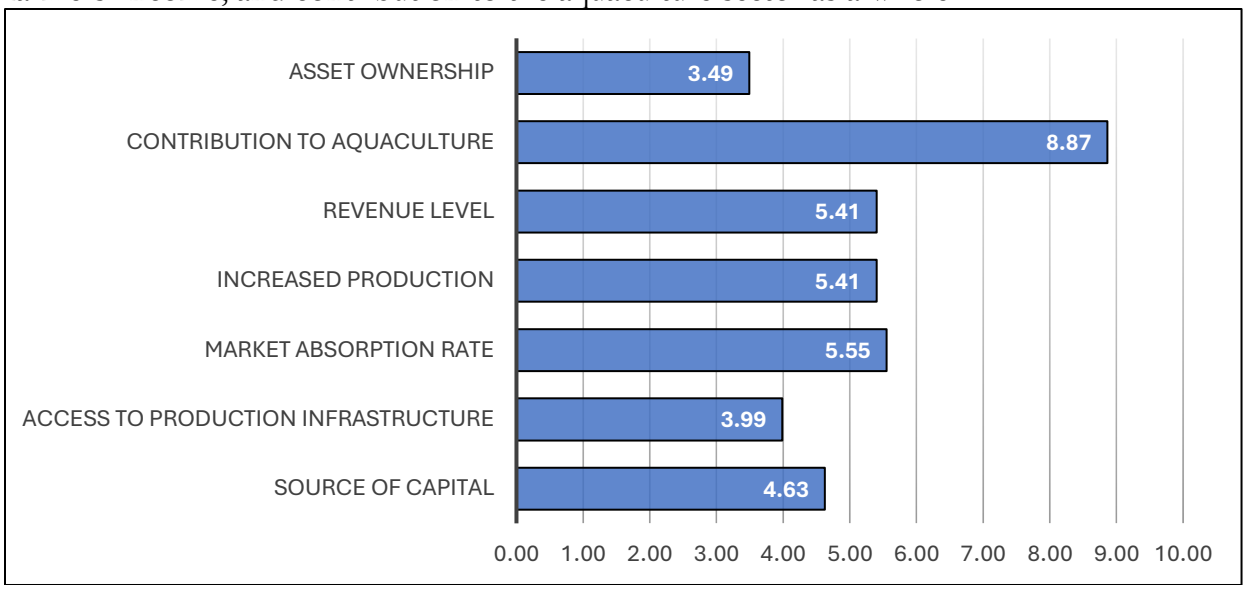

Figure 4. Economic Leverage Value

The **social** dimension showed the highest score in Hurun Bay at 72.97, which indicates good social interaction between cultivators as well as institutional support from BBPBL. Pasaran Island received a score of 67.40, while Labuhan Sawah 66.15, both showed fairly sustainable conditions but still needed strengthening. Leverage analysis showed that the most influential attributes were **social interaction (4.97)** and **social infrastructure (4.50)** (see Figure 5). This shows that social sustainability is highly dependent on the quality of interaction between cultivators, the existence of communication forums, and the support of social infrastructure such as village halls or training centers. Conflicts of interest also emerged as an important factor with a leverage of 3.90, indicating the need for mediation and conflict resolution mechanisms in the management of coastal spaces.

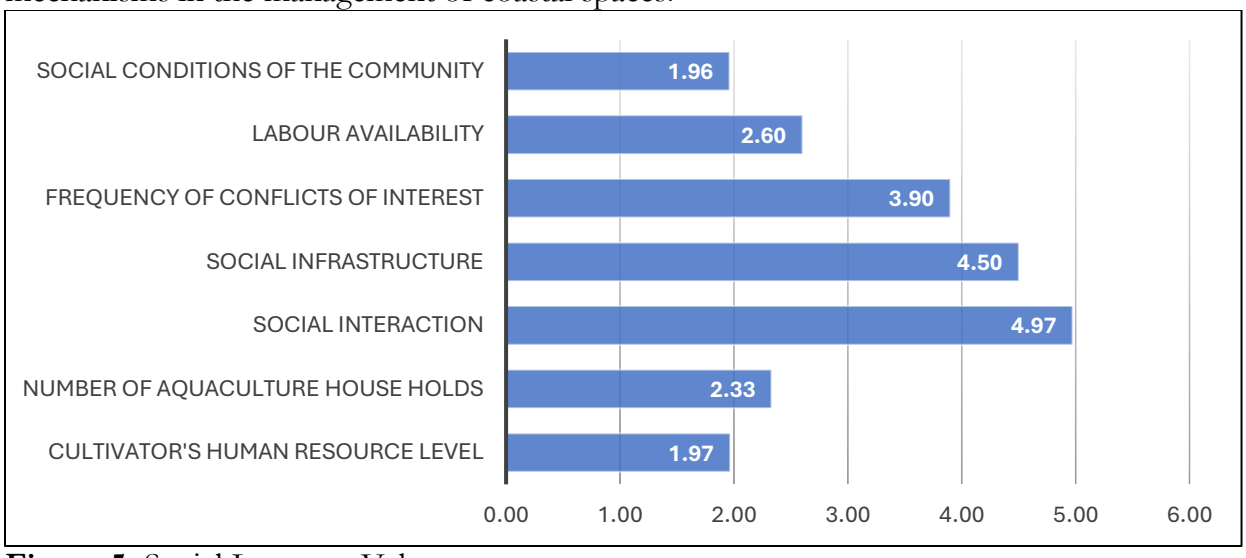

Figure 5. Social Leverage Value

The **institutional** dimension showed the highest score in Hurun Bay at 83.58, which confirms the important role of BBPBL and government support in strengthening aquaculture institutions. Pasaran Island obtained a score of 66.22, while Labuhan Sawah 65.08, both show a fairly sustainable institution but are still weak compared to Hurun Bay. The leverage analysis showed that the most influential attributes were **research and extension institutions (4.46)** and **hatchery institutions (3.39)** (see Figure 6). This confirms that institutional sustainability is highly dependent on research support, counseling, and a strong hatchery system. Government support also emerged as an important factor with a leverage of 2.33, signaling the need for consistent policies and public participation in policy formulation.

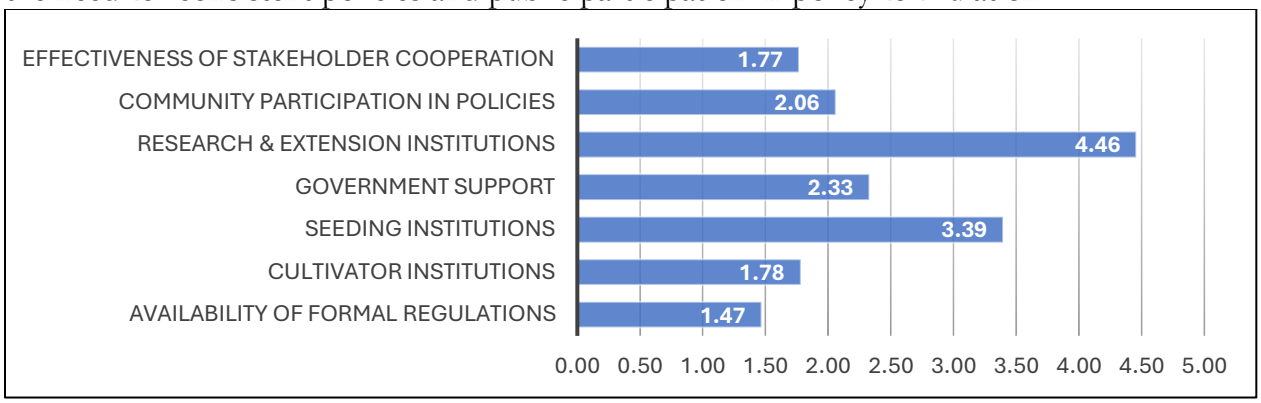

Figure 6. Institutional Leverage Value

The **technology dimension** shows the highest score in Hurun Bay at 89.81, which is in the sustainable category. This can be explained by the application of modern technology such as the use of superior seeds, the implementation of Good Aquaculture Practices (GAP), and the integration of aquaculture systems. Labuhan Sawah received a score of 77.71, which is also in the sustainable category, while Pasaran Island only received a score of 59.99, which shows the limitations of the application of technology at the location. Leverage analysis showed that the most influential attributes were **the use of superior seeds (3.95)** and **integrated aquaculture (3.78)** (see Figure 7). This emphasizes that technological sustainability is highly dependent on the application of efficient and environmentally friendly cultivation innovations.

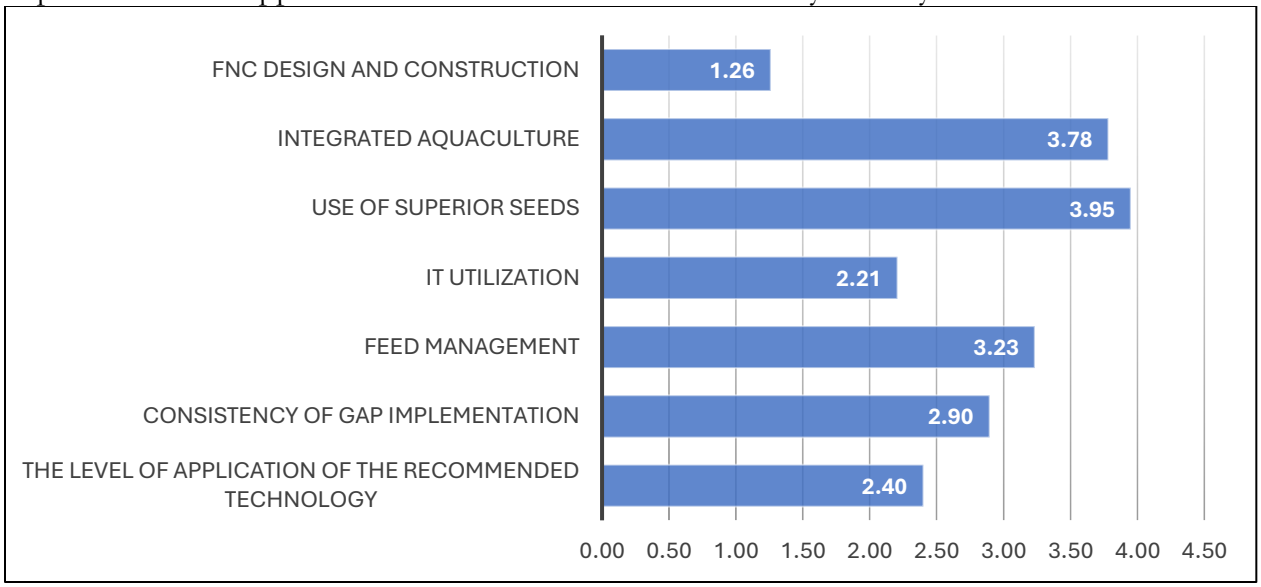

Figure 7. Value of Technology Leverage

Monte Carlo simulations with 500 iterations show that most dimensions have a low robust error (<0.05), indicating stable and reliable analysis results. However, some dimensions such as the economy in the Pasaran Island (0.117), institutions in Hurun (0.115), and technology in Hurun (0.152) show a higher sensitivity to data variations. This emphasizes the need to strengthen data and continuous monitoring on these dimensions so that FNC's sustainability strategy in Lampung Bay is more accurate and effective (Table 3).

Table 3. Monte Carlo analysis results with 500 iterations

	Ecology			Economic			Social			Institution			Technology		
	MDS	Median	Robust	MDS	Median	Robust	MDS	Median	Robust	MDS	Median	Robust	MDS	Median	Robust
Pasaran Island	59.780	62.456	0.045	72.583	64.104	0.117	67.793	66.878	0.013	66.281	67.598	0.020	59.694	65.980	0.105
Hurun Bay	71.799	70.339	0.020	60.262	60.260	0.000	73.024	69.591	0.047	83.756	74.105	0.115	90.038	76.313	0.152
Labuhan Sawah	76.336	74.794	0.020	71.243	63.619	0.107	66.273	66.566	0.004	65.264	67.317	0.031	78.080	72.247	0.075

Overall, the results of the study show that the sustainability of the FNC system in Lampung Bay is greatly influenced by differences in location characteristics. Pasaran Island faces major challenges in the ecological and technological dimensions, Hurun Bay excels in the institutional and technological dimensions but is weak in the economic dimension, while Labuhan Sawah is relatively good in the ecological dimension but weak in the institutional. This shows that the FNC development strategy must be adjusted to the characteristics of each location. For Pasaran Island, the policy focus must be on waste control and increasing the application of technology. For Hurun Bay, the strategy must be directed at strengthening the economic dimension so that FNC's contribution to the welfare of the community is more optimal. Meanwhile, for Labuhan Sawah, institutional strengthening and research support are the top priorities (Figure 8).

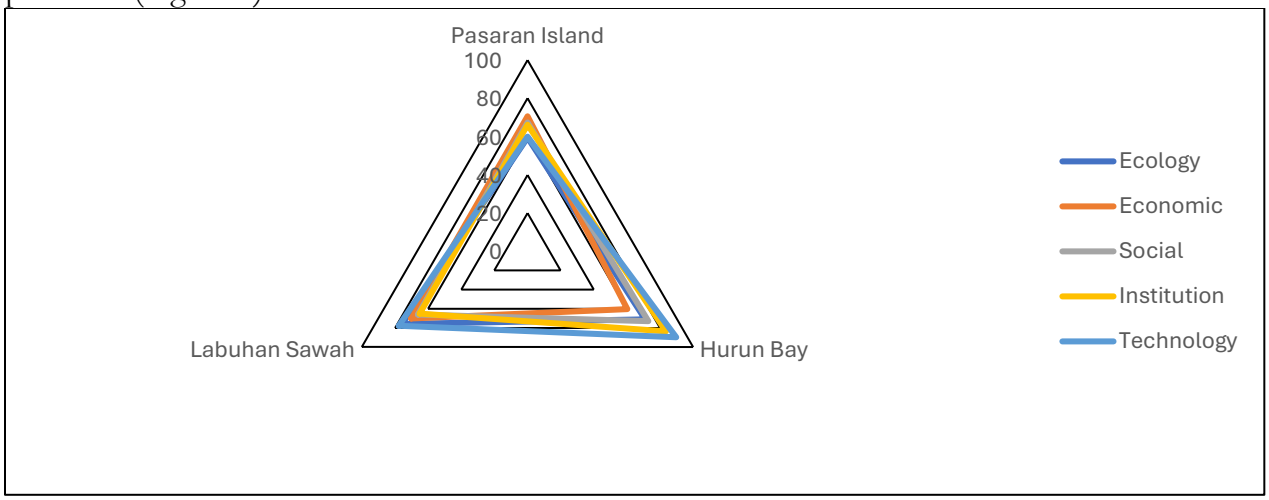

Figure 8. Radar chart of sustainability index comparison between research sites

These findings are in line with the research of Zhang et al. (2021) which emphasizes the importance of a multidimensional approach in assessing the sustainability of aquaculture in Southeast Asia, as well as the study of Chen et al. (2022) which shows that ecological pressures due to intensive aquaculture can reduce the quality of coastal waters. In addition, the results of this study support the findings of Li et al. (2021) who affirm that technological innovations, especially the use of superior seeds and integrated aquaculture systems, can increase aquaculture sustainability by up to 30%. Thus, this research makes an important contribution

in understanding the dynamics of FNC sustainability in Lampung Bay and can be the basis for more effective regional policy formulation.

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