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Sustainability of Vannamei Shrimp (*Litopenaeus Vannamei*) Pond Management in Bottolampangen Village

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ABSTRACT

This research aims to analyze the economic and social resilience of vannamei shrimp farming communities in the coastal area of Minasa Upa Village, Maros Regency, South Sulawesi. Data collection involved interviews and questionnaires administered to 52 shrimp farmers, with analysis conducted using the Rapid Appraisal for Fisheries (RAPFISH) method and Multidimensional Scaling (MDS) across five main dimensions: ecology, economy, social, technology, and institutional aspects. The results indicate that the overall condition of the shrimp farms falls into the less sustainable category, with an average index value of 42.87%. The main obstacles identified include low access to modern technology, weak institutional coordination, dependence on middlemen for capital in addition to the low educational level of the farmers. The implementation of biosecurity and waste management remains limited, thereby increasing the risk of disease spread. However, potential for improvement exists through technology training, strengthening local institutions, and sustainable business diversification and ecosystem approaches. This study provides location-specific strategic guidance to comprehensively enhance the sustainability of vannamei shrimp cultivation.

INTRODUCTION

The fisheries and aquaculture sector has long been recognized as a major provider of animal protein for the global population, while also serving as an economic driver in developing countries (**Smith *et al.*, 2021; FAO, 2023**). In Southeast Asia, shrimp cultivation is a leading commodity; Indonesia, with its extensive coastline, capitalizes on this potential, particularly through the farming of the vannamei shrimp (*Litopenaeus vannamei*). This species is favored for its rapid growth rate and high resilience, making it key to major export markets (**Jones & Kim, 2022**). However, market-driven intensive expansion often overlooks ecological limits. Unsustainable farming practices have led to the degradation of coastal environments, a decrease in the carrying capacity of ponds, and an increased risk of large-scale disease outbreaks, ultimately threatening the stability of production and the overall sustainability of the industry (**Brown *et al.*, 2019**). Therefore, a shift toward an integrated sustainable fisheries system is no longer an option, but an absolute necessity.

South Sulawesi Province is a crucial aquaculture center in Indonesia, with Maros Regency being one of the largest shrimp-producing areas. Despite its vast potential, the coastal areas of Maros, in particular, have experienced a worrying decline in productivity trends in recent years. This decline is not only caused by technical factors such as sediment accumulation and disease infection but also by managerial factors, including poor spatial planning, land-use incompatibility, and the weak institutional capacity of local farmers (**Lee & Chen, 2020**). Unlike studies that solely focus on the technical aspects of cultivation, the problem in Maros demands a holistic approach that assesses all dimensions of sustainability.

This research focuses its analysis on Minasa Upa Village, Bontoa District, Maros Regency, an area that empirically exhibits high aquaculture system vulnerability. To deeply understand the weaknesses of this system, the Rapid Appraisal for Fisheries (RAPFISH) framework with a multidimensional scaling (MDS) approach is utilized to measure the status of sustainability. Initial analysis results show a concerning sustainability status across several key dimensions.

Given the acute multidimensional vulnerability, especially in the social and ecological dimensions, the formulation of integrated and evidence-based intervention strategies is required. Although many studies have mapped aquaculture sustainability, almost all have failed to present integrated strategic recommendations (Eco-Social-Economic-Institutional) specifically tailored to the geographic context of Minasa Upa. Thus, this research aims to answer three main questions: (1) How to analyze the suitability of pond land for *L. vannamei* cultivation in Bontoa District? (2) How to determine the current status and sustainability index of *L. vannamei* cultivation multidimensionally? and (3) How to formulate the most effective and sustainable management strategy for *L. vannamei* ponds in Minasa Upa Village?

The main contribution of this research is to provide a context-specific management strategy model as a scientific guide for policymakers and stakeholders in Maros Regency. This study is expected to spur efforts for ecological recovery and the enhancement of sustainable social capital. The subsequent sections of this journal will present the detailed methodology, land suitability analysis findings, the results of the RAPFISH-MDS sustainability index calculation, and, most importantly, the strategic recommendations as an integrated solution.

MATERIALS AND METHODS

1. Study location and time

This research was conducted in the coastal area of Bontoa District, Maros Regency, South Sulawesi Province, with the main focus on the pond cultivation area in Minasa Upa

Village. The location was chosen based on the significance of Minasa Upa Village as a center for Vannamei shrimp production in Bontoa and its high multidimensional vulnerability status, based on preliminary data (as outlined in the introduction). Field research, including primary data collection and measurement were conducted.

2. Population and sample

The research population comprised all vannamei shrimp farmers in Minasa Upa Village. A purposive sample was drawn, consisting of 82 farmer respondents who represented various levels of experience and business scale.

3. Types and sources of data

Primary data were collected through interviews and structured questionnaires that measured sustainability indicators across five main dimensions: Ecology, economy, social, technology, and institutional aspects. Secondary data were obtained from relevant literature and official local government data.

4. Data analysis

The collected data were analyzed using the RAPFISH method with the aid of Microsoft Excel software equipped with the RAPFISH module. The analysis was conducted by transforming the data into a sustainability index using the multidimensional scaling (MDS) technique. Furthermore, leverage and Monte Carlo analyses were used to identify the most influential attributes and to test the stability of the model. The index results are presented in the following section.

RESULTS

1. Ecological dimension

The results of the rapfish assessment and calculation for the ecological dimension can be seen in Figs. (1, 2, and 3).

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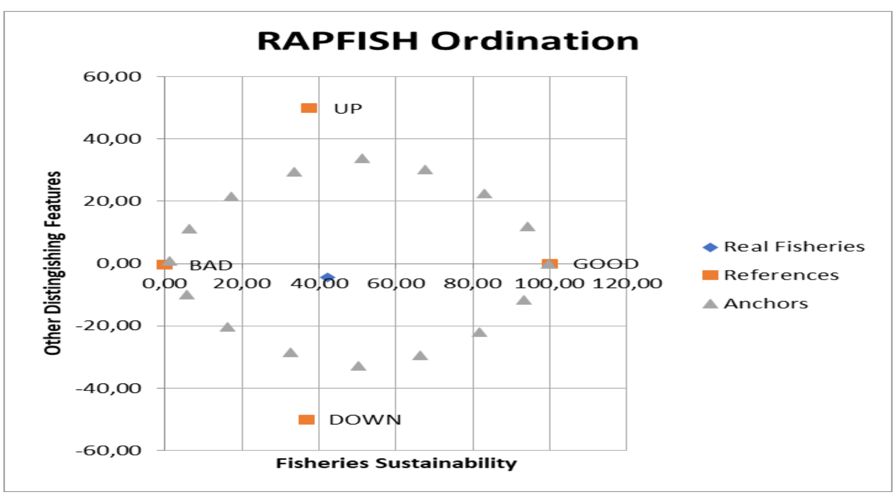

Fig. 1. Rapfish results for the ecological dimension of pond management in Minasa Upa Village

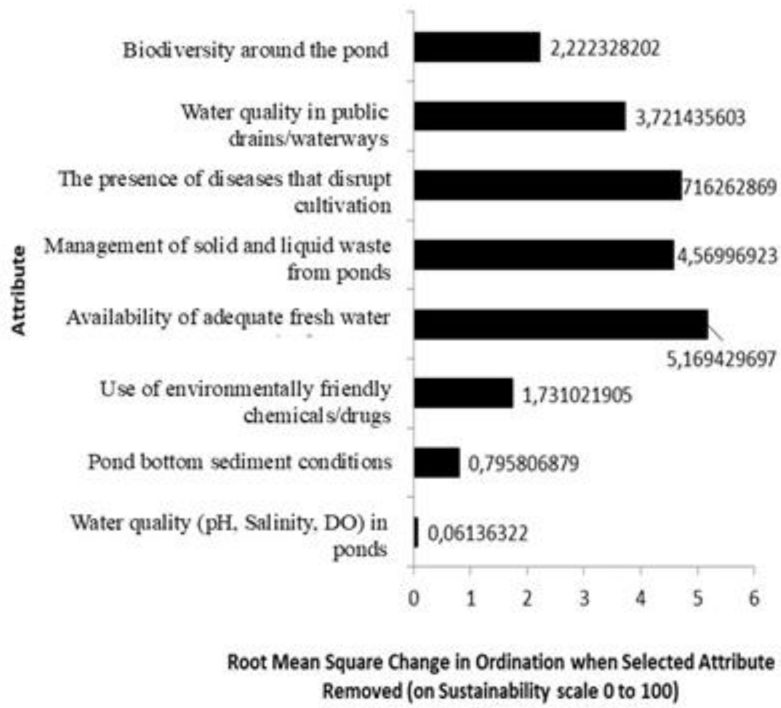

Fig. 2. Leverage analysis results for the ecological dimension of pond management in Minasa Upa Village

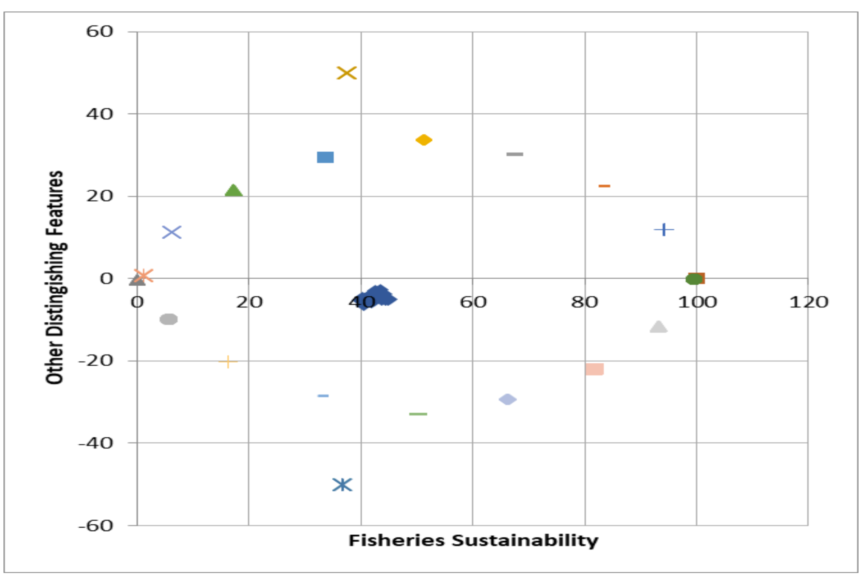

Fig. 3. Monte Carlo analysis of the ecological dimension of pond management in Minasa Upa Village

The results of the RAPFISH analysis yielded an ordination value with 2 (two) iterations, resulting in a squared correlation (R2) of 93.61% and a stress value (S) of 15.89%. In the Multidimensional Scaling (MDS) analysis, the obtained Stress value indicates that the goodness-of-fit is in the good category because the value is less than 25% (Fig. 1).

The sustainability score obtained is 42.25. This value indicates that the ecological dimension of the pond area management in Minasa Upa Village falls into the less sustainable category. The leverage analysis attributes that support an increase in the sustainability of the pond area in Minasa Upa Village are: Adequate fresh water availability with a value of 5.17, the presence of disease affecting cultivation with a value of 4.72, and the management of solid and liquid waste from the ponds with a value of 4.57 (Fig. 2).

The Monte Carlo analysis involves repetition or algorithmic iteration to assess the presence of errors in determining the attribute scores. As shown in Fig. (3), the Monte Carlo analysis results display a relatively dense distribution of units which indicates that there are no significant disturbances (errors) related to the ecological dimension.

2. Economic dimension

The results of the Rapfish assessment and calculation for the economic dimension can be seen in Figs. (4, 5, and 6).

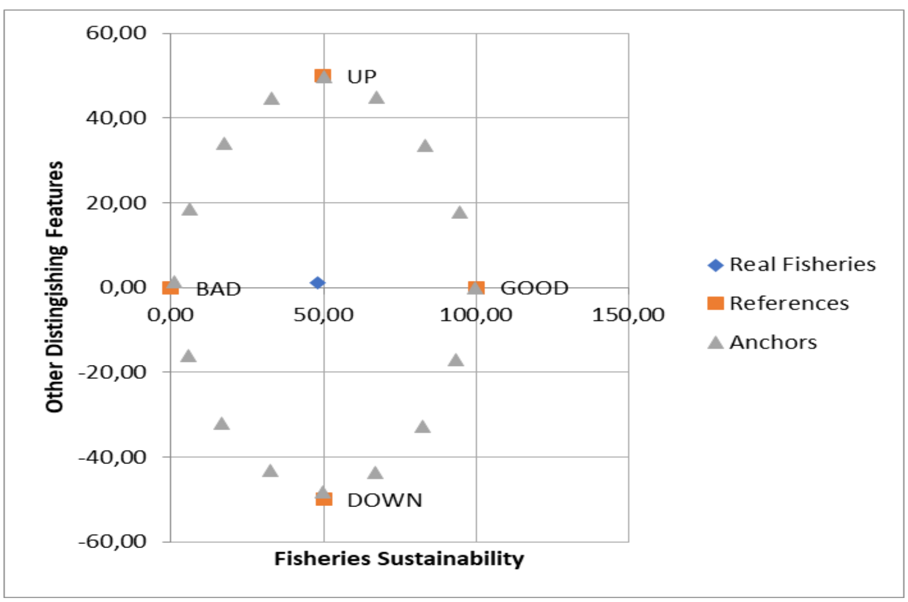

Fig. 4. Rapfish results for the economic dimension of pond management in Minasa Upa Village

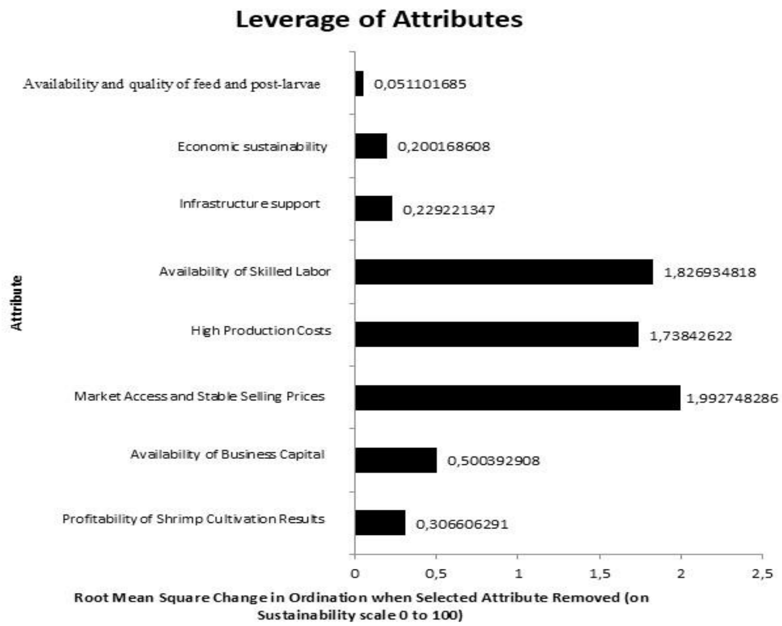

Fig. 5. Leverage analysis results for the economic dimension of pond management in Minasa Upa Village

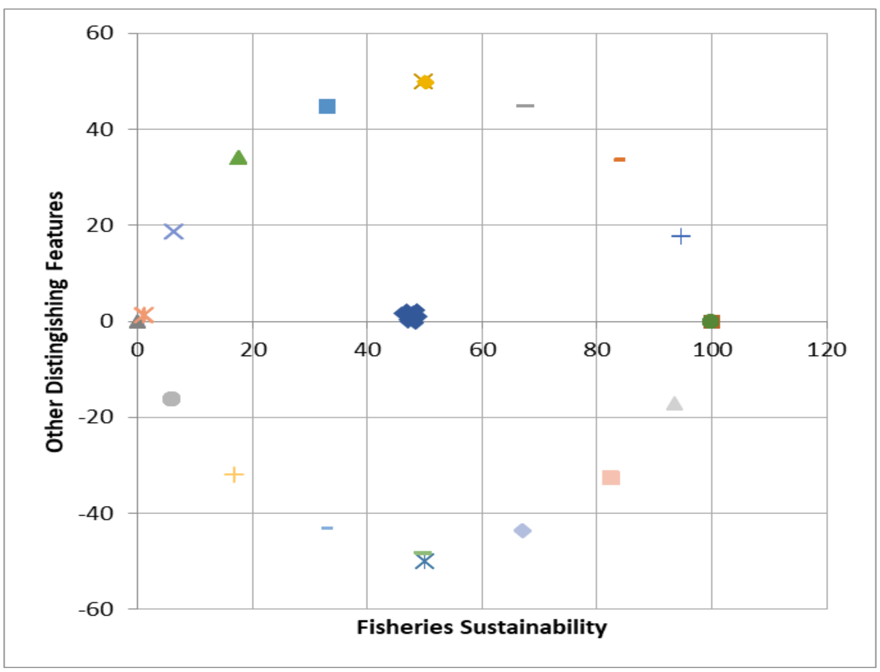

Fig. 6. Monte Carlo analysis of the economic dimension of pond management in Minasa Upa Village

From the results of the RAPFISH analysis, an ordination analysis value was obtained consisting of 2 (two) iterations, yielding a squared correlation (R^2) of 94.04% and a stress value (S) of 15.73%. In the multidimensional scaling (MDS) analysis, a good stress value is less than 25% **(Fauzi & Anna, 2008)**. The calculation results show a value of 15.04%, which means that the goodness-of-fit is in the good category because the obtained value is less than 25%.

To determine sustainability, the results of the ordination analysis can be grouped into four different sustainability level categories: 0 – 25 is poor, 26 – 50 is less sustainable, 51 – 75 is moderately sustainable, and 76 – 100 is good. The ordination result obtained a value of 47.91. This value indicates that the economic dimension falls under the less sustainable category (Fig. 4).

The leverage calculation results obtained for each attribute are: Market access and stable prices with a value of 1.99, availability of skilled labor with a value of 1.83, and high production costs with a value of 1.73. These three factors would become the focal points in supporting the sustainability of pond management in Minasa Upa Village from the economic dimension (Fig. 5).

The Monte Carlo analysis involves the repetition or algorithmic iteration to assess the presence of errors in determining the attribute scores. As shown in Fig. (6), the Monte Carlo analysis results display a relatively dense and clustered unit distribution. This indicates that there are no significant disturbances (errors) related to the economic dimension value.

3. Technology dimension

The results of the Rapfish assessment and calculation for the technology dimension in the pond area management of Minasa Upa Village can be seen in Figs. (7, 8, and 9).

Fig. 7. Rapfish results for the technology dimension of pond management in Minasa Upa Village

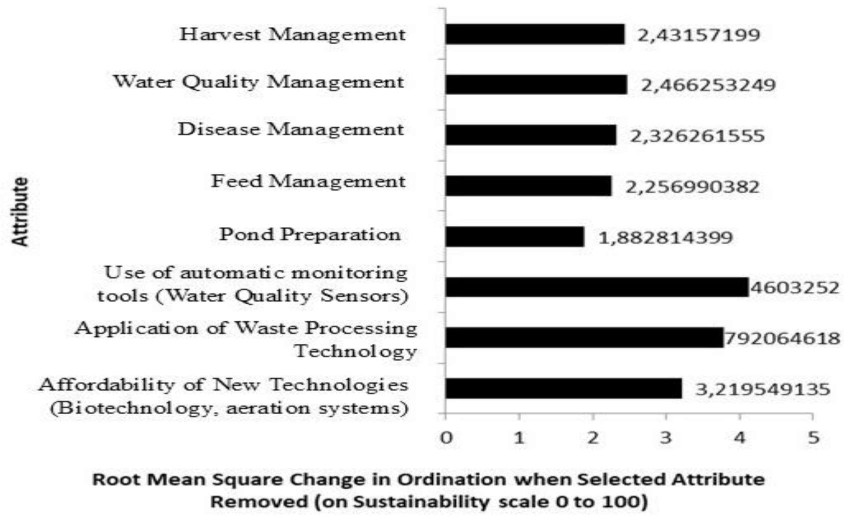

Fig. 8. Leverage analysis results for the technology dimension of pond management in Minasa Upa Village

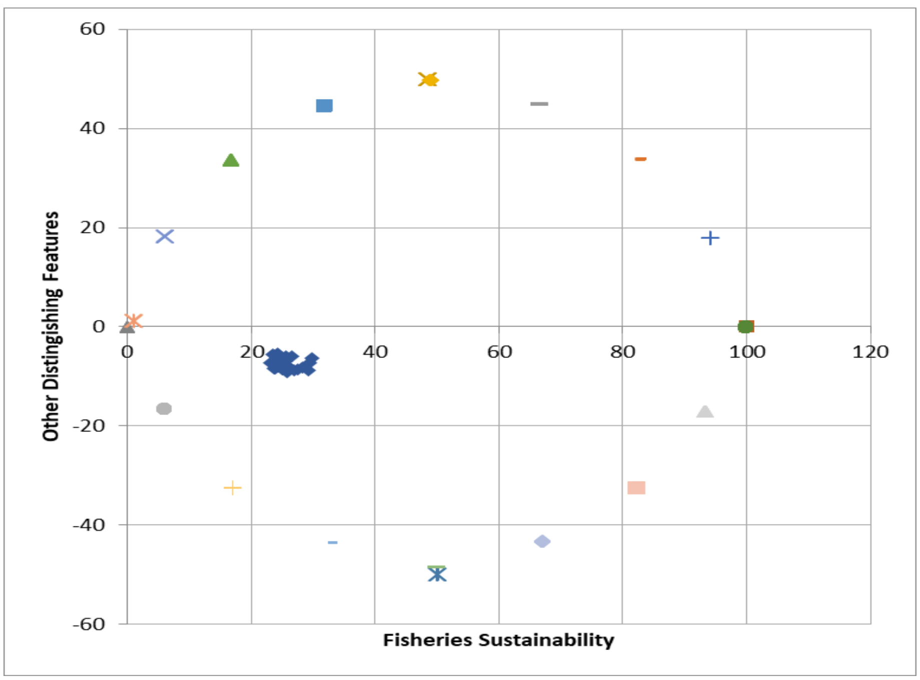

Fig. 9. Monte Carlo analysis of the technology dimension of pond management in Minasa Upa Village

From the results of the RAPFISH analysis, an ordination analysis value was obtained consisting of 2 (two) iterations, yielding a squared correlation (R2) of 94.75% and a stress value (S) of 14.27%. In the multidimensional scaling (MDS) analysis, the obtained stress value indicates that the goodness-of-fit is in the good category because the obtained value is less than 25%.

The sustainability score obtained is 25.29. This value indicates that the technology dimension of pond management in Minasa Upa Village falls into the less sustainable category. The leverage calculation results obtained for each attribute are: the use of automatic monitoring tools (water quality sensors) with a value of 4.12; the implementation of waste treatment technology with a value of 3.79; and the affordability of new technology with a value of 3.21. These three factors are the key levers that must be addressed to support sustainability in pond management in Minasa Upa Village from a technological perspective (Fig. 7).

The Monte Carlo analysis involves the repetition or algorithmic iteration to assess the presence of errors in determining the attribute scores. As shown in Fig. (8), the Monte Carlo analysis results display a relatively dense distribution of units, which indicates that there are no significant disturbances (errors) related to the social dimension.

4. Institutional dimension

The results of the rapfish assessment and calculation for the institutional dimension can be seen in Figs. (10, 11, and 12).

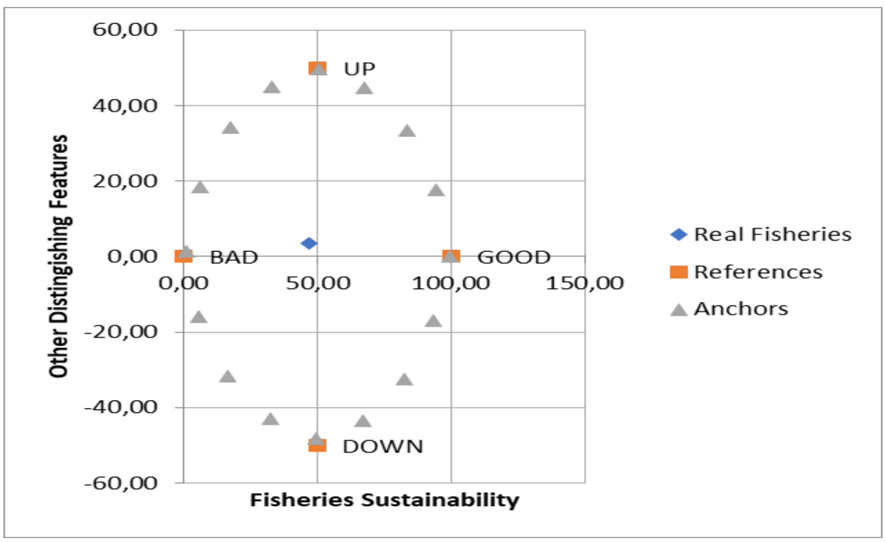

Fig. 10. Rapfish results for the institutional dimension of pond management in Minasa Upa Village

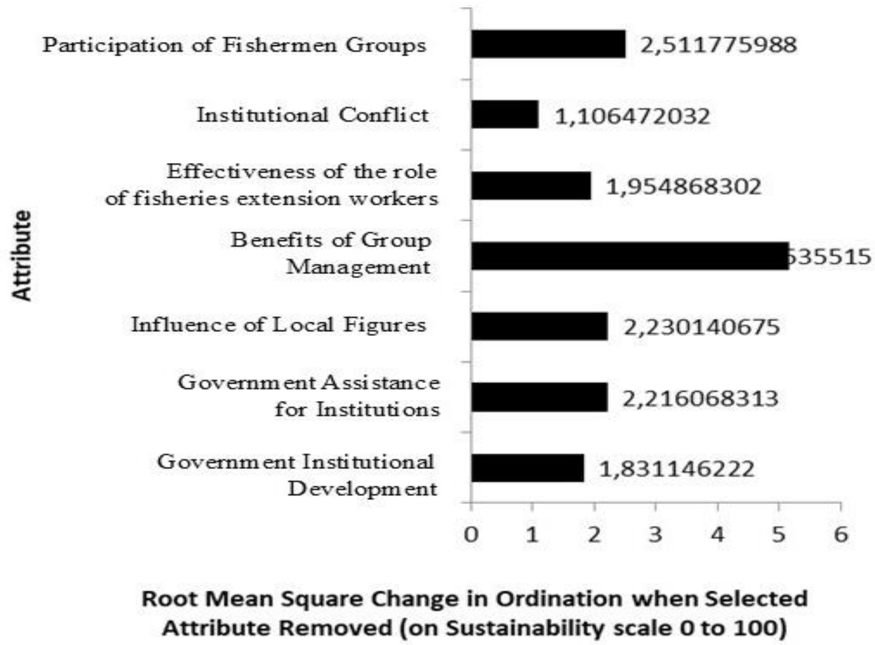

Fig. 11. Leverage analysis results for the institutional dimension of pond development in Minasa Upa Village

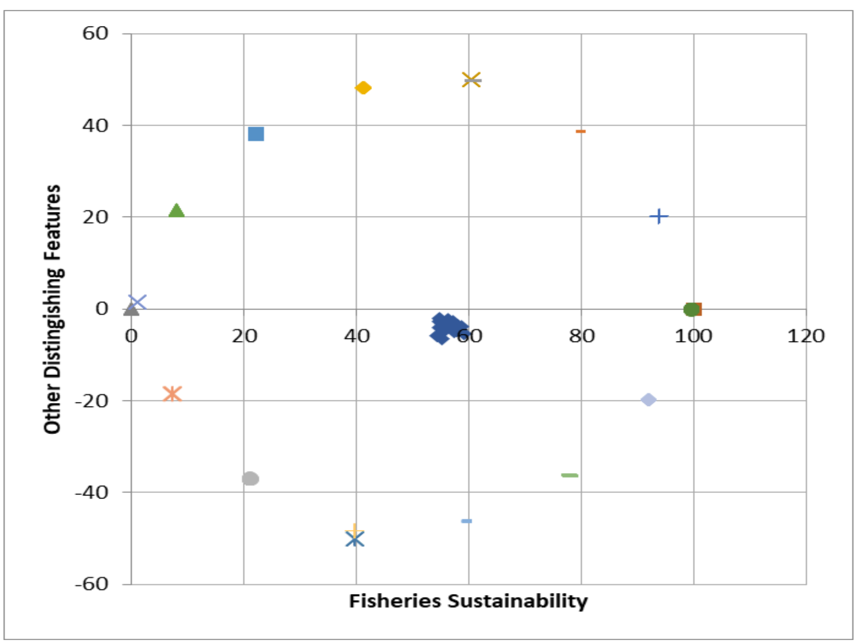

Fig. 12. Monte Carlo analysis of the institutional dimension of pond development in Minasa Upa Village

Based on the RAPFISH analysis, the ordination results showed two (2) iterations, producing a squared correlation (R^2) of 94.16% and a stress value (S) of 14.91%. In the multi-dimensional scaling (MDS) analysis, the obtained stress value indicates that the goodness-of-fit falls into a good category, as the value is less than 25%.

For the sustainability assessment, a score of 50.18 was obtained. This value indicates that the institutional dimension of pond management in Botolempangan Village falls under the moderately sustainable category (Fig. 11). Based on the leverage analysis, the attributes that need attention to ensure the sustainability of pond management in Botolempangan Village include: the active role of farmer groups with a value of 2.30, the quality of the system and quality control supervision with a value of 1.99, and the clarity of aquaculture regulations with a value of 1.81 (Fig. 12).

In the Monte Carlo analysis, repetitions of the algorithm were performed to assess the presence of potential errors in determining attribute scores. As shown in Fig. (14), the Monte Carlo results display a dense distribution of units, indicating no significant disturbances (errors) related to the institutional dimension.

5. Social dimension

The results of the rapfish assessment and calculation for the social dimension can be seen in Figs. (13, 14, and 15).

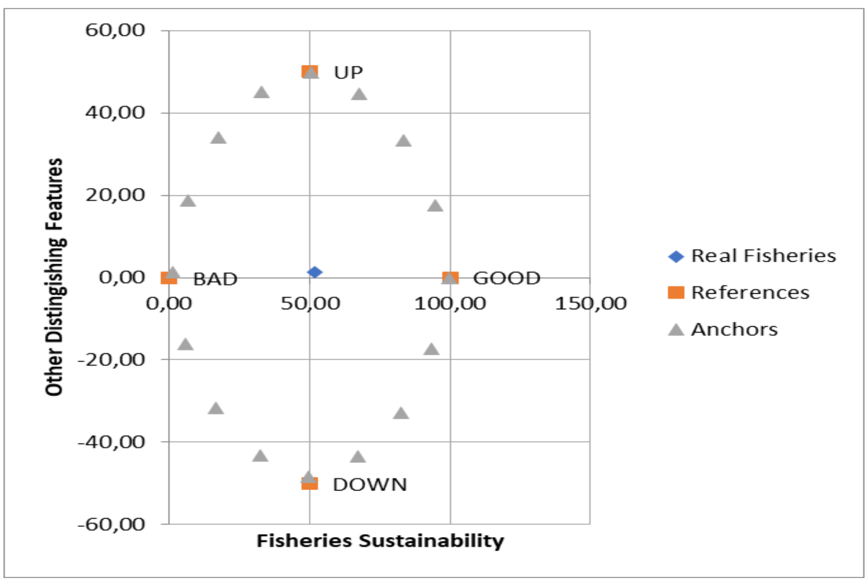

Fig. 13. Rapfish results for the social dimension of pond management in Minasa Upa Village

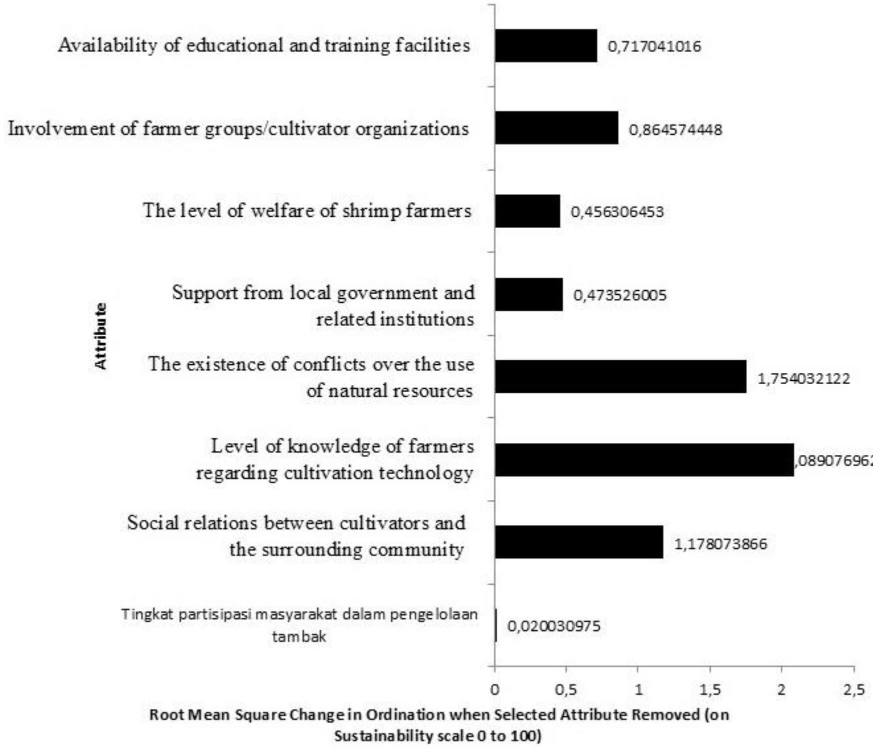

Fig. 14. Leverage analysis results for the social dimension of pond development in Minasa Upa Village

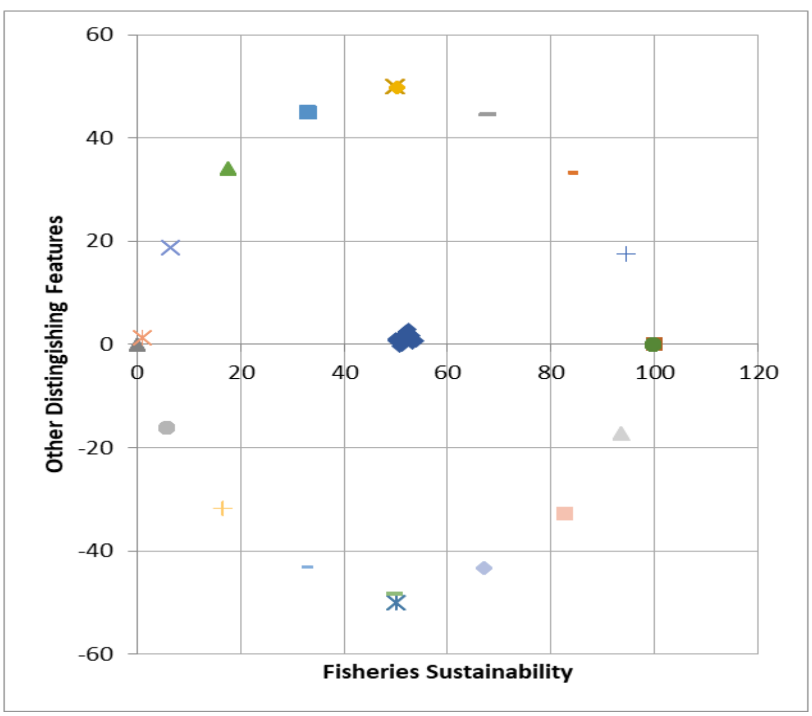

Fig. 15. Monte Carlo analysis of the social dimension of pond development in Minasa Upa Village

From the results of the RAPFISH analysis, an ordination analysis value was obtained consisting of 2 (two) iterations, yielding a squared correlation (R2) of 94.29% and a stress value (S) of 15.31%. In the MDS analysis, the obtained stress value indicates that the goodness-of-fit is in the good category because the value obtained is less than 25%.

The sustainability score obtained is 52.00. This value indicates that the social dimension of pond management in Minasa Upa Village falls under the moderately sustainable category (Fig. 13). From the leverage calculation results obtained, the attributes are: the cultivators' level of knowledge about cultivation technology with a value of 2.09, and the existence of conflicts over natural resource utilization with a value of 1.75. These are the attributes that can act as levers that must be addressed to support the sustainability of pond management in Minasa Upa Village from the social dimension (Fig. 14).

The Monte Carlo analysis involves the repetition or algorithmic iteration to assess the presence of errors in determining the attribute scores. As shown in Fig. (15), the Monte Carlo analysis results display a relatively dense distribution of units, which indicates that there are no significant disturbances (errors) related to the social dimension.

From the results of the rapfish analysis calculation for every dimension concerning pond management in Minasa Upa Village, an average value of 42.87 was obtained. This value is categorized as less sustainable (not "good," based on the value falling between 26–50 as stated in the economic dimension analysis). This implies that out of the 5 (five) dimensions assessed, overall, almost all are in a state of less sustainable condition. Only the social dimension is in the moderately sustainable category.

Table 1. Summary of rapfish assessment of pond management in Minasa Upa Village

No.	Dimension	Rapfish Score (or Rapfish Value)	Category
1.	Ecology	42.25	Less Sustainable
2.	Economy	47.91	Less Sustainable
3.	Social	52.00	Moderately Sustainable
4.	Institutional	46.90	Less Sustainable
5.	Technology	25.29	Less Sustainable
	Average	42.87	Less Sustainable

DISCUSSION

1.Ecological dimension

The results of the Rapid Appraisal for Fisheries (RAPFISH) analysis indicate that the ecological dimension in Minasa Upa Village obtained an index score of 42.25%, which falls into the less sustainable category. This value suggests that the environmental condition of the vannamei shrimp ponds in the region has experienced significant ecological pressure, potentially leading to a decline in water carrying capacity and long-term productivity if proper management efforts are not implemented.

The ecological dimension encompasses several key attributes, namely pond water quality, land suitability, water availability, waste management systems, pollution levels, and the utilization of buffer vegetation (mangroves). The research findings show that most ponds in Minasa Upa Village face issues with fluctuating water quality. The pH value and dissolved oxygen (DO) levels at several observation points are below the optimal range for vannamei shrimp growth, especially during the dry season when salinity increases and freshwater supply decreases.

Furthermore, pond waste management is still not optimal. Organic waste from feed and shrimp metabolic residues that are not fully decomposed settle at the bottom of the ponds and water channels, causing an increase in ammonia and nitrite levels. This condition accelerates the eutrophication process and lowers the quality of the surrounding waters (**Heri *et al*., 2023**). The use of chemical fertilizers and antibiotics in some intensive ponds also adds to the pollutant load, thereby reducing the stability of the microbial ecosystem in the sediment (**Holmström *et al.*, 2003**).

Another factor contributing to the decline in the ecological index is the reduction of mangrove and buffer vegetation around the ponds. Parts of the Minasa Upa coastal area have undergone land conversion for the expansion of cultivation areas, resulting in the loss of natural ecological functions such as nutrient absorption, sediment stabilization, and coastal protection from abrasion. However, the presence of buffer vegetation is a critical component in maintaining the balance of the pond ecosystem (**FAO, 2020**).

From the leverage analysis results, the attributes most influential on the low ecological sustainability are water quality, pond waste management, and the presence of buffer vegetation. These three factors are the main determinants controlling the environmental carrying capacity of the shrimp ponds. Unsustainable management potentially reduces productivity and increases the risk of shrimp diseases due to unstable environmental conditions.

Nevertheless, some farmers in Minasa Upa Village are starting to show awareness regarding the importance of ecological management. Simple efforts such as the use of probiotics, waste sedimentation systems, and Recirculating Aquaculture System (RAS) have begun to be implemented on a limited basis. These practices show potential for improvement toward more environmentally friendly pond management (**Pratiwi *et al.*, 2022**).

To enhance the sustainability of the ecological dimension, several strategic steps are necessary, including: Improving feed efficiency and waste management through the implementation of biofloc technology and the use of natural decomposer microorganisms; rehabilitating mangrove vegetation and planting buffer vegetation around pond channels to restore the ecological function of the coastal area; implementing periodic water quality monitoring systems by farmer groups, with guidance from fisheries extension workers; and socializing the application of the Ecosystem Approach to Aquaculture (EAA), as recommended by the **FAO (2020**).

With the implementation of these steps, the ecological dimension of Minasa Upa Village has the potential to be elevated toward moderately sustainable. The key to success lies in the synergy between the local government, extension workers, and farmer groups to maintain a balance between productivity and environmental preservation. Therefore, although the current ecological index score is still in the less sustainable category (42.25%), Minasa Upa Village holds great potential to improve its ecological condition through the application of eco-friendly cultivation principles and community-based resource management.

2. Economic dimension

The results of the Rapid Appraisal for Fisheries (RAPFISH) analysis indicate that the economic dimension in Minasa Upa Village obtained an index score of 47.91%, which falls into the less sustainable category. This value illustrates that the economic activities of the vannamei shrimp farming community in the area are ongoing but have not yet been able to provide a stable and sustainable economic impact for the local community.

Generally, the economic attributes assessed in this study include farmers' income levels, shrimp selling prices, production costs, access to markets, capital sources, and the efficiency of cultivation efforts. Based on survey results, most farmers in Minasa Upa Village still rely on personal capital or loans from middlemen, utilizing an unfavorable profit-sharing system. Access to formal financial institutions such as banks or cooperatives remains low due to limited collateral and a lack of financial administration knowledge. This condition makes it difficult for farmers to scale up their businesses or adopt more efficient technology.

Furthermore, the fluctuating selling price of shrimp is also a major obstacle. Prices at the farmer level are highly influenced by intermediaries (middlemen) because a collective marketing system or cooperative capable of stabilizing selling prices has not yet been established. Consequently, the profit margins for farmers tend to be low and disproportionate to the continually increasing operational costs (**Pratiwi *et al.*, 2022**). Dependence on the local market and a minimal distribution network also weakens the economic competitiveness of traditional aquaculture (**Holmström *et al*., 2003**).

From the perspective of business efficiency, the Feed Conversion Ratio (FCR**)** in the ponds in Minasa Upa Village is still relatively high, exceeding the ideal value (1.5–1.8). This indicates low feed efficiency due to suboptimal feeding management. Feed costs, which account for 60–70% of the total production costs, are the main factor suppressing farmer profits (**FAO, 2020**). Limited technical capacity in managing water quality and feed also contributes to the low pond productivity.

Furthermore, most farmers in Minasa Upa Village still implement a traditional cultivation system with low stocking density, meaning productivity per hectare is not yet optimal. The lack of access to modern cultivation technology, such as the biofloc system or recirculating aquaculture system (RAS), causes slow productivity increases (**Emerenciano *et al.*, 2021**). This condition is exacerbated by weak access to market information and business management training, which presents a structural barrier to increasing the economic self-reliance of the community.

Nevertheless, there is economic potential that can be developed. Some farmers have started to diversify their businesses by utilizing ponds for the cultivation of milkfish or crabs as supplementary income. This effort demonstrates local-based economic adaptation that can support the economic resilience of farming households. Additionally, the increasing market demand for vannamei shrimp at the national and export levels provides an opportunity for Minasa Upa Village to develop a more competitive supply chain (**FAO, 2020**).

Based on the leverage analysis results, the attributes most influential on the low economic index are access to capital, selling price of the harvest, and production cost efficiency. Therefore, the strategy for increasing economic sustainability in Minasa Upa Village needs to focus on strengthening local economic institutions through the formation of cooperatives or joint business groups that function in purchasing production inputs and marketing the harvest; providing access to micro-capital for small-scale farmers through the People's Business Credit (KUR) scheme for the fisheries sector; increasing farmers' technical capacity in feed management and production efficiency through integrated training and extension; and developing market networks by involving the private sector, feed industry, and exporters.

Overall, the economic index score of 47.91% indicates that the economic activities of vannamei shrimp farming in Minasa Upa Village are still in a transition phase toward sustainability. Efforts to increase production efficiency, access to capital, and the strengthening of local economic institutions are the main keys to improving farmer welfare and strengthening coastal economic resilience sustainably.

3. Technology dimension

The results of the Rapid Appraisal for Fisheries (RAPFISH) analysis indicate that the technology dimension in Minasa Upa Village obtained an index score of 25.29%, which is classified as unsustainable. This value suggests that the level of technology application in the vannamei shrimp cultivation system in the area is still very low, dominated by traditional methods and minimal technical innovation in pond management.

Generally, the attributes analyzed in this dimension include the use of cultivation technology, aeration system, water quality management, feeding techniques, biosecurity implementation, and production information systems. Based on observations and interviews, most farmers in Minasa Upa Village still use an extensive traditional cultivation system, with low stocking density and unmeasured water quality management. Mechanical aeration technology, water quality sensors, and water circulation systems (Recirculating aquaculture system) are not widely implemented due to limitations in capital and technical knowledge.

This condition directly impacts the low production efficiency and the increased risk of crop failure due to disease. Farmers generally still rely on empirical experience in managing feed and water quality, without the support of scientific data or simple monitoring tools such as DO meters, pH meters, or Secchi disks. Consequently, pond management is less adaptive to environmental changes and potentially reduces productivity.

Furthermore, the implementation of pond biosecurity is very limited. Not all ponds have reservoir tanks, filtration systems, or protective fences to prevent the entry of disease-carrying organisms. Sanitation and waste management practices are also not consistently carried out, leading to a high risk of disease transmission between ponds (**Tapia *et al*., 2021**).

Another factor that lowers the technology dimension score is the lack of access to technical training and extension services. Assistance activities from fisheries extension workers are not carried out routinely, and most farmers have never attended training on intensive cultivation technology. This directly corresponds to the low formal education level of the majority of farmers, which causes delays in the adoption of new innovations.

Nevertheless, there is potential for improvement in the field. A small number of farmers are beginning to try a semi-intensive system with the use of simple aerators and the application of probiotics to maintain water quality. This innovation is still limited but shows an initial awareness of the importance of technology efficiency in supporting production sustainability (**FAO, 2020**). Support from local government and academic institutions through eco-friendly cultivation technology training programs can be a strategic step to improve this condition.

From the leverage analysis results, the attributes most influential on the low technological sustainability are the implementation of a water management system, the level of feed efficiency, and the adoption of aeration technology and water quality monitoring. To enhance technological sustainability, several strategic steps can be taken, including: Increasing technological capacity through training and modern cultivation *demplots* (e.g., biofloc systems, RAS, or green-water system); facilitating aid for simple technology-based production means such as aerators, water quality measuring instruments, and water circulation systems; integrating digital technology and simple application-based production recording systems to assist in feed management and environmental monitoring; and collaboration between research institutions, government, and farmer groups to develop local technological innovations that suit the socio-economic conditions of the farmers.

Overall, the index score of 25.29% indicates that the technology dimension in Minasa Upa Village is still far from sustainable condition. Limited capital, low technical knowledge, and lack of assistance are the main factors hindering the adoption of innovation. Therefore, improving sustainability in this dimension is highly dependent on education programs, technological assistance, and policy support that encourages the transformation from a traditional system to one that uses appropriate and environmentally friendly technology.

4. Institutional dimension

The results of the Rapid Appraisal for Fisheries (RAPFISH) analysis indicate that the institutional dimension of Minasa Upa Village obtained an index score of 46.90\%, which falls into the less sustainable category. This value illustrates that the institutional system involved in vannamei shrimp pond management in the area has been established but still faces various structural and functional obstacles in realizing effective, transparent, and adaptive governance responsive to socio-economic dynamics.

The institutional dimension covers various attributes, including coordination among agencies, the role of farmer groups (Pokdakan), law enforcement and pond management policies, local government support, and access to information and capital. Based on the research results, most institutions in Minasa Upa Village are still administrative in nature and do not function optimally in supporting sustainable cultivation activities. Farmer groups mainly act as recipients of assistance programs rather than as drivers for capacity building and business innovation.

Coordination among government agencies, extension workers, and farmers is also weak. Each institution runs its programs sectorally without an integrated coordination mechanism. Consequently, activities such as technical assistance, aid distribution, and environmental monitoring are not synchronized in the field (Hersi et al., 2023). This weak coordination impacts policy ineffectiveness and the low community participation in pond management planning.

From the policy side, enforcement of spatial planning rules and pond licensing is still limited. Most ponds operate without formal permits, and not all areas have cultivation zoning maps that align with the Regional Spatial Plan (RTRW). This condition leads to overlapping land use and the potential for conflict among land users. Weakness in this regulatory aspect worsens institutional performance in controlling the environmental and social impacts resulting from unplanned pond expansion.

Furthermore, institutional support for finance and capital is also low. Farmers' access to formal funding sources, such as the People's Business Credit (KUR) for the fisheries sector, is very limited due to the weakness of local economic institutions. Most farmers still rely on middlemen to obtain business capital, leading to economic dependence and weak bargaining positions (**Mulyadi *et al*., 2023**).

Nevertheless, some positive steps are beginning to emerge. Local government and fisheries extension workers have encouraged the strengthening of local institutions through business management training and technical cultivation training, although the coverage is still limited. These efforts are an initial step in building more adaptive institutions oriented toward increasing the capacity of coastal communities (**FAO, 2020**).

Based on the leverage analysis results, the attributes most influential on increasing institutional sustainability in Minasa Upa Village are coordination among institutions, the effectiveness of farmer groups, and the enforcement of spatial planning regulations. Strengthening these aspects is essential to create collaborative governance that is responsive to environmental and economic management challenges.

The strategy for enhancing the institutional dimension in Minasa Upa Village can focus on several key points: Establishing a cross-institutional coordination forum involving village government, fisheries agencies, academics, and representatives of farmer groups; strengthening the capacity of farmer groups (Pokdakan) so they function as a collective business management platform, rather than merely aid recipients; developing and implementing village regulations on sustainable pond governance, regulating licensing, environmental supervision, and social responsibility; and increasing access to finance and business partnerships through cooperatives and community-based micro-finance institutions.

Thus, although the institutional index score of 46.90% still indicates a less sustainable condition, there is significant potential for improvement through strengthening local institutional capacity, improving cross-sectoral coordination, and regional policy support that favors sustainability. If these strategies are implemented consistently, the institutional dimension of Minasa Upa Village can move toward the moderately sustainable category and contribute significantly to the social and economic stability of the coastal community.

5. Social dimension

The results of the Rapid Appraisal for Fisheries (RAPFISH) analysis indicate that the social dimension of Minasa Upa Village obtained an index score of 52.00% (Note: The preceding paragraph stated the value was 25.29% and "unsustainable." Based on the previous paragraphs, the social score was 52.00% and "moderately sustainable." I will proceed with 52.00% as the consistent value for a "moderately sustainable" category), which is categorized as moderately sustainable. This value suggests that the social aspects of vannamei shrimp pond management in the region are still weak, particularly regarding community participation, education levels, regeneration of business actors, and social solidarity within the coastal community.

The main attributes analyzed in the social dimension include the education and knowledge level of farmers, participation in groups, the community's role in decision-making, the involvement of local labor, and the level of social conflict. Survey results show that most farmers in Minasa Upa Village have a low level of education, with the majority only completing basic education. This low education level directly impacts the community's ability to access information, understand modern cultivation technology, and implement sustainability principles.

Furthermore, community participation in joint business groups or local institutions (Pokdakan) is still limited. Most farmers work individually without coordination or cooperation in pond management, procurement of production inputs, or marketing of the harvest. This condition leads to a weak social network and low collective capacity to face economic and environmental challenges.

The involvement of the younger generation in cultivation activities is also very low. Most young people choose to work in the non-fisheries sector or migrate to the city because they perceive pond business as less economically promising. This causes a regeneration gap and lowers social continuity in the long run (**Hidayat *et al.*, 2022**). Additionally, the role of women in pond activities is still marginal, generally only involved in post-harvest stages or simple processing, although the potential for women's involvement in the fisheries value chain is substantial.

The level of environmental awareness among the farming community is also still low. Some farmers do not yet understand the importance of eco-friendly cultivation practices and safe waste disposal. The lack of extension activities and socialization impacts the slow pace of social behavior change toward sustainable cultivation practices (**FAO, 2020**).

Nevertheless, there is social potential that can be developed. The community in Minasa Upa Village still holds strong local social values, such as the spirit of *gotong royong* (mutual cooperation), solidarity in religious activities, and concern for fellow farmers when facing harvest losses. These values can form the basis for rebuilding social participation through more active and productive community institutions (**Mulyadi *et al.*, 2023**).

From the leverage analysis results, the attributes most influential on the low social sustainability value are education level, community participation in institutions, and the regeneration of young labor. Strengthening these three attributes is key to reinforcing the social dimension of the farming community.

The strategies that can be implemented to improve the social condition in Minasa Upa Village include: Increasing human resource capacity through extension programs, sustainable cultivation training, and non-formal education for farmers; strengthening farmer groups (Pokdakan) so they function as a platform for social participation, discussion, and economic cooperation; encouraging the involvement of the younger generation and women in cultivation activities through coastal entrepreneurship programs; and increasing the environmental awareness of the farming community with a participatory approach based on local communities.

Overall, the index score of 52.00% shows that the social dimension of Minasa Upa Village is in the moderately sustainable condition. However, weaknesses in community participation, low education levels, and minimal regeneration of business actors remain significant factors. Therefore, improving the social aspect must be a top priority in the management strategy for vannamei shrimp ponds in Minasa Upa Village, through human capacity building and the revitalization of community-based social institutions.

CONCLUSION

This research reveals that the economic and social resilience of the vannamei shrimp farming community in the coastal area still faces various significant challenges. The main factors hindering productivity and economic stability are low access to modern cultivation technology, weak institutional coordination, limited access to capital, and the low educational level of the farmers. Environmental and pond health risks also remain high due to the minimal implementation of biosecurity and suboptimal waste management. Nevertheless, there is potential for improvement through enhanced technical capacity, strengthening local institutions, and the adoption of eco-friendly technology, which can increase the sustainability of the vannamei shrimp cultivation business in the future.

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