Sustainability of whiteleg shrimp, *Litopenaeus vannamei*, farming business on Sumatera Island, Indonesia

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Abstract. Whiteleg shrimp (*Litopenaeus vannamei*) farming is a key aquaculture activity on Sumatera Island, Indonesia, particularly in Riau and Bangka Belitung Provinces. This study assessed the sustainability of shrimp farming using the Multi-Dimensional Scaling (MDS) approach, evaluating five dimensions: ecological, economic, social, institutional, and technological. Data were collected through surveys, interviews, observations, and literature review involving 12 respondents, including farmers and relevant stakeholders. The results showed that the farming systems are moderately sustainable in ecological (51.73), economic (58.20), and technological (70.30) dimensions, but less sustainable in social (46.33) and institutional (47.10) dimensions. Key sensitive attributes include pond preparation, mangrove vegetation, shrimp selling prices, farmer involvement in resource management, and technology adoption. The findings highlight the need for improved regulations, community engagement, and technological support to enhance sustainability. This study provides a basis for strategic interventions and policies to support sustainable whiteleg shrimp farming in coastal Sumatera.
Key Words: aquaculture, Rapfish, shrimp farming, multidimensional scaling, strategic interventions.

Introduction. Whiteleg shrimp (*Litopenaeus vannamei*) is one of the aquaculture commodities with an important role in the Indonesian economy (Mutakin et al 2019). Based on the Ministry of Marine Affairs and Fisheries (2023), Indonesia is the 4th largest shrimp producing country in the world after Ecuador, India and Vietnam, with a production of 503,800 t year^{-1} in the aquaculture sector. The increasing demand for shrimp in Indonesia requires from shrimp farmers to maximize the production. A possible approach to achieving higher shrimp production is by expanding cultivation areas. High production levels are the primary objective of *L. vannamei* farming to meet market demands (Nagara 2021).

One of the areas producing *L. vannamei* in Indonesia is Sumatera Island. The Sumatera Island has the potential to become an area producing fishery commodities from aquaculture activities. Riau Province and Bangka Belitung Province are provinces on the Sumatera Island that are developing cultivation areas in the coastal zones. The vastness of the coastal zones and the close distance to the coastline make it an ideal location for *L. vannamei* cultivation activities because this facilitates easy access for cultivators to seawater as a primary source for aquaculture operations. The length of the coastline in the coastal area of Riau Province is estimated to reach 2,713 km^2. The coastal area is an area that is often used for human activities, such as the designation of government centers, settlements, industry, ports, fisheries, agriculture, fisheries and tourism (Husaini & Novreta 2020).

Bangka Belitung Province is also one of the provinces in the eastern part of the Sumatera Island which consists of two large islands, namely Bangka and Belitung. Data show that the area of waters is around 65,301 m^2 and land is 16,424.4 km^2, and Bangka Belitung has a water area of around 79.90% of the total area of the province, with a coastline of around 1,295.83% which has been developed as part of the fisheries development sector (Safadiva 2024). High shrimp production represents a key aspect of

coastal fisheries development, contributing to the economic growth. The concept of fisheries development requires an effective management to ensure a long-term sustainability. Sustainable fisheries must use natural resources in a rational way and must not damage the adjacent ecosystem (Nurdiansyah 2020).

Aquaculture development should equally prioritize productivity and ecosystem protection to maintain the sustainability of resources. Five aspects of sustainability must be considered, namely: ecological (maintaining stock/biomass and increasing ecosystem capacity and quality), economic (welfare of fishermen and related parties at the individual level), social (community welfare), institutional sustainability (efficient administration) and technological (adequate infrastructure and technology) (Warningsih et al 2020).

The utilization of coastal areas on Sumatera Island for *L. vannamei* cultivation, both in current operations and future developments, could eventually impact the surrounding environment if not managed responsibly. Such impacts may ultimately threaten the sustainability of fishery resources in the coastal regions of Sumatera Island. This study aimed to analyze the sustainability of *L. vannamei* cultivation on the Sumatera Island, Riau Province and Bangka Belitung Province by measuring the sustainability of 5 dimensions, namely ecological, economic, social, institutional and technological.

Material and Method

Description of the study sites. This study was conducted for 12 months (November 2023-November 2024) in Riau Province (Bengkalis Regency), and Bangka Belitung Province (Bangka Regency) which are brackish water aquaculture centers on the Sumatera Island that develop *L. vannamei* cultivation activities.

Research methods. The method used in this study is a survey method with a quantitative approach. According to Sugiyono (2019), quantitative methods are research methods based on the philosophy of positivism, used to research certain populations and samples, data collection using research instruments, quantitative/statistical data analysis aimed at testing predetermined hypotheses.

Respondent determination. Respondents were selected using a purposive sampling method, based on specific criteria relevant to the study. The criteria set by the researcher for respondents to obtain information are: location around the coast of Bengkalis Regency and Bangka Belitung islands Province (totaling 8 people), as well as expertise in governance (related agencies, Marine and Fisheries Service and Forestry and Environment Service, totaling 4 people), so that the number of respondents in this study was 12 people.

Data collection. Data collection techniques are by observation, interviews with questionnaire guides, and scientific literature studies. The data taken in the study are primary data and secondary data. Primary data was obtained using a questionnaire and structured interviews with farmers and expert respondents from government bodies. Secondary data was obtained from related agencies and related research literature.

Data analysis. The data processing and analysis method is carried out using the Multi-Dimensional Scaling-Rapid Appraisal for Sustainability (MDS) which is a modification of the Rapid Appraisal for fisheries (Rapfish) using 5 dimensions, namely ecology, economy, social, institutional, and technology. In Rapfish, sustainability is described quantitatively by a set of criteria defined in a numerical analysis by a set of attributes that are scored (Fauzi & Anna 2005). According to Wibowo (2015), the stages of MDS analysis include: (1) Determination of attributes; (2) Assessment of each attribute on an ordinal scale (scoring) based on sustainability criteria in each dimension; (3) Rapfish ordination analysis using the MDS method to determine ordination and stress values; (4) Assessment of the index and sustainability status of pond businesses both in each dimension and multidimensionally with reference to sustainability criteria based on

Kavanagh & Pitcher (2004); (5) Sensitivity analysis (leverage analysis) to determine attributes that are sensitive to sustainability. In determining attributes that are sensitive to the sustainability of shrimp farming, the Pareto optimum 75% analysis is used in accordance with the third law of attribute determination (Yusuf et al 2021); (6) Monte Carlo analysis to determine the stability of the ordination results. Table 1 presents the sustainability status index (Kavanagh & Pitcher 2004), which will serve as a reference for measuring the sustainability of *L. vannamei* farming on Sumatera Island.

Table 1

Guidelines for sustainability assessment of *Litopenaeus vannamei*

Index value	*Category*
<5.00	Bad (not sustainable)
25.00–49.99	Less (less sustainable)
50.00–74.99	Good (moderately sustainable)
>75.00	Very good (continuous)

Results. The research location is a *L. vannamei* cultivation area in the form of ponds located around the coastal areas of Bengkalis Regency and Bangka Belitung Regency, which are brackish water aquaculture centers that utilize coastal areas close to brackish water that supports *L. vannamei* cultivation. Table 2 shows the coordinates of the research locations of *L. vannamei* ponds in Bengkalis Regency Riau Province.

Table 2

Location of fish ponds in Bengkalis Regency

Research station	*Pond location*	*Coordinates*
I	Black Coral Pond in Jangkang Village	N 1.56686° E 102.188895°
II	Sebastian Utama Nindo Fish Pond in Selatbaru Village	N 1.51657° E 102.249525°
III	Jamik Farm Pond in Bengkalis Village	N 1.47955° E 102.091142°
IV	Anugrah Global Makmur Fish Pond in Buruk Bakul Village	N 1.41881° E 102.05729°
V	Tirta Makmur Pond Operational in Buruk Bakul Village	N 1.440971° E 102.031935°

Bengkalis Regency is one of the regencies in Riau Province. The business being developed is the cultivation of *L. vannamei*. The location of the research in the *L. vannamei* pond in Bengkalis Regency can be seen in Table 2. Around the mangrove forest ecosystem in the Bengkalis island and Bengkalis Darat areas, several shrimp ponds useintensive cultivation technology. According to Nuriansyah & Maulana (2023), the Government in Bengkalis Regency, Riau Province encourages the community to run fish cultivation, such as freshwater fish and *L. vannamei*. The Marine and Fisheries Service assists and facilitates local communities who do business on land, such as fish ponds and *L. vannamei* ponds. Table 3 shows the coordinates of the research locations of *L. vannamei* ponds in Bangka Regency.

The research location in the *L. vannamei* pond in Bangka Regency can be seen in Table 3. *L. vannamei* cultivation business activities continue to grow on Bangka Island. The existence of *L. vannamei* ponds is widely established along the coastal areas in regencies and cities on Bangka Island such as South Bangka Regency, Pangkal Pinang City and Central Bangka Regency.

Table 3

Shrimp pond locations in Bangka Regency

Research station	*Pond location*	*Coordinates*
I	Eagle Pond in Tukak Sadai District, South Bangka Regency	N 2.97789° E 106.639768°
II	Mega Perkasa Pond, Tukak Sadai District, South Bangka Regency	N 2.98617° E 106.644943°
III	Mr. Arifin's Fish Pond, Gerunggang District, Pangkal Pinang City	N 2.101664° E 102.091142°

L. vannamei is an export commodity whose demand in the world market is increasing. Several communities of investors have begun to switch from tin mining business to *L. vannamei* production in ponds (Suriawan et al 2019). This is supported by the potential of the waters on the coast of Bangka Island for *L. vannamei* cultivation activities. Most of the *L. vannamei* ponds on Bangka Island are intensive cultivation systems, with very high shrimp stocking densities.

Sustainability of L. vannamei cultivation on Sumatera Island. The sustainability of *L. vannamei* cultivation in Sumatera Island was analyzed using the Multi-Dimensional Scalling method using Rapfish (Rapid Appraisal Technique for Fisheries) which is used to estimate the level of sustainability in *L. vannamei* cultivation from the perspective of various dimensions. Rapfish produces index values and sustainability status of each dimension and multidimensional *L. vannamei* cultivation in Sumatera Island.

Ecological dimension. The sustainability of the ecological dimension will provide an overview of the extent to which the ecological capacity supports the *L. vannamei* cultivation activities. The support of ecological conditions in the *L. vannamei* cultivation process will provide a positive assessment for the sustainability of *L. vannamei* cultivation. Conversely, if the ecological conditions are unable to provide support for the *L. vannamei* cultivation process, it will provide a bad value for the sustainability of *L. vannamei* cultivation, which means that *L. vannamei* cultivation activities should not be carried out. The results of the Rapfish analysis on the ecological dimension show a sustainability index value of 51.73, this value is categorized as moderately sustainable (50.00-74.99) as seen in Figure 1. Figure 1 shows that the ecological sustainability status of *L. vannamei* farming on the Sumatera Island is less to moderate, with an index close to 49.99. This situation illustrates that the ecological condition of shrimp ponds on the Sumatera Island must be managed responsibly.

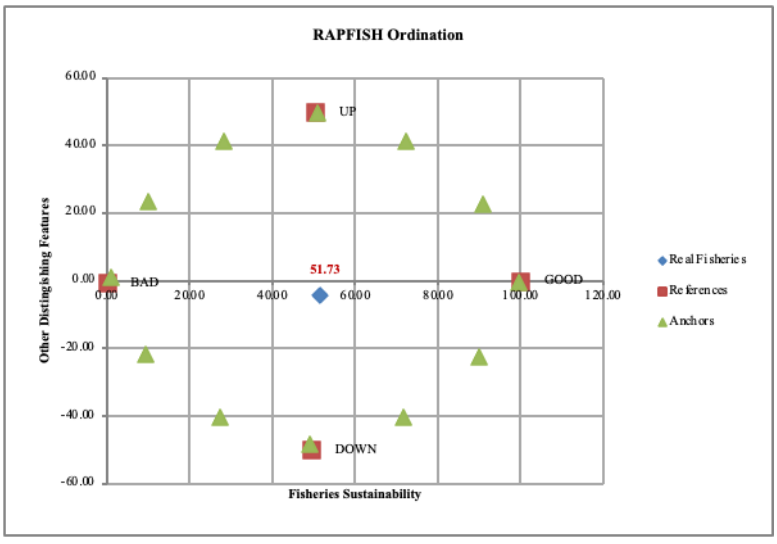

Figure 1. Status of sustainability of ecological dimensions.

Determination of sensitive attributes for the sustainability of *L. vannamei* cultivation on Sumatera Island using 75% optimum Pareto analysis showed two attributes that were sensitive to sustainability, namely the pond preparationand the mangrove vegetation, which can be seen in Figure 2. These should be prioritised for improvement in an effort to increase the sustainability status of *L. vannamei* farming on the Sumatera Island.

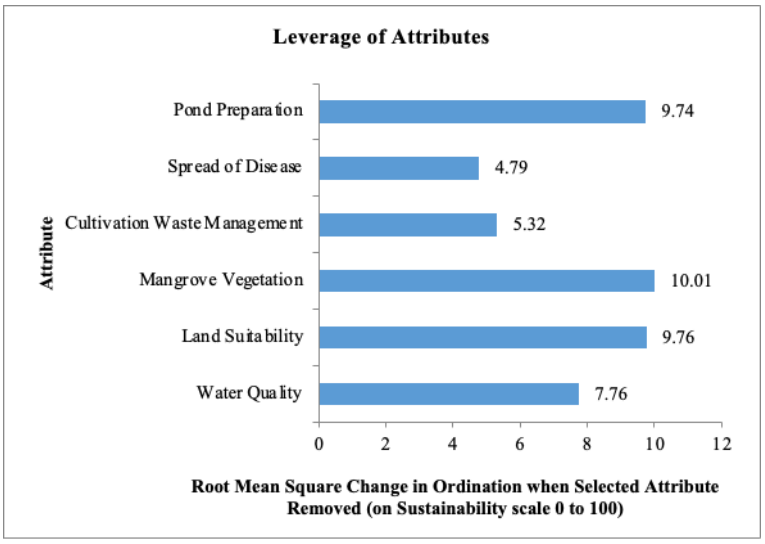

Figure 2. Attribute sensitivity to ecological dimensions.

Economic dimension. The existence of economic dimensions in *L. vannamei* cultivation on Sumatera Island to provide an assessment of the extent to which economic aspects support the existence of *L. vannamei* cultivation on Sumatera Island. The economic aspects of *L. vannamei* cultivation on Sumatera Island are assessed by the ability of economic development created by *L. vannamei* cultivation. The economic support created by *L. vannamei* cultivation is indeniable and demonstrates a success. The results of Rapfish analysis on the economic dimension show a sustainability index value of 68.20 (Figure 3), classified as a moderately sustainable status (50.00-74.99).

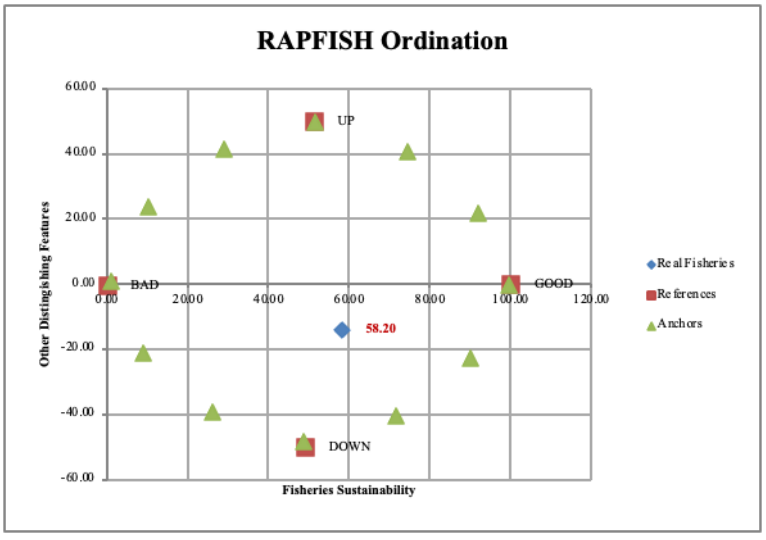

Figure 3. Sustainability status of economic dimension.

Sensitive attributes of the economic dimension of sustainability, based on the 75% optimum Pareto analysis, include product marketing, wage level and shrimp selling price. Sensitive attributes displayed in Figure 4 should be the economic levers which can be used to increasethe sustainability status of *L. vannamei* farming on the Sumatera Island.

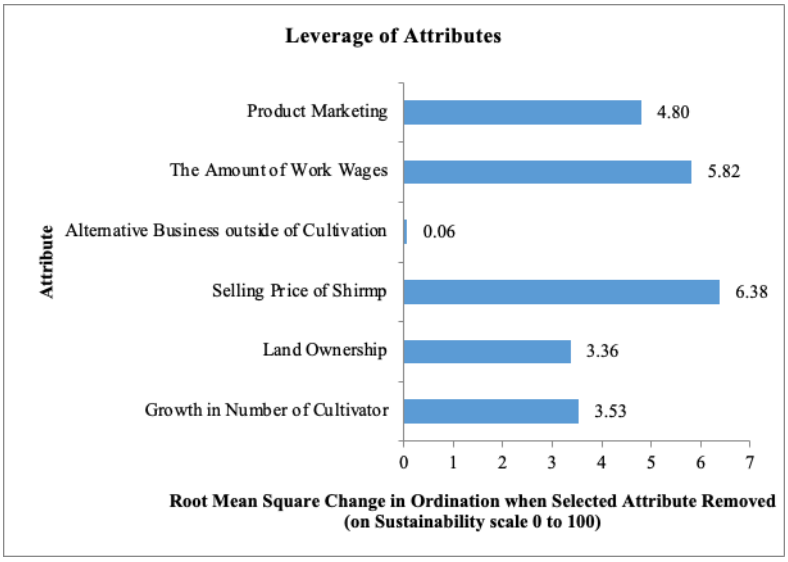

Figure 4. Attribute sensitivity on economic dimensions

Social dimension. Social or cultural consequences due to the existence of *L. vannamei* cultivation on the Sumatera Island provide an partial view of the sustainability of *L. vannamei* cultivation. The results of Rapfish's analysis on the social dimension show a sustainability index value of 46.33 as seen in Figure 5. This value is classified as less sustainable (50.00-74.99), which shows that the social dimension is one aspect that requires improvement from the government/stakeholders as an effort to increase the sustainability status of shrimp cultivation on the Sumatera Island.

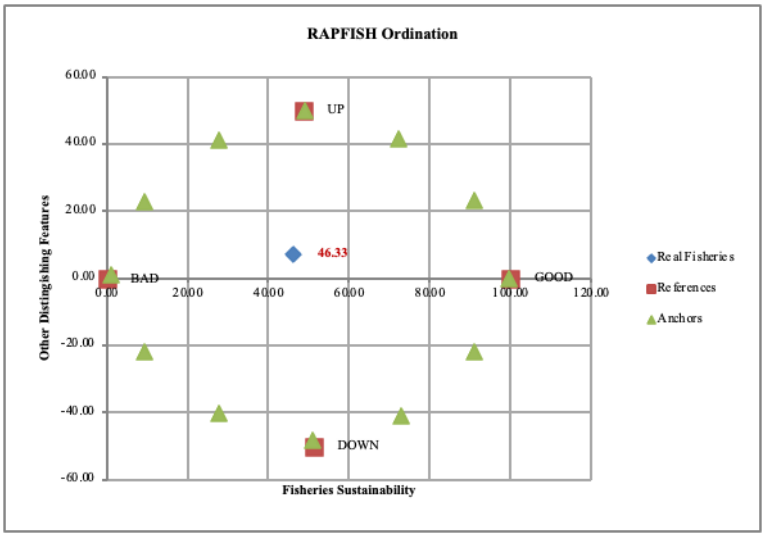

Figure 5. Status of sustainability of social dimension.

Sensitive attributes of the social dimension of the sustainability of *L. vannamei* cultivation on Sumatera Island include farmer involvement in fisheries resource management and local labor absorption, a it can be seen in Figure 6. Sensitive attributes are entry points for the improvement of social conditions that exist in the area, in support to the sustainability of *L. vannamei* farming on the Sumatera Island.

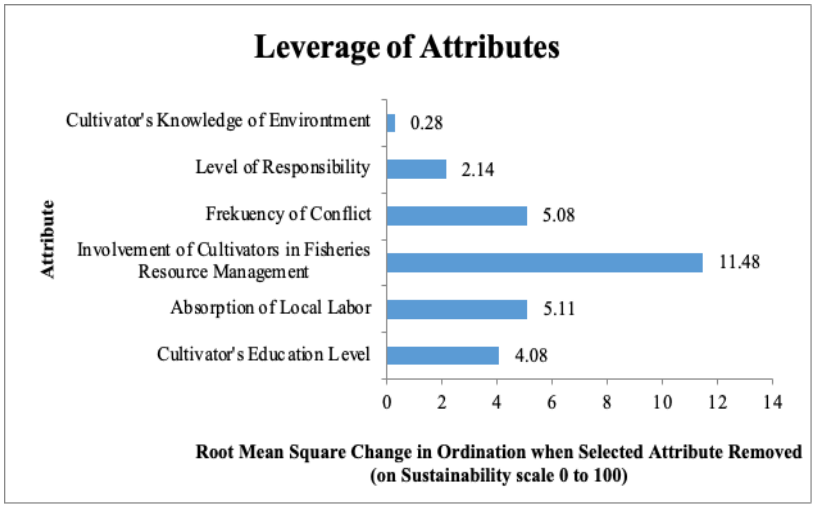

Figure 6. Attribute sensitivity to social dimensions.

Institutional dimensions. Institutions in shrimp farming on Sumatera Island provide a measure of the assessment of the extent of the influence of governancein supporting the existence of *L. vannamei* farming on Sumatera Island. The results of Rapfish analysis on the institutional dimension showed a value of 47.10 (Figure 7), classified as less sustainable (25.00-49.99), which is an important concern that must be improved by the government or stakeholders.

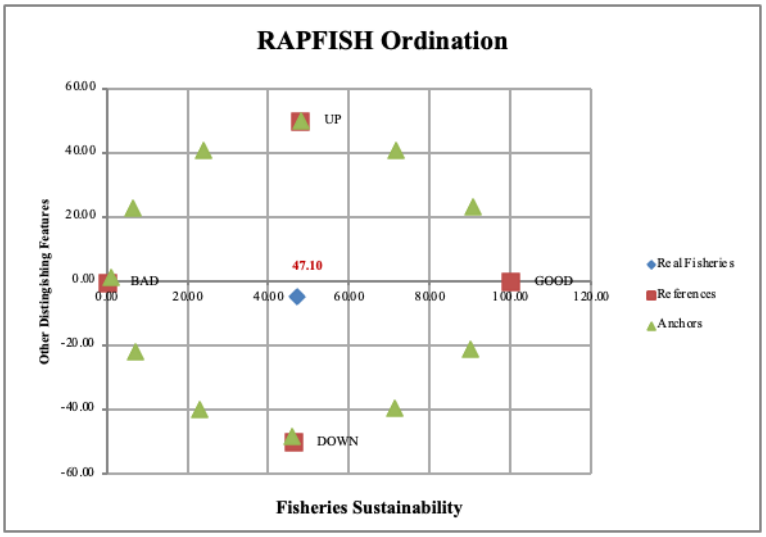

Figure 7. Sustainability status of institutional dimensions

Sensitivity analysis on the institutional dimension aims to provide management priorities that will support the sustainability status of *L. vannamei* cultivation in Sumatera Island. The research results show that the only sensitive attribute of the institutional dimension is the existence of a cultivation group, as seen in Figure 8. The existence of a cultivation group is expected to be a place for cultivators to provide support to each other and form solidarity which will form a complete cultivation group so that every right and government subsidy will be more easily distributed with the existence of a cultivation group. These rights and subsidies will certainly be stronger and their existence can be guaranteed with the existence of cultivation groups so that this can become one of the supporting factors for the sustainability of the vaname shrimp cultivation business in the institutional dimension.

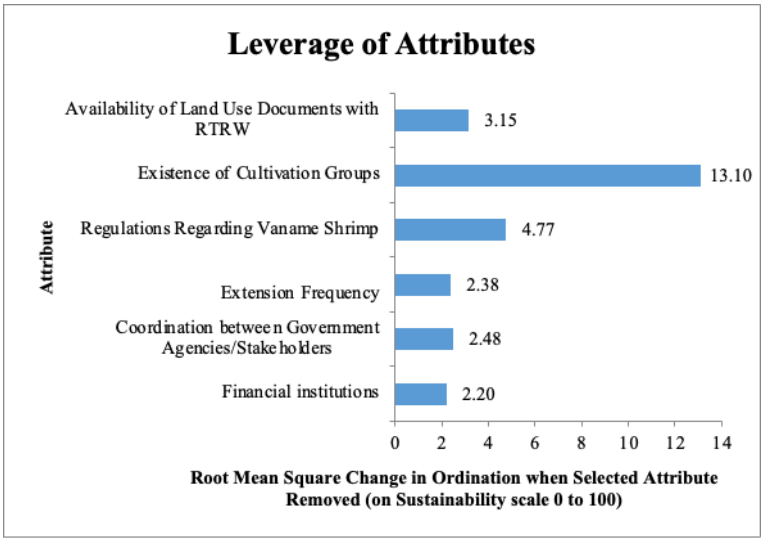

Figure 8. Attribute sensitivity to institutional dimensions.

Technology dimensions. Adequate technology will help to establish *L. vannamei* cultivation on solid bases and will enable a quality shrimp production. Procurement of technology and its mastery will support the concept of sustainable *L. vannamei* cultivation, under ecological, economic and efficiency constraints. The results of Rapfish analysis on the technology dimension show a sustainability index value of 70.30 (Figure 9), classified as moderately sustainable (50.00-74.99). The available technology used in Sumatera Island supports the sustainability of *L. vannamei* cultivation now and in the future.

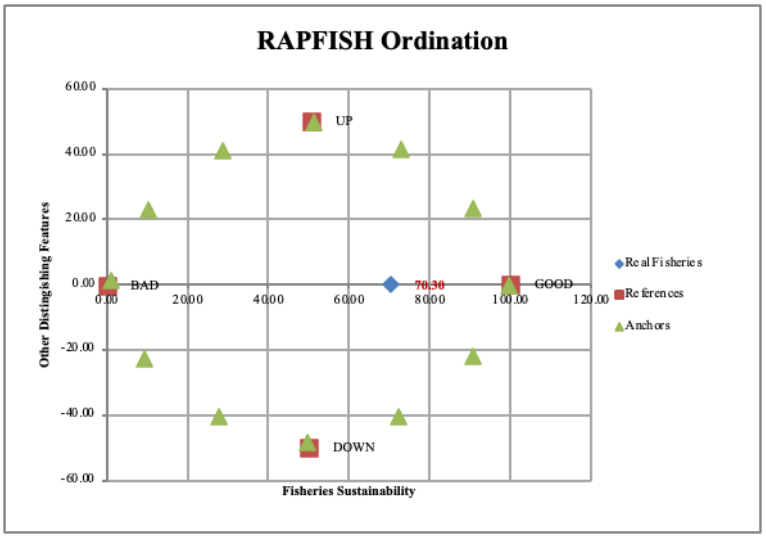

Figure 9. Sustainability status in the technological dimension.

The attributes sensitive to sustainability in the dimension of sustainable technology for *L. vannamei* cultivation on Sumatera Island, based on the 75% optimum Pareto analysis, include water quality management, application of cultivation technology and electrical infrastructure which can be seen in Figure 10.

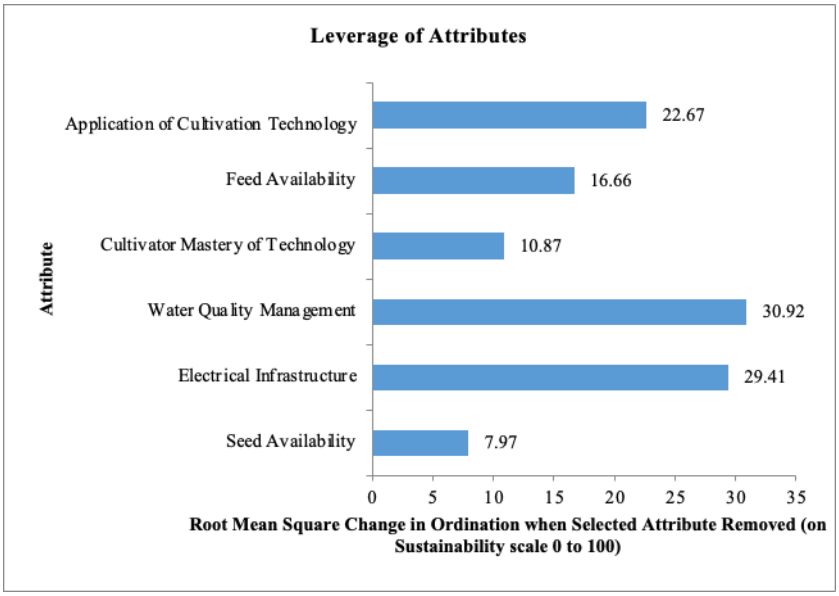

Figure 10. Attribute sensitivity on technology dimension.

Goodness of fit analysis. Stress value and coefficient of determination are used to see the extent of the accuracy of the values of the sustainability index or in other words whether or not additional attributes are needed to reflect the level of accuracy of the five dimensions studied so that they can be scientifically accounted for. The stress value obtained from the five dimensions, namely the ecological, economic, social, institutional and technological dimensions is less than 0.25. The R-Square values for the five dimensions, as shown in Table 4, are close to 1 or exceed 90%. The sustainability status of *L. vannamei* farming is presented in Figure 11, in a kite diagram that shows the sustainability status of each dimension. The kite diagram is a combination of the sustainability indices into a radar and shows the overall sustainability index. The cross-sectional area generated by this diagram shows the sustainability index, where the dimension with the largest area has a higher sustainability index.

Table 4

Stress Value and R-square

No	*Dimensions*	*Stress value*	*R^2*
1	Ecological dimension	0.16	0.93
2	Economic dimension	0.15	0.93
3	Social dimension	0.15	0.93
4	Institutional dimension	0.14	0.94
5	Technologic dimension	0.15	0.93

The sustainability assessment of each dimension in the *L. Vannamei* farming industry in Bantan District reveals the following index values: the ecological dimension scores 51.73 (moderately sustainable), the economic dimension scores 58.20 (moderately sustainable), the social dimension scores 46.33 (less sustainable), the institutional dimension scores 47.10 (less sustainable), and the technological dimension scores 70.30 (moderately sustainable).

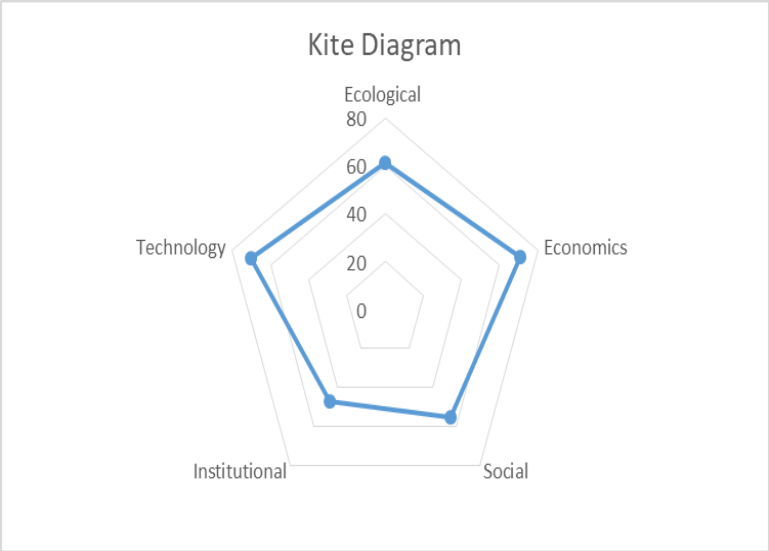

Figure 11. Kite diagram.

Discussion. The management of natural resources and the environment is influenced by several interconnected factors. Generally, in coastal areas, there are three types of components, namely mangrove ecosystems, small-scale capture fisheries, and traditional pond shrimp farms. Over time, several issues have emerged, such as the degradation and destruction of mangrove ecosystems. This can lead to the degradation of fish resources and threaten the sustainability of both fisheries and shrimp farming activities. The water quality of *L. vannamei* ponds at the research location still supports the growth of *L. vannamei* being cultivated. Good water quality that meets the cultivation standards (Indonesian National Standard 2016) can support an optimal growth. Conversely, poor water quality can cause stress, which leads to stunted growth due to a loss of appetite. In *L. vannamei* farming, it is crucial to maintain the environmental carrying capacity to avoid the culture's failure. In aquaculture, water is a key component, and understanding water quality parameters is essential for *L. vannamei* farming. If the temperature exceeds the optimum level, the metabolism in the Whiteleg shrimp's body accelerates. If the environmental temperature is lower than the optimal temperature, shrimp growth may decline due to reduced appetite. The water depth factor is one of the factors that can influence the temperature of the water. Light penetration into the water heats the surface more quickly than the deeper layers, and optimizing the use of aerators can make the water temperature more homogeneous between the upper and lower parts.

The research results show that the *L. vannamei* farming activities carried out by the community groups in Bengkalis Regency, Riau Province, and Bangka Regency, Bangka Belitung islands Province, are relatively sustainable (in terms of the 5 studied dimensions). According to Wigiani et al (2019), carrying capacity is the maximum level of use of an ecosystem or area, in terms of both the number and type of activities accommodated within it, before the decline in the ecological quality of that area. Hasrat et al (2014) stated that in the concept of sustainable development, it does not mean that all indices from each dimension must have the same value, but that there should be a dominant priority that becomes the focus, so that sensitive attributes identified serve as a reference in formulating management strategies. If shrimp pond businesses are established according to the physical standards set, sustainability in *L. vannamei* farming can be achieved, benefiting both the present and future generations. The geographic location of the *L. vannamei* farming activities on the coast of Sumatera Island isa key supporting factor. A good management of *L. vannamei* production can provide guarantees for the sustainability of shrimp farming businesses on Sumatera Island.

Conclusions. The sustainability assessment of *L. vannamei* cultivation on Sumatera Island indicates the following index values: the ecological dimension scores 51.73 (moderately sustainable), the economic dimension scores 58.20 (moderately

sustainable), the social dimension scores 46.33 (less sustainable), the institutional dimension scores 47.10 (less sustainable), and the technological dimension scores 70.30 (moderately sustainable). Key sensitive attributes influencing the sustainability of *L. vannamei* cultivation on Sumatera Island include: water quality management, electrical infrastructure, existence of cultivation groups, farmer involvement in fisheries resource management, cultivation technology use, shrimp selling prices, wage rates, and feed availability.

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Conflict of interest. The authors declare that there is no conflict of interest.

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