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Research Article

Sustainable Pangasius Aquaculture Management Strategy using Multidimensional Scaling (MDS) and Analytical Hierarchy Process (AHP) in Tulungagung Regency, East Java, Indonesia

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Abstract

Aquaculture activities in Tulungagung Regency provide livelihoods for 12,050 households. Therefore, ensuring the sustainability of Pangasius aquaculture activities is crucial for the welfare of fish farmers. This study aims to analyze the sustainability of existing Pangasius aquaculture businesses in Tulungagung Regency, East Java, Indonesia, and to create a sustainable Pangasius aquaculture policy strategy. This quantitative study used Multi-Dimensional Scaling (MDS) and Analytical Hierarchy Process (AHP) analyses to determine the sustainability status of Pangasius aquaculture based on five dimensions: ecological, economic, social, institutional, and technological infrastructure. Among these dimensions, two are less sustainable, particularly infrastructure technology and the economy.

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1. Introduction

Tulungagung Regency is a prominent hub for Pangasius production in East Java Province, boasting a substantial output of 10,449 tons (BPS, 2021). The Tulungagung Regency community's enthusiasm for aquaculture has been steadily growing each year, as seen by the expansion of the production area from 299.56 hectares in 2014 to 357.84 hectares in 2022 (BPS, 2023). The ongoing expansion of aquaculture areas can result in adverse consequences when it meets with other land use interests (Handisyde *et al.*, 2014). Furthermore, the aquaculture endeavors in Tulungagung Regency support the livelihoods of 12,705 households, as reported by BPS (2023). Therefore, it is imperative to ensure the sustainable execution of pangasius farming operations.

According to Abidin *et al.* (2019), sustainable aquaculture systems can ensure the well-being of farmers. Sustainable aquaculture can enhance food variety by serving as a significant provider of animal protein to the population (Agarwal, 2018). Through the use of sustainable aquaculture methods, farmers may guarantee the enduring viability of their enterprises. This is because healthy fish populations will lead to consistent production and high-quality output (Vormedal, 2017).

Sustainable aquaculture encompasses various aspects, including ecological, economic, social, institutional, and technological infrastructure, as discussed by Wilfart *et al.* (2013), Nayak *et al.* (2018), Andréfouët *et al.* (2018), Pattanaik and Prasad (2011), Longdill *et al.* (2008), Moogouei (2014), Gimpel *et al.* (2015), and Gimpel *et al.* (2018). These factors offer diverse perspective in assessing the sustainability of aquaculture enterprises. Ecological aspects are employed to examine the influence of aquaculture on the environment, as well as the reverse (Costa-Pierce, 2010; Byron *et al.*, 2011). Conventional aquaculture operations frequently result in adverse effects such as water pollution, increased feed consumption, and a heightened risk of disease (Nhu *et al.*, 2016). Pangasius aquaculture, which is ecologically sustainable, aims to tackle these concerns in order to achieve lasting sustainability. It places emphasis on improved water and environmental management (Wilfart *et al.*, 2013). Adopting ecologically sustainable aquaculture methods can effectively mitigate the negative effects on the environment (Clark and Tilman, 2017).

The economic aspects are employed to assess the well-being status of aquaculture industry participants (Primyastanto *et al.*, 2020). Nevertheless, the sustainability of aquaculture should not be solely evaluated based on economic aspects; it must also be assessed from various other perspectives. For instance, the expansion of aquaculture in Ireland has been found to have a beneficial effect on the economy but has adverse consequences for the environment (Grealisa *et al.*, 2017). Similarly, in the case of aquaculture area development planning in Malpeque Bay, Canada, social impacts are also taken into consideration (Filgueira *et al.*, 2015). In planning the stages of developing these activities, the first step is to assess their suitability based on the potential availability of existing space. Moreover, Europe has started implementing the circular economy approach in sustainable aquaculture businesses to enhance economic outcomes while safeguarding human, animal, and environmental health (Fraga-Corral *et al.*, 2022).

Social aspects are employed to assess the degree of security in aquaculture enterprises (Lynch *et al.*, 2016). Social aspects exhibit a strong interconnection with other facets, notably institutions. The examination of institutional elements involves analyzing the involvement of governmental and private organizations in establishing regulatory frameworks for aquaculture enterprises (Engle and van Senten, 2022). Aquaculture relies heavily on social, economic, and regulatory aspects (Joffre *et al.*, 2015). Institutions that can facilitate sustainable aquaculture include collaborative efforts between farmers, government entities, and researchers. These institutions have the capacity to formulate optimal methods for aquaculture, provide education to farmers, and implement legislation that promotes sustainable aquaculture (Haque *et al.*, 2021).

According to Jayanthi *et al.* (2020), the technological infrastructure aspect is employed to investigate the components that provide support for aquaculture businesses. Aquaculture's technological advancements have made it possible to use sustainable techniques like water temperature control, waste management systems, and real-time environmental condition monitoring (Mustapha *et al.*, 2021; Rowan *et al.*, 2022; Mahamuni and Goud, 2023). It has been demonstrated that the use of advanced aquaculture infrastructure technologies raises the yields of aquaculture output (Fitridge *et al.*, 2012).

Samerwong *et al.* (2020) identify various factors that contribute to the assessment of aquaculture sustainability, including environmental, socio-economic, and governmental elements. Studies have been carried out on sustainable management of aquaculture, including both marine aquaculture management (Marzuki *et al.*, 2013; Radiarta *et al.*, 2016) and freshwater aquaculture (Wibowo *et al.*, 2015). However, to the best of the authors' knowledge, previous studies have addressed sustainability aspects separately (Nobile *et al.*, 2020; Zhan *et al.*, 2021; Brakel *et al.*, 2021; Odende *et al.*, 2022; Koniyo, 2023). In this study, the sustainability aspects are carried out across multiple dimensions, namely the ecological, economic, social, institutional, and technological infrastructure dimensions. An approach that can be used to evaluate the level of sustainability is multi-dimensional scaling (MDS) using Rapfish software (Kavanagh and Pitcher, 2004).

This study aims to analyze the sustainability of existing Pangasius aquaculture businesses in Tulungagung Regency, East Java, Indonesia, and provide recommendations for sustainable Pangasius aquaculture policy strategies for policy makers.

2. Materials and Methods

2.1 Material

2.1.1 Study area

This research was conducted in 16 districts of Tulungagung Regency, East Java Province, Indonesia, from 2022 to 2023 (Figure 1). Tulungagung Regency's coordinates are 111°43'–112°07' east longitude and 7°51'–8°18' south latitude. To the north, Tulungagung Regency borders Kediri Regency; to the east, Blitar Regency; to the south, the Indian Ocean; and to the west, Trenggalek Regency. The study area is 115,469.1 ha and includes land, mountainous areas, and coastal areas. Tulungagung Regency has a variety of potential resources, such as food crops, plantations, and fisheries. Administratively, Tulungagung Regency is divided into 19 districts and 271 villages. Tulungagung Regency is divided into three plains: high, medium, and low. The lowlands cover all villages and districts except parts of Pagerwojo District (four villages) and Sendang Subdistrict (four villages). Medium plains include parts of Pagerwojo District (six villages) and Sendang District (five villages). Meanwhile, highlands include parts of Pagerwojo District (one village) and parts of Sendang District (two villages) (BPS, 2022).

2.1.2 Sampling and data collection

Data collection was carried out by means of field observations and using research instruments in the form of questionnaires. Questionnaire research instruments can complement data that is not obtained during field observations (Arsanti *et al.*, 2020). The questionnaire

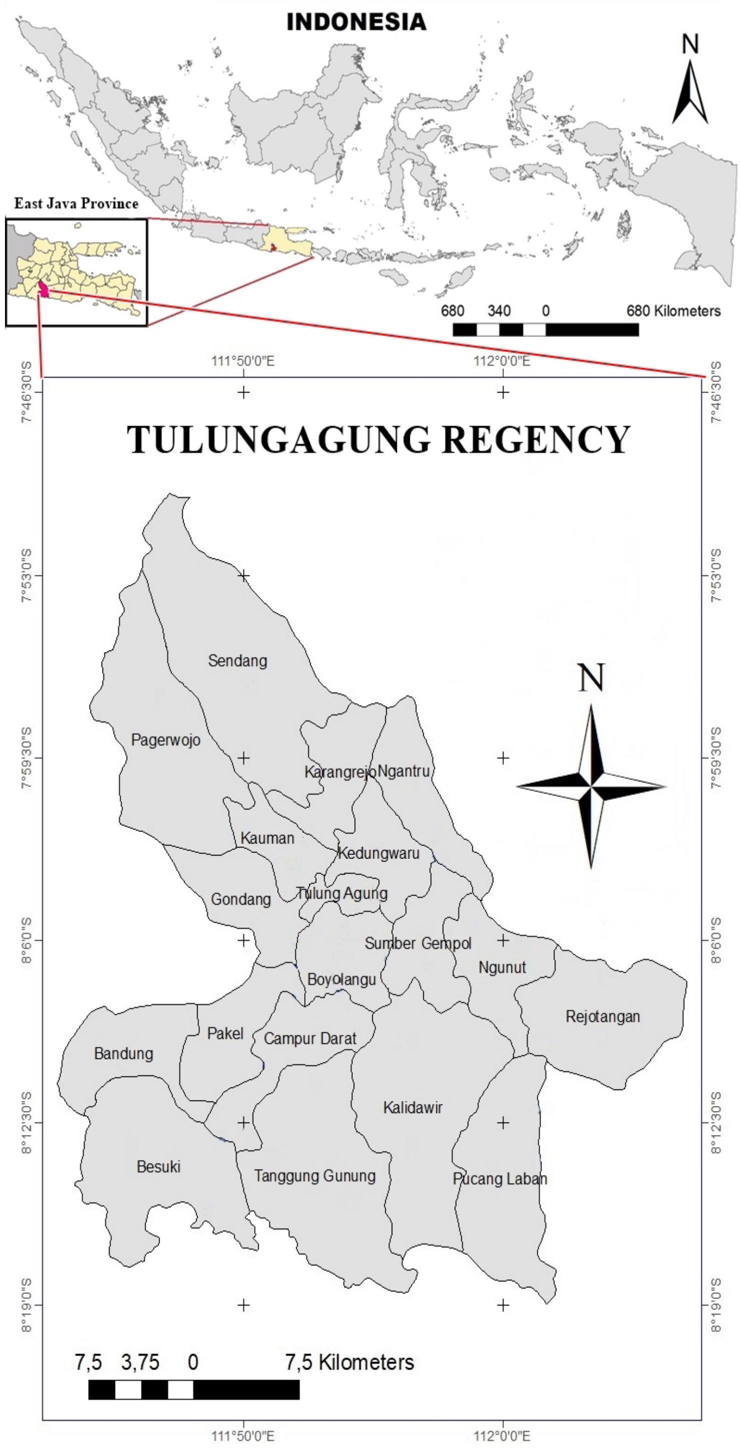


Figure 1. The study area is located in Tulungagung Regency, East Java Province, Indonesia.

is divided into two parts: the MDS questionnaire, which collects data on sustainable dimensions, and the AHP questionnaire, which collects priority data. Each questionnaire has different respondent specifications. The questionnaire was distributed to respondents using a non-probability sample data collection method, which means that the respondents were chosen at the discretion of the researcher (Davis and Lachlan, 2012). The selected respondents have specific criteria, therefore, not everyone in the population has the same opportunity of being chosen (Sugiyono, 2016). This method is suitable for this study because Tulungagung Regency has more than 12,000 fish farmers (BPS, 2023), but not all of them cultivate Pangasius. Some fish farmers focus on ornamental fish, while others focus on other types of consumable fish. The MDS questionnaire respondent criteria were determined based on the respondent's knowledge and experience with Pangasius aquaculture in Tulungagung Regency. Based on data from the Tulungagung Regency Fisheries and Marine Service 2020, there are 563 Pangasius farmers, but only 263 have consistently cultivated Pangasius for the last five years. Using these criteria, the number of samples was rounded up to 160 respondents and determined using the following Solvin formula (Robbins, 2013):

$$n = N / (1 + N e^2) = 263/(1+263x0.052)=159.76 \quad .....(1)$$

This number has exceeded the minimum number of respondents suggested by Kerlinger and Lee (2000), which is 30 respondents. The chosen respondents for the AHP questionnaire were experts. The five respondents that participated in this study were Pangasius aquaculture experts, with the criteria of having an educational background in fisheries and experience in work or research on Pangasius more than 10 years. The respondent's expertise is seen based on their educational background, work background, and published scientific papers. According to Saaty (1993), the determination of expert respondents is based on quality rather than quantity, with a minimum of two respondents. Arrington *et al.* (2015), in their AHP research, used three experts as respondents. When filling out the questionnaire, respondents were asked to choose the position on the scale that best represented their interests and preferences from the nine available scales. The scale ranges from 1 to 9, with 1 being equally important and 9 being the most important (Morgan, 2017).

2.2 Method

2.2.1 Determination and assessment of sustainability attributes

The process of determining sustainability attributes and indicators involves referring to several approaches to the dimensions of sustainability, namely the ecological, economic, social, technological, and institutional dimensions that are compiled in accordance with the literature, as well as in other fields related to the sustainability of Pangasius aquaculture. In addition, various considerations used in compiling attributes are based on the opinions of experts, practitioners, or academics. The process of assessing the attributes and determining scores for each dimension based on data and information obtained from primary or secondary data. The range of scores was determined to be between 0 and 2 with regard to the condition of each dimension. The determination value of 0, which is bad, describes a condition that provides the least advantage for fisheries sustainability. Likewise, a score of 2, indicating good, describes a condition that provides the most benefits for fisheries sustainability (Alder *et al*., 2000). Meanwhile, the intermediate or middle value is determined by comparing the bad and the good assessments (Nuryadin *et al*., 2015). The modified attributes for the assessment of sustainable Pangasius aquaculture activities are based on five dimensions.

2.2.2 Sustainability index scale determination

The process of determining the sustainability index scale for Pangasius aquaculture activities begins with the creation of an index scale ranging from 0% (bad) to 100% (good). Determination of the index scale to determine the system studied: if the index is >50, the system is classified as sustainable. Vice versa, if the index scale is <50, the system is categorized as unsustainable. The sustainability status of Pangasius aquaculture activities in this study is determined by four categories (Table 1) (Marzuki *et al*., 2013; Nuryadin *et al*., 2015).

Table 1. The sustainability status of Pangasius aquaculture in Tulungagung Regency is determined based on four categories with a value ranging from 0 to 100

Index	Categories
0-25	Poor / Unsustainable
26-50	Less Sustainable
51-75	Sustainable
75-100	Good/Very Sustainable

2.2.3 Stages of ordination

The ordination stage is carried out by conducting an analysis through the MDS technique to determine the location of the existence (position) of the points: 100%, indicating good, and 0%, indicating bad. The position of the object or the location of the point in the MDS is then mapped into a space dimension (two or three dimensions), with the closest possible distance. According to Fauzi and Anna (2005), this ordination phasing process determines the distance in the MDS according to the Euclidian distance. The existence of evil and good point positions is described by horizontal positions. In comparison, the existence of a vertical position indicates the difference in mixing scores of the evaluated attributes. The ordination technique in MDS is based on the Euclidean distance, which is in dimensional space and can be written as follows (Alder *et al*., 2000):

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

The configuration or layout of an object or point in MDS is approximated by regressing the Euclidean distance (d_{ij}) from point i to point j, with the origin with the following equation:

$$d_{ij} = \alpha + \beta\delta_{ij} + \varepsilon \quad \text{..................(3)}$$

2.2.4 Sensitivity analysis (leverage)

The leverage sensitivity analysis process was carried out to determine the attributes with a high level of importance (sensitivity). Attributes are said to have a high level of importance and sensitivity if the results of the sustainability analysis show a change in ordination if certain attributes are removed from the analysis. Sensitive attributes are described by the RMS (root mean square) value. Influential attributes are described by changes in the RMS. The magnitude of the RMS value describes the attributes that are increasingly sensitive to supporting the sustainability of Pangasius aquaculture. The sensitivity value affects sustainability either positively or negatively. According to Fauzi and Anna (2005), the Rapfish analysis technique can be used to analyze the sensitivity of the reduction of attributes to the sustainability score (leverage) obtained from the calculation of the difference between scores with attributes and scores obtained without attributes based on standard error. Attributes with high sensitivity values are used as a reference in determining attributes in the analysis of sustainable Pangasius aquaculture management scenarios.

2.2.5 Monte Carlo analysis, stress value and coefficient of determination (R^2)

Monte Carlo analysis is used to assess the influence of computation errors and errors in attribute assessment by respondents. If the difference between the Monte Carlo sustainability and the MDS sustainability indexes is less than 1, the influence of errors in the analysis is small (Kavanagh and Pitcher, 2004). Monte Carlo analysis is a simulation method for evaluating the impact of random errors that is useful for investigating a variety of issues, including (a) the impact of scoring errors due to lack of information, (b) the impact of variability in scoring due to differences in judgment, (c) errors in data entry, and (d) the high-stress value obtained from the ALSCAL algorithm.

The ALSCAL Method optimizes the squared distance (squared distance = dijk) to the square of the data (starting point = Oijk), which in three dimensions (i, j, k) is written as in the following formula called S-Stress (Alder *et al*., 2000):

$$S = \sqrt{\frac{1}{m}\sum \begin{matrix} m \\ k=1 \end{matrix} \left| \frac{\sum_i \sum_j (d_{ijk}^2 - o_{ijk}^2)^2}{\sum_i \sum_j o_{ijk}^2} \right|} \quad \text{..................(4)}$$

where the squared distance is the Euclidean distance Euclidean distance is written as follows:

$$d_{ijk}^2 = \sum_{a=1}^{r} w_{ka}\left(x_{ia} - x_{ja}\right)^2 \quad \text{..................(5)}$$

The goodness of fit hypothesis testing of MDS calculations is characterized by the magnitude of the stress value (Alder *et al*., 2000), while model validity is indicated by the magnitude of the coefficient of determination (R2) (Kavanagh and Pitcher, 2004). The results of the analysis that can present the model well are indicated by the stress value below 0.25 and R2, which is close to 1 or 100%.

2.2.6 Multidimensional weights

The Rapfish technique analysis results only determine the status of each sustainability dimension but cannot determine the status of multidimensional sustainability. It cannot be averaged because each sustainability dimension has different attributes. According to Budiharsono (2014), determining the weight of each dimension of sustainability in a multidimensional manner, namely by determining the weight using an Excel program, which is a modification of the AHP (Analytical Hierarchy Process), begins with experts or stakeholders filling out a questionnaire and comparing pairwise between dimensions of sustainability and scoring. Furthermore, fill in the table on the worksheet with numbers entered by all respondents until the weight value of each sustainability dimension is obtained. After obtaining the weight of each sustainability dimension, multiply the sustainability index value of each dimension by the total weight value of all sustainability dimensions. Then the results are summed up to obtain a multidimensional sustainability index value.

2.2.7. Formulation of policy strategies using AHP

The Analytical Hierarchy Process (AHP) is used to solve complex multi-criteria problems by dividing the problem into several levels of hierarchy. There are factors or criteria that are interrelated at each level of the hierarchy (Saaty, 1993). AHP can be used to formulate policy strategies in various fields, including business, government, and social (Myeong *et al.*, 2018). In this research, AHP is utilized to prioritize the main policy strategies that must be implemented. In calculating the pairwise matrix using AHP analysis, a consistency value is required as a basis for the filling consistency in the scale of importance by respondents (Sambah and Miura, 2014). The calculation uses the following equation:

$$CR = \frac{\mathrm{CI}}{\mathrm{RI}}\ dan\ CI = \frac{(\lambda\mathrm{max} - \mathrm{N})}{(\mathrm{N} - 1)} \tag{6}$$

Where CR is the consistency ratio, CI is the consistency index, RI is the random consistency index, N is the metric comparison size and λmax is the largest eigenvalue.

2.3 Analysis Data

In this study, data was analyzed by combining two methods: multidimensional scaling (MDS) and analytical hierarchy process (AHP). MDS analysis was used to analyze the level of sustainability of existing Pangasius aquaculture businesses in Tulungagung Regency. MDS analysis consists of five dimensions, namely ecology, economy, socio-culture, institutions, and infrastructure technology. Data analysis is divided into several stages; in MDS, ordination techniques are used to determine the position of good and bad points, the Monte Carlo (MC) method aims to evaluate the impact of random errors made in estimating coordination values using leverage to determine the sensitive attributes of each sustainability dimension (Eunike *et al.*, 2018).

3. Results and Discussion

3.1 Results

3.1.1 Ecological dimension sustainability status

According to the observation results of the ecological dimension, there are 12 attributes that affect the dimension (Figure 2). Sustainability analysis in each district was grouped based on the sustainability index. The majority of Tulungagung Regency area conditions were in the moderately sustainable category, with a sustainability index ranging from 52.01 to 74.66. Those areas include the districts of Besuki, Boyolangu, Campurdarat, Gondang, Kalidawir, Karangrejo, Pakel, Kauman, Kedungwaru, Ngantru, Ngunut, Pagerwojo, and Rejotangan. The district of Bandung was the only one with a sustainable category, with a sustainability index of 79.77. When the sustainability value is averaged, it has a sustainability index value of 63.05, indicating that Tulungagung Regency's ecological dimension is moderately sustainable. This value is good enough; however, it needs to be increased again so that the status will be very sustainable. The results of MDS and Monte Carlo analysis on the ecological dimension have an average differences value of 0.68 (Table 2).

The next step is to look at sensitive indicators that can contribute significantly to the ecological dimension. Therefore, leveraging analysis is used in looking at these indicators. According to Eunike *et al.* (2018), leverage analysis is conducted to find out which attributes are sensitive to the various sustainability dimensions. The influence of each attribute is represented by changes in the form of a root mean square (RMS). This implies that when the RMS value increases, the attribute becomes more sensitive to supporting sustainability. Based on the leverage analysis, there are four attributes that are considered sensitive to the sustainability of the ecological dimension, namely the application of the CBIB system, the availability of reservoir ponds and waste treatment facilities, and the entry of pollutant sources with RMS values of 3.13, 3.03, 2.86, and 2.41, respectively (Figure 3).

3.1.2 Economic dimension sustainability status

The economic dimension includes characteristics that affect the economic aspects of Pangasius aquaculture activity, there are 12 attributes that affect the dimension (Figure 2). Of the 16 districts studied, Pagerwojo is one with a less sustainable category, with a sustainability value of 50.76; however, this value is close to the value of the moderately sustainable category. In addition, Sumbergempol district also has a sustainable status, namely, a sustainability score of 78.7. Meanwhile, other areas are in the moderately sustainable category, with MDS values ranging from 51.81 to 74.45. On average, the sustainability level of Tulungagung Regency is in the moderately sustainable category, with a value of 62.34. The results of MDS and Monte Carlo analysis on the economic dimension have an average differences value of 1.15 (Table 3).

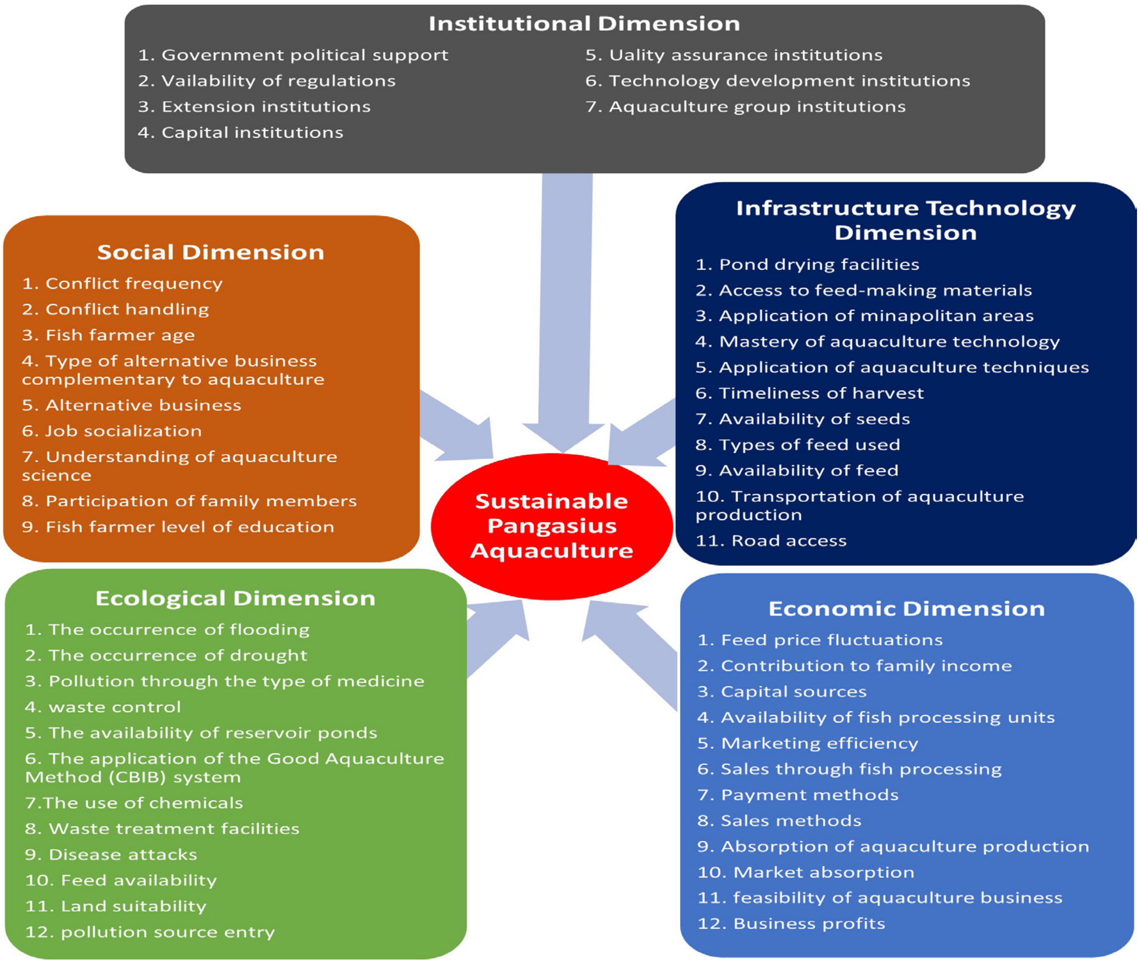


Figure 2. Five dimensions of sustainability of pangasius aquaculture consisting of ecological (12 attributes), economic (11 attributes), social (9 attributes), institutional (7 attributes) and technological infrastructure (11 attributes) dimensions.

Table 2. Sustainability value of Pangasius aquaculture in 16 districts of Tulungagung Regency based on ecological dimension

District	MDS Analysis	Monte Carlo Analysis	Differences
Bandung	79.77	77.75	2.02
Besuki	52.01	52.03	0.03
Boyolangu	65.70	64.96	0.74
Campurdarat	70.65	69.58	1.07
Gondang	56.83	56.41	0.42
Kalidawir	70.90	69.82	1.08
Karangrejo	74.66	72.75	1.91
Kauman	63.19	62.45	0.74
Kedungwaru	58.51	57.85	0.67
Ngantru	53.71	54.04	0.33
Ngunut	55.73	55.75	0.02
Pagerwojo	58.33	58.06	0.27
Pakel	50.24	50.24	0.00
Rejotangan	61.40	61.05	0.34
Sumbergempol	69.36	68.89	0.47
Tulungagung	67.80	67.08	0.72
Average	63.05	62.42	0.68

Table 3. Sustainability value of Pangasius aquaculture in 16 districts of Tulungagung Regency based economic dimension

District	MDS Analysis	Monte Carlo Analysis	Differences
Bandung	74.45	72.91	1.54
Besuki	57.54	56.12	1.42
Boyolangu	60.25	59.45	0.80
Campurdarat	64.95	63.08	1.87
Gondang	69.39	68.46	0.92
Kalidawir	60.25	58.78	1.47
Karangrejo	80.05	77.94	2.11
Kauman	59.53	58.78	0.76
Kedungwaru	51.82	51.31	0.50
Ngantru	56.64	56.27	0.37
Ngunut	60.26	59.14	1.12
Pagerwojo	50.76	51.62	0.86
Pakel	51.81	51.97	0.16
Rejotangan	63.49	62.31	1.18
Sumbergempol	78.70	76.69	2.01
Tulungagung	57.60	56.23	1.37
Average	62.34	61.32	1.15

The results of the leverage analysis from 12 attributes of the economic dimension revealed that two of them were sensitive to the dimension. These attributes include fish processing sales and the availability of fish processing units, with RMS values of 5.77 and 4.69, respectively (Figure 4). These two attributes are considered to have the most influence on the sustainability value of the economic dimension compared to the other eight attributes.

3.1.3 Social dimension sustainability status

The social dimension relates to the activities or lives of people who have an influence on Pangasius aquaculture business activities. The social dimension consists of nine attributes (Figure 2). The overall MDS analysis of 16 districts fell into the moderately sustainable category, with values ranging from 57.02 to 73.62. Tulungagung Regency is classified as moderately sustainable based on the social dimension, with an average sustainability value of 65.81. The results of MDS and Monte Carlo analysis on the social dimension have an average differences value of 1.66 (Table 4). The results of the leverage analysis revealed one attribute that is sensitive to the social dimension. The attribute is the aquaculture business' independence, which has an RMS value of 8.17 (Figure 5).

Table 4. Sustainability value of Pangasius aquaculture in 16 districts of Tulungagung Regency based on social dimension

District	MDS Analysis	Monte Carlo Analysis	Differences
Bandung	73.62	72.32	1.73
Besuki	58.91	57.45	0.02
Boyolangu	57.58	57.07	1.92
Campurdarat	59.46	58.52	2.15
Gondang	74.86	72.67	0.3
Kalidawir	57.60	55.81	1.78
Karangrejo	57.02	55.12	1.47
Kauman	83.69	81.45	0.52
Kedungwaru	60.88	59.31	0.07
Ngantru	65.18	63.27	0.09
Ngunut	68.96	66.64	0.29
Pagerwojo	57.26	57.18	0.15
Pakel	58.42	57.17	0.2
Rejotangan	83.68	80.99	0.03
Sumbergempol	77.38	74.35	1.16
Tulungagung	58.48	57.12	1.5
Average	65.81	64.15	1.66

3.1.4 Institutional dimension sustainability status

An institution is a group or group of people in which there are rules to govern its members. Good relationships and coordination between institutions can have a positive impact on Pangasius aquaculture activities. There are seven attributes in the institutional dimension (Figure 2), including government political support, availability of regulations, extension institutions, capital institutions, quality assurance institutions, technology development institutions, and aquaculture group institutions. According to the results of the MDS analysis in 16 districts, three districts, including Karangrejo, Pagerwojo, and Tulungagung districts, are less sustainable, with sustainability values of 43.99, 50.52, and 53.98, respectively. Three districts, including Ngunut, Rejotangan, and Sumbergempol districts, are in the sustainable category, with values of 76.7, 89.32, and 89.32, respectively. The rest are in the moderately sustainable category, with a score ranging from 53.96 to 70.85. Overall, the average sustainability score is

63.73, which is classified as moderately sustainable. The results of MDS and Monte Carlo analysis on the institution dimension have an average differences value of 0.78 (Table 5). The leverage analysis revealed three attributes that are sensitive to the institutional dimension, namely institutional capital, institutional extension, and institutional quality assurance, with RMS values of 5.98, 5.86, and 5.11, respectively (Figure 6).

Table 5. Sustainability value of Pangasius aquaculture in 16 districts of Tulungagung Regency based on institutional dimension

District	MDS Analysis	Monte Carlo Analysis	Differences
Bandung	70.85	70.01	0.84
Besuki	55.13	54.96	0.17
Boyolangu	65.31	64.79	0.53
Campurdarat	56.63	56.78	0.15
Gondang	65.53	64.34	1.19
Kalidawir	65.31	64.68	0.63
Karangrejo	43.99	44.21	0.22
Kauman	66.34	65.11	1.23
Kedungwaru	53.96	53.34	0.62
Ngantru	66.05	65.82	0.24
Ngunut	76.70	75.48	1.21
Pagerwojo	50.52	50.76	0.24
Pakel	53.98	53.84	0.14
Rejotangan	89.32	86.73	2.59
Sumber gempol	89.32	87.02	2.30
Tulungagung	50.67	50.85	0.19
Average	63.73	63.05	0.78

Business capital is one aspect of the sustainability of a business, including aquaculture. Due to the business capital constraints faced by entrepreneurs, capital institutions have emerged to foster mutually beneficial cooperation. Several capitalization businesses, such as banks, cooperatives, and other capital institutions, are increasingly emerging both online and offline. The results of questionnaires and observations showed that all aquaculture areas in Tulungagung Regency have capital institutions such as banks, cooperatives, and others. Tulungagung Regency also has extension institutions, which are effective in providing training and assistance to Pangasius farmers. They are not yet owned by quality assurance institutions; however, the relevant agencies still carry out controls on the aquaculture area to maintain the quality of the aquaculture environment. For aquaculture production, quality will be controlled a few weeks before harvest using sampling by collectors in order to determine the right market value based on quality.

Table 6. Sustainability value of Pangasius aquaculture in 16 districts of Tulungagung Regency based on infrastructure technology dimension

District	MDS Analysis	Monte Carlo Analysis	Differences
Bandung	51.41	50.86	0.55
Besuki	45.93	47.34	1.40
Boyolangu	54.60	54.92	0.32
Campurdarat	62.72	62.51	0.21
Gondang	65.74	64.75	0.99
Kalidawir	54.61	55.24	0.63
Karangrejo	58.45	57.01	1.44
Kauman	50.83	50.68	0.15
Kedungwaru	54.99	54.60	0.39
Ngantru	48.88	48.82	0.06
Ngunut	52.73	52.41	0.33
Pagerwojo	61.46	60.63	0.83
Pakel	57.98	57.82	0.16
Rejotangan	63.52	61.29	2.24
Sumber gempol	52.74	52.06	0.68
Tulungagung	56.77	55.96	0.80
Average	55.84	55.43	0.70

3.1.5 Sustainability status of infrastructure technology dimension

The dimensions of technology and infrastructure as supporting facilities, both physical and non-physical, are able to support aquaculture activities. There are eleven attributes in the infrastructure technology dimension (Figure 2). MDS analysis of 16 districts found that three districts were less sustainable, namely Besuki, Kauman, and Ngantru districts, with sustainability values of 45.93, 50.83, and 48.88, respectively, and the rest were fairly sustainable, with a sustainability value ranging from 51.41 to 65.74. The average sustainability score of all districts was 55.84, which is categorized as moderately sustainable. The results of MDS and Monte Carlo analysis on the infrastructure technology dimension have an average differences value of 0.70 (Table 6). The leverage analysis obtained four attributes with RMS values of 2.44, 2.33, 2.03, and 1.97 (Figure 7) that are sensitive to technology and infrastructure dimensions, namely seed availability, harvest timeliness, reliance on commercial feed, and application level of aquaculture techniques.

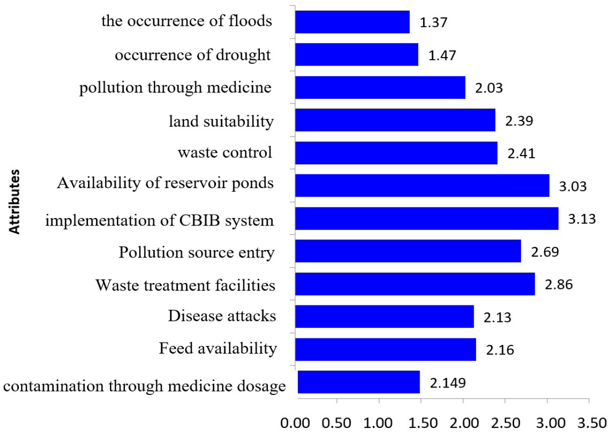


Figure 3. Leverage value of the 12 attributes of the ecological dimension

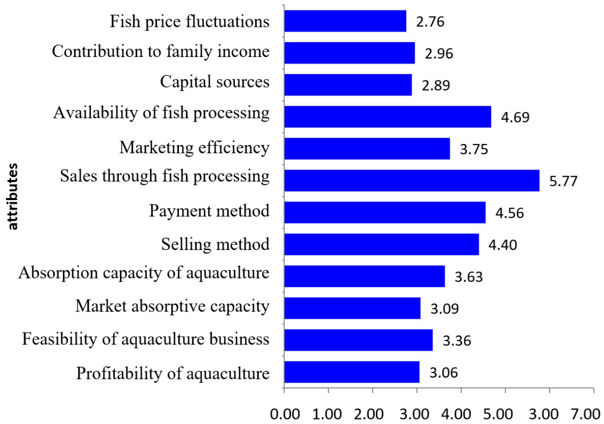


Figure 4. Leverage value of the 12 attributes of the economic dimension

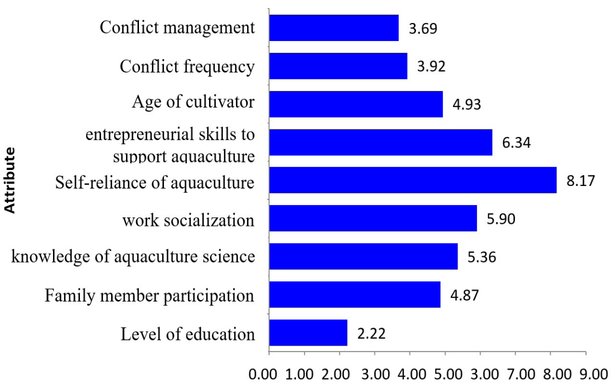


Figure 5. Leverage value of 9 attributes in the social dimension

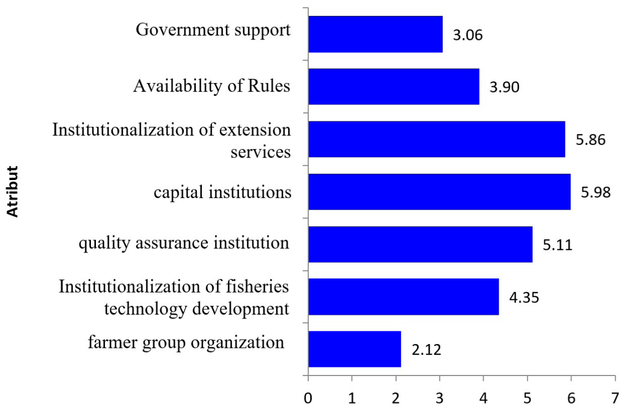


Figure 6. Leverage value of the seven attributes of the institutional dimension

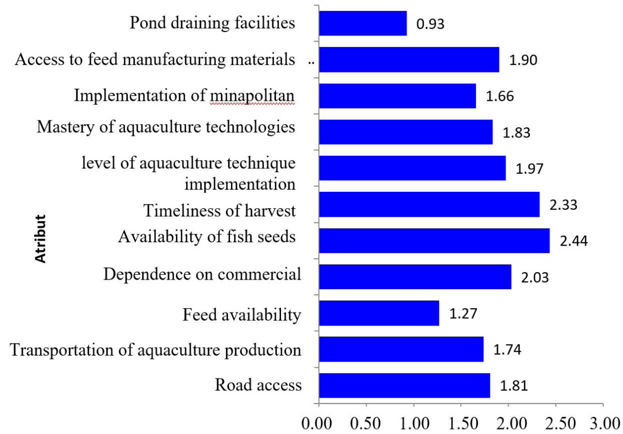


Figure 7. The leverage value of the 11 attributes of the infrastructure technology dimension

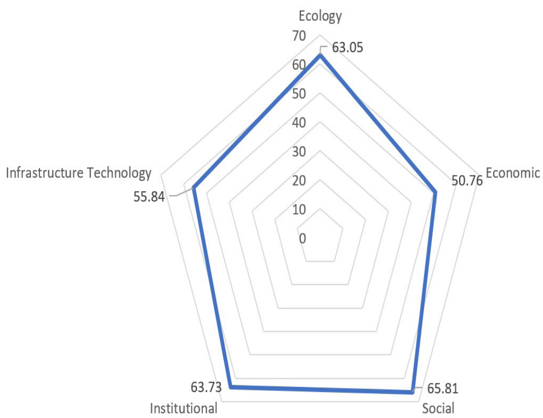


Figure 8. Fly diagram of the sustainability index of Pangasius aquaculture management in Tulungagung Regency

The results of field observations showed that there were at least two fish hatcheries in Tulungagung Regency, located in Tulungagung and Boyolongu Districts. However, some farmers received seeds from outside Tulungagung Regency. One of the Pangasius seed suppliers in Tulungagung Regency is the Fish Breeding Research Center (BPPI) in Sukamandi, Subang, West Java (Yulisti and Putri, 2013). The accuracy of the harvest time greatly affects the profit obtained by the fish farmer. The longer it takes to reach harvest, the higher the production costs. In Tulungagung Regency, the typical duration for rearing Pangasius is 6–8 months, with a Pangasius size of 0.8–1.2 kg/head. The type of feed used during rearing period is commercial feed, which can be bought directly from fisheries stores or through partnership cooperation with several feed supplier companies. Commercial feed was chosen by farmers due to the difficulty of obtaining raw materials for making feed in Tulungagung Regency. The production cost for making independent feed is higher than that of using commercial feed.

3.1.6 Multidimensional sustainability status

Multidimensional analysis was conducted by combining all dimensions, such as ecological, economic, social, institutional, infrastructural, and technological. Each dimension was then evaluated to determine the sustainability status of the management of the Pangasius aquaculture area in Tulungagung Regency, East Java. The results of the analysis showed that the multi-dimensional sustainability index was 58.503, indicating that multi-dimensional sustainability management is in a fairly sustainable position (Table 7). The ecological dimension has the highest sustainability value of 24.085, while the social dimension has the lowest value of 3.338. Although the current sustainability status is quite sustainable, the number of values is quite small and close to the status of less sustainable; therefore, the value must be increased so that the status changes to very sustainable.

Table 7. Sustainability status of Pangasius aquaculture in Tulungagung Regency based on 5 dimensions of sustainability

Dimensions	Weight	Aspect Value	Total Value
Ecology	0.382	63.05	24.085
Economy	0.27	50.76	13.705
Social	0.054	65.81	3.554
Institutional	0.094	63.73	5.991
Infrastructure Technology	0.2	55.84	11.168
Total	**1**	**299.19**	**58.503**

A five-dimensional analysis was used to determine the sustainability status of Pangasius aquaculture management in Tulungagung Regency. The analysis showed that overall, the dimensions were fairly sustainable. Some dimensions have values that are close to the value of less sustainable status, namely the dimensions of infrastructure, technology, and economy (Figure 8). Therefore, work on the attributes of these dimensions must be strengthened so that they become very sustainable.

The stress value (S) and coefficient value (R2) are statistical parameter values that are used to assess the feasibility of the sustainability study. Both parameters are used to determine whether or not to add dimensional attributes to describe the dimensions studied in conditions that are close to the truth. The results of the statistical parameters calculation showed that the stress value was in the range of 0.14–0.19, or below 0.25, and the value of R^2 was in the range of 0.91–0.93, or close to 1 (Table 8). This value is good enough because, according to Kavanagh and Pitcher (2004) and Fauzi and Anna (2005), good rap analysis results are indicated by a stress value of less than 25 and a determination value (R^2) close to 1. Furthermore, Rapfish analysis also showed the number of iterations three times, meaning that the Rapfish analysis, which aimed to discover errors in scoring each dimension, was repeated three times. Thus, the results obtained from the sustainability analysis process can be said to have met the standards of statistical parameters.

Table 8. Multidimensional Scaling analysis results of several statistical Pangasius aquaculture sustainability parameters in Tulungagung Regency

Statistical Value	Ecology	Economy	Social	Institutional	Infrastructure Technology
Stress	0.19	0.14	0.16	0.17	0.19
R2	0.91	0.93	0.91	0.91	0.92
Number of iterations	3	3	3	3	3

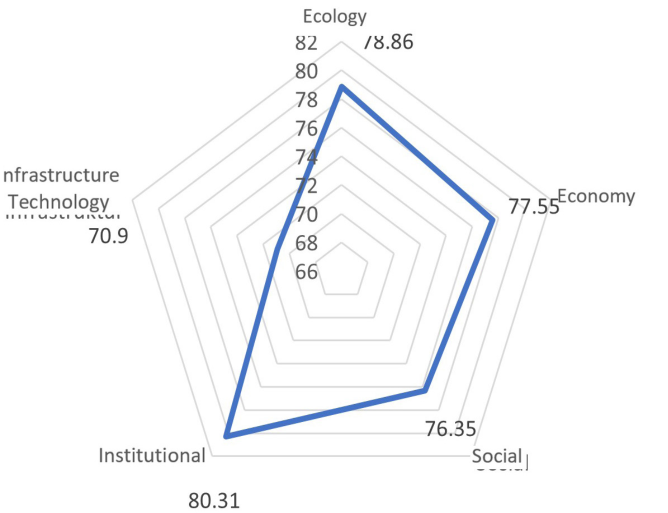


Figure 9. Scenario fly diagram of the sustainability index of Pangasius aquaculture management in Tulungagung Regency

The confidence level test for each dimension was performed using Monte Carlo analysis. This analysis has been developed since 1994 using random number statistical techniques to obtain the probability of one of the mathematical solutions or equations. To obtain the solution, a repetitive calculation mechanism was carried out. Monte Carlo analysis can be used to help determine the sustainability index to see the effect of errors either in the creation of scores, errors in implementation procedures, or understanding of dimensional attributes (Alder *et al*., 2000).

The Monte Carlo analysis was conducted with several iterations, and the results showed that there was not much change in the total (multi-dimensional) index or in the index of each dimension itself. The difference in values between MDS and Monte Carlo analysis is not far adrift or can be said to be more than 95% similar (Table 9). The low difference in value between the MDS and Monte Carlo sustainability indices indicates that the effect of errors can be avoided (Wibowo *et al*., 2015). The MDS method used in this study further demonstrates that the sustainability level of Pangasius aquaculture management in Tulungagung Regency has a high level of confidence (Table 9).

3.1.7 Management strategy for sustainable Pangasius aquaculture area

3.1.7.1 Structure of management strategy for Pangasius aquaculture area

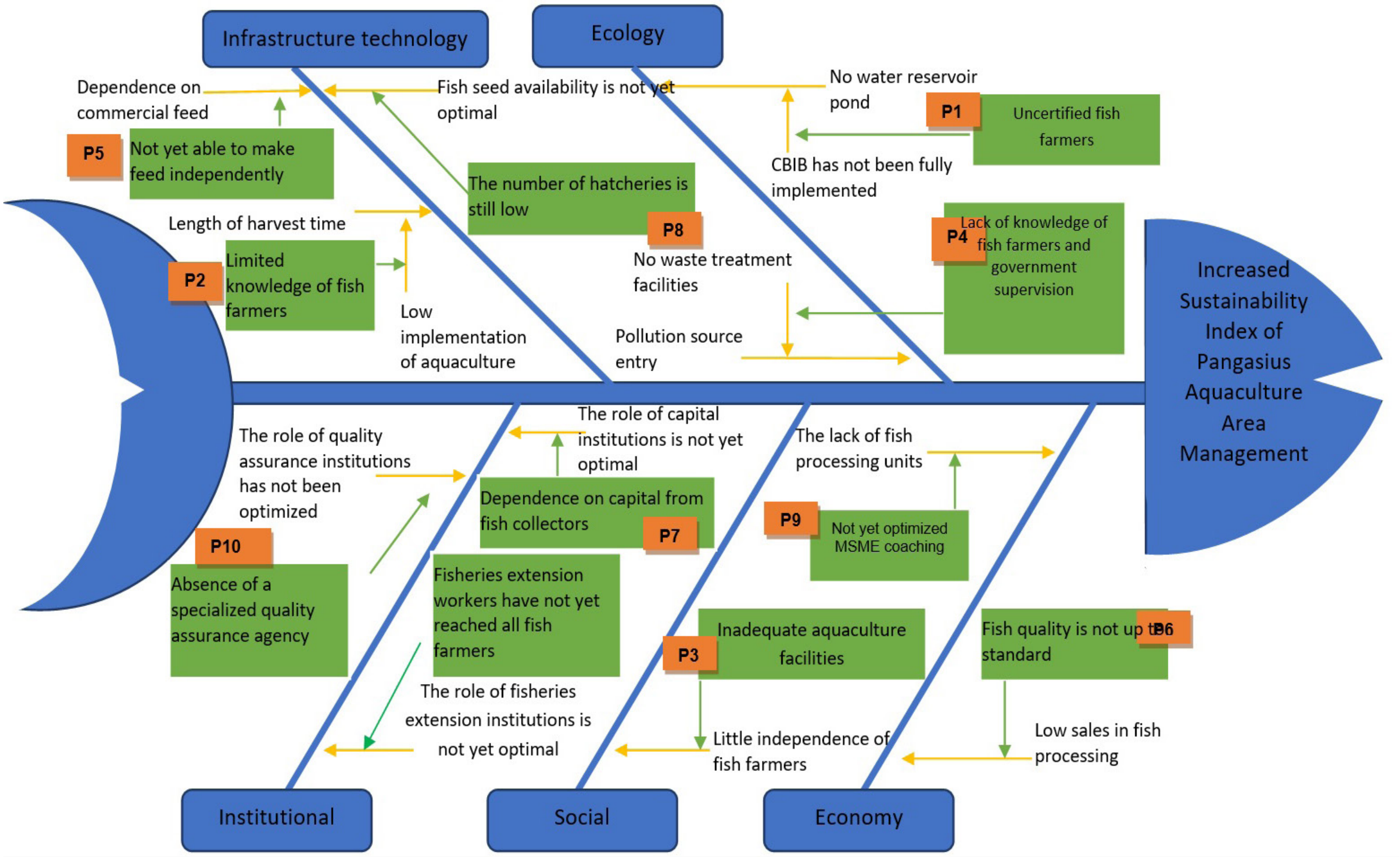
Based on the findings of the overall sustainability analysis of the attributes in all dimensions of Pangasius aquaculture area management, eight sustainable management strategies were obtained based on sensitive attributes in each dimension. These attributes are indicators that must be considered to improve the sustainability status of Pangasius aquaculture area management (Table 10). Therefore, the management of sustainable Pangasius aquaculture areas in Tulungagung Regency must take these indicators into account.

Table 9. Monte Carlo analysis results for ecological, economic, social, institutional, and technological infrastructure dimensions

Dimensions	MDS Analysis	Monte Carlo Analysis	Differences
Ecology	63.05	62.42	0.63
Economy	50.76	56.27	5.51
Social	65.81	61	4.81
Institutional	63.73	63.05	0.68
Infrastructure Technology	55.84	55.43	0.41

Table 10. Sensitive indicators of sustainable management of Pangasius aquaculture areas in Tulungagung Regency

Dimensions	Sensitive indicators
Ecology	1. Implementation of CBIB system
	2. Availability of reservoir ponds
	3. Waste treatment facilities
	4. Pollutant source introduction
Economy	1. Sales through fish processing
	2. Availability of fish processing units
Social	1. Self-reliance in fish aquaculture
Institutional	1. Institutional capital
	2. Institutionalization of extension services
	3. Institutional quality assurance
Infrastructure Technology	1. Fish seed availability
	2. Timeliness of harvest
	3. Dependence on commercial feed
	4. Level of application of aquaculture techniques



Notes: P = Priority

Figure 10. Fishbone diagram on the management of Pangasius aquaculture area in Tulungagung Regency

Each indicator has a relationship with each other operationally; nevertheless, in its implementation, it is necessary to select indicators that are most related to other indicators or have the highest influence. The arrangement of management strategies based on these indicators is used as the basis for prioritizing the management of sustainable Pangasius aquaculture areas in Tulungagung Regency, East Java.

3.1.7.2 Management scenarios for sustainable Pangasius aquaculture areas

Scenarios are created using sensitive attributes based on MDS analysis and intervene on attributes to estimate what will happen in the future. Scenarios are carried out by increasing the value of sensitive attributes in each sustainability dimension. The value increase can also be done by considering rationality, financing, human resources, and the level of implementation difficulty. There are 9 attributes whose scores were increased from 1 to 2 on the 0-2 attribute scale or from 1 to 0 on the 2-0 attribute scale (Table 11).

Scenarios were carried out to determine the sustainability index by increasing the leverage value of the attributes of the dimensions of sustainable Pangasius aquaculture area management. The sustainability index of each dimension increased from moderate to highly sustainable. The MDS value of the ecological, economic, social, institutional, and infrastructure technology dimensions has increased from 62.42 to 78.86, 56.27 to 77.55, 61 to 76.35, 63.05 to 80.31, and 55.43 to 70.9, respectively (Figure 9). The multidimensional sustainability status, which was previously 59.871 with a fairly sustainable status, was increased to 76.91 with a very sustainable status (Table 12).

The success of enhancing the sustainability index value of Pangasius aquaculture area management is not always determined by scenarios or modeling. There needs to be a follow-up to increase the value under actual conditions. To accomplish this, it is necessary to identify the source of the problem and formulate strategies to address it. This will certainly involve various parties in its implementation, including government agencies, the private sector, and the community. Identifying the source of the problem can be performed by making a fishbone diagram (Figure 10).

3.1.7.3 Formulation of sustainable Pangasius aquaculture area management strategies

A fishbone diagram was used to conduct a root-cause search based on the attributes that are sensitive

Table 11. Scenario of increasing the value of sustainability attributes of Pangasius aquaculture in Tulungagung Regency

No.	Leverage Attributes	Score Value		Scale
		Currently	Scenario	
	Ecological Dimension			
1.	Implementation of CBIB aquaculture system	1	2	0-2
2.	Availability of reservoir ponds	1	2	0-2
3.	Waste treatment facilities	1	2	0-2
4.	Pollutant source introduction	1	0	Feb-00
	Economic Dimension			
1.	Sales through fish processing	0	2	0-2
2.	Availability of fish processing units	1	2	0-2
	Social Dimension			
1.	Self-reliance in fish aquaculture	1	2	0-2
	Institutional Dimension			
1.	Institutional capital	1	2	0-2
2.	Institutionalization of extension services	1	2	0-2
3.	Institutional quality assurance	0	2	0-2
	Infrastructure technology dimension			
1.	Fish seed availability	1	2	0-2
2.	Timeliness of harvest	1	2	0-2
3.	Dependence on commercial feed Level of application of aquaculture techniques	1	2	0-2
4.	Fish seed availability	1	2	0-2

to the sustainability index of the Pangasius aquaculture area (Figure 10). The fishbone diagram obtained 10 root causes of sustainability-sensitive attributes. The AHP method was then used to weigh the underlying causes in order to prioritize the problems that needed to be addressed (Table 13). Each root cause was analyzed for problem-solving.

Table 12. Multi-dimensional sustainability scenarios of Pangasius aquaculture in Tulungagung Regency

Dimensions	Weight	Aspect Value	Total Value
Ecology	0.382	78.86	30.12
Economy	0.27	77.55	20.94
Social	0.054	76.35	4.12
Institutional	0.094	80.31	7.55
Infrastructure Technology	0.2	70.9	14.18
Total	**1**	**383.97**	**76.91**

Management Status (Marzuki *et al*., 2013; Nuryadin *et al*., 2015): Highly sustainable

3.2 Discussion

When it comes to the ecological dimension, there are four aspects that require attention. These include the application of the CBIB system, the availability of reservoir ponds, waste treatment facilities, and the entry of pollutant sources. CBIB has long been recognized in Indonesia and has become a scheme of legislation, education, and certification. Some CBIB regulations include controlling feed, fertilizer, and chemicals and verifying sanitation requirements throughout production, including harvesting, management, and distribution. CBIB can evaluate aquaculture producers CBIB and grant them a certificate of eligibility (Rimmer *et al*., 2013). The purpose of CBIB is to regulate Pangasius aquaculture activities in order to implement proper farming methods. Furthermore, CBIB ensures the food safety of Pangasius aquaculture products. The scope of CBIB includes food safety in aquaculture, the use of aquaculture materials, and food safety during harvest. Each CBIB scope has several parameters in its application (Nugroho *et al*., 2015).

The second ecological dimension attribute that needs to be considered is the availability of reservoir ponds. Reservoirs have an important role in maintaining the availability of water for aquaculture. Water availability is the most important requirement in aquaculture. Water reservoirs can be used to reduce pollution in aquaculture pond waters in addition to preserving water availability (Syamsunarno and Sunarno, 2016). According to the questionnaire, most farmers do not have a water reservoir, either as a water storage reserve or as a filter to maintain water quality. In fact, water reservoirs are very important for maintaining water availability and quality. The use of water reservoirs in aquaculture systems reduces ammonia content, which affects aquaculture production (Abidin *et al*., 2019).

The next ecological dimension attribute is waste treatment facilities. One of the negative impacts of aquaculture activities is aquaculture waste production. The disposal of fishpond wastewater in aquaculture environments has a negative impact on the surrounding community, especially on well water pollution. As a result, it is important to cleanse fishpond wastewater before discharging it into the environment (Maharani and Sari, 2016). One of the methods that can be conducted to improve water quality and reduce the harmful effects of aquaculture waste is to construct wetlands (CWs) (Suswati and Wibisono, 2013). In addition, aquaponics can be used to address the issue of aquaculture waste (Taragusti *et al*., 2019).

The last ecological dimension attribute to consider is the introduction of pollutant sources. Chemicals are one of the causes of water pollution. If not done properly, the use of chemicals in aquaculture activities has a significant negative impact (Jeanson *et al*., 2021). Some chemicals in aquaculture are commonly used as antifoulants, antibiotics, parasiticides, anesthetics, and disinfectants (Burridge *et al*., 2010). The use of these materials must be administered at the right dose to minimize the negative effects they cause. The use of chemicals without regard for the right dosage can result in disease resistance and water pollution (Sutarjo and Samsundari, 2018).

Concerning the economic aspect, there are two characteristics that require significant attention. These attributes are fish processing sales and the availability of fish processing units. One of the steps to increase earnings in a business is to shorten the supply chain. The shorter the chain between producers and consumers, the greater the profit will be. The supply chain is carried out to improve the production and marketing systems of Pangasius products in order to achieve sustainable fisheries development, which will ultimately benefit the main actors in the Pangasius fisheries business in particular (Yulisti and Putri, 2013). In aquaculture activities, one way to shorten the supply chain is to sell directly to the fish processing industry.

Table 13. Prioritization of problems on sensitive attributes

Sensitive attributes		Root of the problem	Solution	Implementation method
- No water reservoir pool - CBIB has not been fully implemented	P1	Fish farmers not yet certified	More than 50% of fish farmers are certified	1. CBIB socialization 2. Socialization of fish health and environmental control 3. Setup and use of water reservoir ponds 4. CBIB coaching and supervision
- Long harvest time - Low application of aquaculture techniques	P2	Limited knowledge of fish farmers	Improving fish farmers' knowledge	1. Socialization of aquaculture techniques 2. Aquaculture training 3. Coaching and mentoring of fish farmers
Little self-reliance of fish farmers	P3	Inadequate aquaculture facilities	Improving aquaculture facilities	1. Establish and foster aquaculture groups 2. Facilitate technical guidance on aquaculture 3. Facilitate technical guidance on aquaculture business management
- Pollutant source introduction - Not having waste treatment facilities	P4	Lack of knowledge of fish farmers and government supervision	Fish farmers have knowledge of waste management and supervision is routinely carried out	1. Extension of processing and utilization of fishery resources 2. Preparation and use of waste treatment facilities 3. Facilitation of aquaculture waste treatment 4. Monitoring of processing and utilization of fishery resources
Dependence on commercial feed	P5	Not yet able to make feed independently	Has the ability to make feed independently	1. Self-feeding training 2. Facilitate feed-making facilities 3. Facilitate the provision of raw materials for feed making
Low sales of fish processing	P6	Fish quality does not meet factory standards	Quality of aquaculture production improved	1. Training on improving the quality of aquaculture products 2. Activating a partnership system with fish processing plants 3. Establish cooperation with various parties in quality improvement
The role of capital institutions is not yet optimal	P7	Dependence on capital from fish collectors	Collaborate with capital institutions	1. Training on establishing cooperation and partnerships 2. Facilitating access to capital for fish farmers 3. Business capital management assistance
Fish seed availability is not optimal	P8	The number of hatcheries is still low	Increasing the number of hatcheries	1. Provide fish hatchery training 2. Establish cooperation with the private sector or MSMEs in the provision of fish seeds 3. The government participates in providing fish seed needs for the community
The lack of fish processing units	P9	Not yet optimized MSMEs development	Increase of fostered MSMEs	1. Facilitate the establishment of fish processing program 2. Manage fish processing 3. Promotion and campaign of fish-eating movement
The role of quality assurance institutions has not been optimized	P10	No specialized quality assurance agency	Establish a quality assurance agency	1. Socialization of the role and function of aquaculture quality assurers 2. Establishment of a quality assurance agency by the government 3. Providing assistance to quality assurance agencies

Description: P= Priority

Because the competition in the fish processing industry is fierce, especially in obtaining raw material supplies, the selling price in the fish processing industry will be more competitive (Sari *et al*., 2015). According to Masturoh (2020), the presence of fish processing plants in Tulungagung Regency has a positive impact, including a reduction in the number of unemployed, labor absorption that occurs not only in employee partnerships but also in fish farmer partnerships, farmers having multiple livelihoods, the opening of other businesses outside the fishing industry, improving the welfare of the community and farmers, ownership of equitable health insurance, and good relations that occur between indigenous villagers and migrants.

Payment and sales methods are very important in enhancing the welfare of fish farmers. In general, according to the questionnaire, more than 80% of farmers are paid instantly after the sale and purchase transaction, although a minor portion is still paid in stages. This will hinder the development of the aquaculture business since it requires funds to run. Another problem is the sales method, in which more than 60% of the community sells their aquaculture products to collectors who have contributed capital for aquaculture, with the price set by the collectors. This has become a chain system that is difficult to cut, considering that the collectors contribute to the business capital. The business capital is in the form of seeds, feed, or other items, with the condition that the products must be sold to the capital provider.

In the social dimension, there is one attribute that is of concern: the independence of aquaculture businesses. Aquaculture independence is needed so that farmers are not dependent on other parties, whether institutions or certain groups. One way to accomplish that is to have alternative businesses to support aquaculture. Combining alternative businesses can boost the added value of aquaculture (Stevens *et al*., 2018). Some alternative businesses include agriculture, trade, processing, and others. These businesses can be run simultaneously and complement each other (Little *et al*., 2018). In agriculture, for example, farmers can use aquaculture waste as organic fertilizer. Farmers benefit from two sources of income when they use an aquaponic system: aquaculture and fishery products, and the relationship between the two is mutually beneficial (Tidwell and Bright, 2018).

In the institutional dimension, there are three attributes that need to be considered, namely institutional capital, institutional extension, and institutional quality assurance. Business capital is an important aspect of the sustainability of a business, including aquaculture. Due to the limited business capital faced by entrepreneurs, capital institutions have emerged to foster mutually beneficial cooperation. Several capital businesses, such as banks, cooperatives, and other capital institutions, are increasingly emerging both online and offline. Business capital in aquaculture is not only in the form of money, but it can also be in the form of fish feed, fish seeds, aquaculture support facilities, and so on. The level of trust from lenders depends on how well the aquaculture business is managed. Based on the results of questionnaires and observations, fish farmers who run aquaculture businesses in groups have better management compared to those who run them individually. This is evident from the facilities owned and the price or selling value of the property. Group aquaculture equipment is more comprehensive in terms of amenities, extending from seed handling to harvesting. Not only that, but aquaculture groups have access to supervision and assistance from many institutions. As for the selling price, aquaculture groups can sell on a large scale and reduce the distribution expenses of cultivated products, allowing for a more controlled and controllable price. According to Puspita and Sunartomo (2019), running an aquaculture business in groups has the benefits of facilitating the regulation of aquaculture production, accelerating the process of transferring technology, and facilitating the provision of production facilities, as well as providing social benefits such as security in the aquaculture business and expanding and accelerating learning.

The next attribute is extension and quality assurance institutions. In Indonesia, extension and quality assurance institutions are institutions under the authority of the local or central government. These institutions play an important role in educating farmers to improve the quality and quantity of aquaculture products. Extension institutions must be able to provide the latest aquaculture knowledge that can be easily understood and applied by fish farmers. Therefore, the quality of extension workers must be maintained, and their expertise in aquaculture must be ensured. Similar to extension institutions, quality assurance institutions also need to maintain the quality of their supervision. This will ensure the quality of the aquaculture products produced. These two institutions can complement each other in efforts to improve the quality of cultivators and the quality of aquaculture products.

Four factors need to be taken into account when analyzing the technological infrastructure dimension: the availability of seeds, the promptness of harvesting, the reliance on commercial feed, and the degree of application of aquaculture techniques. Since fish seeds represent the first stage of fish growth, they are important to the life cycle of fisheries (Solaiman and Sugihartono, 2012). The supply of high-quality, healthy fry is essential to aquaculture's success. The advancement of technology in the realm of fish fry production and rearing has significantly contributed to the rise in availability. Effective methods for enhancing seed output include artificial spawning, egg hatching, and larval rearing (Nurlaela *et al*., 2010). The manufacturing of fish seeds is subject to significant regulation and oversight by the government. Appropriate laws can guarantee sustainable aquaculture methods and the supply of healthy fry.

The second technological infrastructure dimension attribute is timeliness of harvest. The timeliness of fish harvesting is a key factor in getting the most out of aquaculture. Timely harvesting can improve fish quality and overall production yield. Environmental conditions, such as water temperature, oxygen levels, and water quality, can affect fish growth and health (Yin *et al*., 2018). Proper feeding management can also affect fish growth (Silva *et al*., 2011). The use of technology, such as temperature and oxygen sensors and automated monitoring systems, can help fish farmers to accurately monitor environmental conditions and fish health (Mustapha *et al*., 2021; Rowan *et al*., 2022; Mahamuni and Goud, 2023). This can support timely harvesting decisions. In addition, engagement with the market and an understanding of consumer demand can also influence harvesting decisions. Harvesting too early or too late can affect selling prices and profits.

The third technological infrastructure dimension attribute is reliance on commercial feed. Commercial fish feed can be designed to provide the right nutrients in the amounts required to maximize fish growth and health. By using commercial feed, farmers can achieve better efficiency in the conversion of feed to fish meat (Syamsunarno and Sunarno, 2016). However, the development of the aquaculture industry and increased fish production can increase the demand for commercial feed. As the industry grows, sometimes the supply of feed may not match the demand, leading to price increases. In anticipation of this, fish farmers must be able to be independent in producing feed. By producing their own feed, fish farmers can become more independent in their daily operations. Fish farmers are not completely dependent on external feed supplies and can control certain aspects of their own production, including feed availability and quality. Producing their own fish feed gives farmers more control over feed quality and formulation. They can customize the feed formulation according to the specific needs of their fish, ensuring that the nutrients provided are appropriate for the growth stage and health needs of the fish. Farmers who produce their own commercial fish feed can utilize local resources or raw materials that are easier to find in their region. This can increase feed diversity and reduce dependence on raw materials that must be imported.

Sustainable Pangasius aquaculture area management strategies are determined by various factors that have been identified and adapted to ecological, economic, social, institutional, and technological infrastructure circumstances. The strategies are based on the following priorities:

3.2.1 Strategies for improving the human resources of Pangasius farmers

An important factor for fish farmers is human resources. The certification of more than 50% of farmers is a measure of the effectiveness of enhancing farmers' human resources. This will solve the issue of imperfect CBIB implementation, one of which is the lack of a water reservoir. In order to address these issues, fish farmers need to receive information and training, either through formal or informal education programs. Pangasius aquaculture, pond management strategies, and other facets of the fishery industry are included in the training to assist farmers in understanding best practices in Pangasius aquaculture. Experts or seasoned fish farmers participate in practical field training to help in the development of practical skills such as effective water management, adequate feeding, disease control, and the selection of high-quality fingerlings. Pangasius farmers are trained in marketing and business management to help them promote their products and run their businesses successfully. It can be achieved by improving financial management, business planning, and cost-benefit analysis skills. Additionally, seeking the right advice and direction from professionals in Pangasius aquaculture as well as working with outside service providers (researchers, agricultural advisors, and pond management consultants).

The following project focuses on expanding access to technological advancements and knowledge. The most recent developments in Pangasius farming, management practices, and market changes are among the information that needs to be established. This can be accomplished by utilizing real-time-accessible technology such as the internet, smartphone apps, and social media, as well as technological advancements such as software programs, effective aeration systems, or automatic pond monitoring.

3.2.2 Strategies to improve the application of Pangasius aquaculture techniques

The second step is to improve the way aquaculture practices are applied. This will alleviate the issue of the Pangasius fish's long harvest period, allowing the fish to reach 0.8–1.2 kg in less than 8 months. The issue arises from Pangasius farmers' lack of understanding of agricultural practices. One action that can be performed is to regularly train Pangasius farmers on the most recent agricultural methods. Training can be in the form of workshops or seminars with Pangasius farming specialists to exchange information and real-world experiences. Farmers must also monitor the pond's water and soil quality, implement an effective aeration system, and choose Pangasius seedlings that are of high quality, healthy, and disease-free, employing high-quality feed that has the appropriate nutritional makeup for the stage of Pangasius growth. Illness and pest control are also necessary, as is, if necessary, vaccination. Maintain regular monitoring of pond conditions and Pangasius health while isolating and treating infected Pangasius as necessary. It is possible to monitor the state of the water in real time using technology such as oxygen, pH, and temperature sensors.

3.2.3 Strategies for improving Pangasius aquaculture facilities

The final action that needs to be taken is to improve Pangasius cultivation facilities. This tactic is used to address the issue of inadequate cultivation facilities. This contributes to aquaculture's lack of independence. Among the actions that can be taken is to carry out appropriate pond planning and design while considering variables like size, depth, drainage, and aeration systems. Investment in pond infrastructure, including dams, canals for irrigation, watering systems, and effective drainage systems. Infrastructure must be built to withstand the effects of extreme weather and to make Pangasius accessible to fish farmers. Additionally, it is important to ensure that Pangasius farming facilities are both convenient and profitable for fish farmers. Reduced infrastructure constraints that can obstruct pond growth are also necessary.

3.2.4 Waste management strategy for Pangasius aquaculture

The fourth action item on the priority list is waste management strategy. This tactic is used to address the issues of farmers' lack of waste management expertise and monitoring. This is what brings pollution into the aquaculture region. Assistance and instruction in sound waste management techniques can be given to fish farmers, among other things. Access to tools and services that support proper waste management and conformance with relevant environmental norms and guidelines must also be made easier for fish farms.

Additionally, using the proper equipment or sensors for monitoring, regularly check the water quality in ponds for things like ammonia, nitrate, pH, temperature, and oxygen. Using technology like biological or mechanical filters to rid the water of organic debris and fish feces is another way to control waste. These innovations may aid in reducing nitrate and ammonia levels in water. Furthermore, wastewater can be transferred to farms or other appropriate places using a competent irrigation system. Organic fertilizers can be made by recycling organic wastes such as fish feces and feed residues. These organic fertilizers can be used for farming or other types of crops, which reduces waste while increasing additional value.

The use of chemicals, such as fertilizers or prescription medications, should adhere to the recommended dosages and fish farmer regulations. Overdose should be avoided, as this can contaminate the soil and water. Fish farmers also need a method for collecting fish waste that accumulates at the bottom of ponds in order to utilize the waste as a source of organic fertilizer.

3.2.5 Strategies for improving self-reliance in feed production

The fifth action is to increase people's ability to self-feed. Therefore, the issue of reliance on commercial feed is addressed. Commercial feed offers a number of disadvantages, including variable costs and the possibility of annual feed price increases. Some possible actions include educating fish farmers on the proper nutritional makeup and the method of producing independent feed using inexpensive and easily accessible local raw materials, such as vegetable feed ingredients (for example, soybean meal, agricultural waste), and nearby animal protein sources.

The raw materials must be correctly processed in order to maximize pangasius fish feed digestibility. Techniques like fermentation and extraction can be utilized to enhance the nutritional value of feed. When feed is effectively produced, it is put through a series of nutritional and safety tests in a lab. The accessibility of raw material stockpiles needs to be taken into consideration as well. To avoid contamination, it is critical to maintain sanitation and hygiene throughout the feed-producing process.

3.2.6 Strategies for improving the quality of Pangasius aquaculture production

The sixth step was to develop a standard for Pangasius aquaculture production that would address the issue of low-quality Pangasius that could not be sold to fish processing facilities. Selecting Pangasius seedlings that are of high quality, sound, and disease-free is one action that can be taken. To prevent differential growth, seedlings should all be the same size. The next step is to practice effective pond management by managing the pond's soil quality, water quality, temperature, pH, and other factors. An effective aeration system must be used to enhance the oxygen content of the water. Additionally, the feed must be of high quality and contain the proper nutritional composition for Pangasius' stage of growth. A regular and scheduled feeding schedule is used to manage the feed.

The next step was implementing a successful disease and pest control program, including vaccination if necessary. To stop the spread of the illness, isolation and proper care for the afflicted Pangasius are needed. Regularly checking on Pangasius health and pond conditions is equally crucial. Ecologically harmful effects, such as water pollution or ecosystem destruction, are minimized by using ecologically friendly farming techniques.

3.2.7 Strategies for optimizing capital institutions for Pangasius aquaculture businesses

The seventh task that needs to be completed is the capital institution optimization strategy for Pangasius aquaculture, which will address the issue of financial dependence on fish collectors. Having to sell the product to the capital provider at a price set by the capital provider is one drawback of employing capital from collectors. Steps that can be taken to solve these issues include explaining the capital needs for effectively managing Pangasius aquaculture. Fishermen need to be aware of the financial needs for startup costs, ongoing expenses, and company growth. It is suggested to create a financial consulting service to assist fish farmers with financial planning and funding.

The next step is utilizing financial institutions such as banks, cooperatives, or neighborhood financial institutions to get financial goods and services. A thorough and detailed business plan that includes revenue, cost, and cash flow estimates must also be written. Grants and subsidies from the government or nonprofit organizations that support the fisheries sector can also be used to fund fish farming operations. In order to accomplish this, submit a project proposal that meets the grant funding criteria. By establishing transparent and equitable business agreements with the investors or partners, it is also feasible to identify investors or business partners that are eager to engage in the Pangasius farming business, affiliating agricultural groups or cooperatives that can give you access to marketing opportunities, joint resources, and collective funding. Farmers should employ adequate accounting systems and maintain accurate records of their income and expenses to ensure efficient financial management. Examining the company's financial performance on a regular basis is needed to see if capital use is yielding the desired results. Determine opportunities to increase capital usage efficiency.

3.2.8 Strategy for increasing the number of Pangasius hatcheries

The eighth step to accomplish is a plan to increase the number of Pangasius hatcheries. This can address the issue of a few hatcheries in Tulungagung Regency. One measure that can be taken is to improve hatchery infrastructure, such as spawning ponds, hatcheries, and larval rearing tanks. Another is to educate and teach fish farmers about proper hatchery procedures. Infrastructure for hatcheries must be able to accommodate increasing production. The Pangasius broodstock used is of the highest caliber, healthy, and has good genetics to produce robust and disease-resistant offspring. The best nutrition and care are provided to the broodstock in order for them to lay the best eggs possible.

Additionally, the use of cutting-edge hatchery technology is effective, such as artificial reproduction systems or managed natural spawning. An increased number of eggs can be produced by using spawning technology. When moving eggs or larvae from the spawning sites to the hatchery, it is suggested to use sterilized tools and containers to ensure proper handling. Collaboration with other research facilities or hatcheries is required for genetic enhancement and exchange. It can improve the genetic variety and robustness of Pangasius fish.

3.2.9 Strategies for improving the quality and quantity of Pangasius processing units

The ninth step is a strategy to increase Pangasius fish processing units in order to address the issue of there still being few fish processing facilities in Tulungagung Regency. It is possible to take action by carefully designing the building of processing units that are effective and adhere to food safety regulations, while also paying attention to features that make the production and processing process easier. Purchasing high-quality fish processing equipment, such as cutting, filtering, packaging, and refrigeration tools, is another investment that must be made in machinery and technology. Verify that the processing facility meets all required licensing and legislative specifications for the food and fishing industries. Observe any applicable environmental laws and food safety regulations.

The source of the raw materials must also be reliable and free of contamination. It needs to build a monitoring mechanism in place to confirm the raw materials' quality. Establish a quality and food safety management system, such as HACCP (Hazard Analysis and Critical Control Points), to make sure that the Pangasius fish products produced are safe to eat.

The last phase is to generate various processed products from Pangasius fish to boost added value, such as frozen fillets, grilled products, smoked products, or ready-to-eat packaged foods. Product innovation is needed to meet consumer demand. Create marketing strategies that work to sell Pangasius fish products. If possible, provide seamless distribution to local, regional, or even global markets. Form alliances with public or commercial organizations that can offer funding or technical assistance for the creation of processing units.

3.2.10 Strategy for optimizing the quality assurance agency for Pangasius aquaculture

The tenth, or last, step is to develop the strategy for optimizing Pangasius cultivation quality assurance institutions. This will address the issue of the lack of specialized quality assurance institutions. Developing precise and quantifiable quality standards for Pangasius fish that take into account factors like size, weight, color, texture, and flavor is one way to address these issues. These requirements must comply with all local, state, federal, and international laws. Encourage Pangasius fish products to be certified by qualified quality assurance organizations. Certification can boost consumer confidence in Pangasius fish products. Maintain consistent quality control over Pangasius fish production by monitoring output on a regular basis. The use of technology or monitoring tools aims to measure quality metrics objectively. Conduct internal audits of the growing and processing operations to ensure every step complies with quality standards. Identify and correct non-conformances as soon as possible. Establish or collaborate with a reputed laboratory capable of testing Pangasius items. Verify the product's quality using the results of laboratory tests. Implement a risk management program to identify and reduce product quality risks. Create backup plans in case there are any quality problems. Using a tracking system that permits products to be tracked from manufacture to distribution. Implement open communication with potential customers and other interested parties. Work with recognized government organizations to make sure that Pangasius farming and processing practices abide by all rules. Include government organizations in the monitoring and auditing process. Promote certified Pangasius products as being of the highest caliber. In order to gain an edge over competitors, emphasize product quality. Create a quality labeling program that will allow consumers to easily recognize Pangasius fish products that adhere to specified requirements. Offer rewards to fish farmers who meet specific standards for quality.

4. Conclusion

The Pangasius aquaculture business in Tulungagung Regency is currently in fairly good condition. Two of the five dimensions used as a benchmark for the sustainability of aquaculture businesses are less sustainable, particularly infrastructure technology and the economy. The scenario of increasing the value of dimensions from less sustainable to sustainable can be accomplished by implementing 10 strategies, namely increasing the human resources of Pangasius fish farmers, increasing the application of Pangasius aquaculture techniques, improving Pangasius aquaculture facilities, managing Pangasius aquaculture waste, increasing the making of independent feed, increasing the production quality of Pangasius aquaculture, optimizing Pangasius aquaculture business capital institutions, increasing the number of Pangasius hatcheries, increasing the quality and quantity of Pangasius fish processing units, and optimizing Pangasius aquaculture quality assurance institutions. This research has not tested the percentage of success if all policy strategy recommendations are carried out. There is a need for modeling that is able to simulate and calculate precisely before the strategy is implemented. Research on modeling sustainable pangasius aquaculture is highly recommended.

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Authors' Contributions

The contributions of each author are as follows: Asro; Collect data, data analysis, original manuscript drafting, graphical abstract design. Aida; conceptualization, funding acquisitions, data acquisitions, supervision, writing review and editing. Mimit, and Maheno; designed the main conceptual idea and critical revision of the article. Lugu and Andra; provided research facilities and accommodation. Suharun; analyzed the research data. All authors discussed the research results and contributed to the final manuscript.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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