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Sustainability analysis of skipjack tuna catch based on multidimensional scaling (MDS) in the coastal area of Pasuruan Regency

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ABSTRACT

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Introduction: Indonesian tuna production holds significant economic value, yet Pasuruan Regency experienced a drastic decline from 21,391 tons in 2018 to only 467 tons in 2020. This downturn is attributed to multiple factors including deteriorating seawater quality, constrained distribution channels, price volatility, and various socio-environmental challenges. Issues such as potential overfishing, reliance on middlemen, and insufficient fisheries management further compromise the industry's sustainability. **Methods:** This study employed the RAPFISH technique, utilizing Multidimensional Scaling (MDS), to assess the sustainability of the tuna fishery across four key dimensions: ecological, economic, social, and institutional. Primary data collection involved surveys and interviews with principal stakeholders (fishers, collectors, micro-enterprises), complemented by secondary data analysis from relevant fisheries institutions to evaluate long-term trends. **Results:** The assessment indicated a 'fairly sustainable' overall status for the Pasuruan tuna fishery, although revealing considerable vulnerabilities and variations among stakeholders. Key challenges identified include ongoing environmental degradation, unstable market conditions, and socio-economic dependencies limiting fishers' long-term stability. Leverage analysis pinpointed critical factors with the highest impact on sustainability, primarily social aspects, economic factors, and market responsiveness. **Conclusion:** The moderate sustainability level necessitates targeted strategies focused on the identified leverage points. Enhancing work safety, fostering collaboration, improving operational cost management, and increasing customer responsiveness are crucial. These targeted actions, combined with improved resource management practices and stronger institutional support, offer the most promising pathway to ensure the long-term viability and resilience of the skipjack tuna fisheries sector in Pasuruan Regency.

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INTRODUCTION

Indonesia is the largest maritime country in the world, with 70% of its territory consisting of ocean and more than 17,000 islands spread out, with a coastline of 81,000 km (Kennedy, 2021). The large marine and fisheries potential makes this sector one of the main pillars of the coastal community economy (Prasetiawan, 2020). One of the fishery commodities that has high economic value is tuna (*Euthynnus affinis*) (Illahi *et al.*, 2023). Based on data from the Central Statistics Agency (BPS) in 2020, tuna production in Indonesia reached 20,907 tons with a transaction value of IDR 457.34 billion (Akbar, 2022). At the provincial level, East Java contributed 15,702 tons or around 62.16% of the total national production (KKP, 2020).

Pasuruan Regency, as one of the coastal areas in East Java, has significant fisheries potential. Its coastal areas include Nguling to Bangil Districts, which consist of capture fisheries and pond cultivation. (Misbah & Mulyasaroh, 2019). The main activities of the fishing industry in this area include sea fishing and processing the catch. Areas such as Rejoso, Lekok, and Kraton Districts are equipped with Fish Auction Places (TPI), which support fisheries-based economic activities (Puryono, 2016). In addition, there are efforts to increase fisheries efforts through exploration to the Exclusive Economic Zone (EEZ) outside the Madura Strait (Arif, 2020).

However, tuna production in Pasuruan Regency experienced a significant decline in the period 2018 to 2020, from 21,391 tons to 467 tons (Masud & Wahid, 2020). This decline was caused by various factors, including degradation of sea water quality, limited distribution, instability of fish prices, and dependence of fishermen on middlemen. In addition, environmental challenges such as over-exploitation and damage to marine ecosystems have further worsened the sustainability of the fisheries sector (Sapanli *et al.*, 2024). Socio-economic factors, such as limited

market access for micro-entrepreneurs in the fisheries supply chain, also influence the resilience of this sector (Telaumbanua & Ndraha, 2023).

In facing these challenges, the sustainability of the fisheries supply chain becomes a very important aspect. According to Morana 2013, organizations need to redesign their supply chains by incorporating sustainability principles into every operational process, from raw material procurement to distribution (Morana, 2013). Sustainable Supply Chain Management (SSCM) is an approach that integrates social, economic, and environmental factors in supply chain management, so that it can meet customer demand for product quality, quantity, and delivery time (Seo & Kaleka, 2024).

One method that can be used to measure the sustainability of the supply chain in the fisheries sector is Rapid Appraisal for Fisheries (RAPFISH) (Sukmawati *et al.*, 2020). RAPFISH is an analysis technique based on Multidimensional Scaling (MDS) which is able to evaluate fisheries sustainability in a multidisciplinary manner by considering ecological, economic, social and technological aspects (Chaliluddin *et al.*, 2023). This approach has proven effective in assessing the sustainability status of fisheries and can be replicated for inter-regional and periodic evaluations.

Although the RAPFISH method has been widely used in the sustainability analysis of the fisheries sector, its application to micro-businesses processing fish catches is still limited. Studies on the integration of the MDS-based SSCM model in optimizing the sustainability of micro-businesses in fisheries in the coastal areas of Pasuruan Regency are still very minimal. Therefore, this study aims to develop an MDS-based SSCM model to improve the efficiency and sustainability of the fisheries supply chain, as well as provide policy recommendations that can support the sustainability of micro-businesses processing fish catches in Pasuruan Regency.

METHODS

Location and time of research

This research was conducted in the coastal area of Pasuruan Regency and was limited to three sub-districts of Rejoso, Kraton and Lekok. The research was conducted in the coastal area of Pasuruan Regency because it is an area of fishermen, collectors and micro-businesses processing trash fish of the tuna type. This research was conducted from May to September 2024.

Population

The population of this study was 25 tuna fishermen, 6 tuna collectors, and 16 micro businesses processing tuna type trash fish in Pasuruan Regency and are still active. According to the Ministry of Cooperatives and Small and Medium Enterprises (Menegkop and UKM) (Krisnantara & Dewi, 2023), what is meant by Small Business (UK) is a business entity that has a net worth of at most IDR 200,000,000, excluding land and buildings for business premises, and has annual sales of at most IDR 1,000,000,000. Meanwhile, Medium Enterprises (UM) are business entities owned by Indonesian citizens who have a net worth of more than IDR 200,000,000 to IDR 10,000,000,000, excluding land and buildings (Septiani & Wuryani, 2020).

The Badan Pusat Statistik (BPS) defines SMEs based on the quantity of workers. Small businesses are business entities that have 5 to 19 workers, while medium businesses are business entities that have 20 to 99 workers (Sudirman, 2020).

Sample

The sample of this study used the main actors in the processing of trash fish of the type of tuna that are still active, namely 10 tuna fishermen, 4 collectors, and 16 Micro Businesses processing trash fish of the type of tuna in Rejoso, Kraton and Lekok sub-districts, Pasuruan Regency and are still active. The sampling technique used purposive sampling.

Data collection technique

The data collection technique in this study is the questionnaire method by providing written questions to respondents to be answered. Data collection in this study uses direct surveys (Observation), interviews and documentation (Wekke., 2019).

- a. Direct survey (Observation), namely by visiting respondents and giving questions to deepen information related to the research. Respondents are free to give opinions according to reality by giving clear answers that are considered to represent the attitudes and perceptions of respondents from Fishermen, Collectors and Micro Businesses processing small fish of the type of tuna.
- b. Interviews to obtain additional information related to the activities of sustainable supply chain management carried out by Fishermen, Collectors and Micro Businesses processing small fish of the type of tuna in Pasuruan

Regency. Interview activities were conducted twice. First when collecting data for all respondents (clarification). Second, in-depth interviews with several selected respondents who were communicative and accommodating in providing information related to research problems and were conducted after processing primary data from the questionnaire.

- c. Documentation, namely studying the documents held by fishermen, collectors and micro businesses processing small fish of the tuna type (if permitted) which are related to the research problem.

RAPFISH method

The Rapid Appraisal for Fisheries (RAPFISH) method was used in this study because of its flexible nature and ability to assess fisheries sustainability in a multidisciplinary manner. RAPFISH uses the Multidimensional Scaling (MDS) technique to measure sustainability status based on various dimensions (social, economic, environmental, technological, and institutional). This approach is suitable for assessing the tuna supply chain because it can provide a quantitative Figure of the factors that influence the sustainability of the fisheries sector in Pasuruan Regency.

Data analysis techniques

Data obtained from questionnaires, interviews, and observations were analyzed using the following steps:

1. Questionnaire Data Processing . Data from the questionnaire were processed using Microsoft Excel and RAPFISH Software to convert Likert scale data into sustainability scores.
2. Multidimensional Scaling (MDS) Analysis . MDS is used to identify sustainability patterns and visualize the sustainability level of the fisheries sector.
3. Monte Carlo Analysis . Used to test the reliability of MDS analysis results by simulating variables randomly.
4. Leverage Analysis. This technique is used to determine the most influential factors in the sustainability of the tuna fish supply chain.

RESULTS AND DISCUSSIONS

This study was conducted with objects in the coastal area of Pasuruan Regency and limited to three sub-districts of Rejoso, Kraton and Lekok from May to September 2022. The reason for the research location in the coastal area of Pasuruan Regency is because this area is an area for fishermen, collectors and micro-businesses processing tuna (*Euthynnus affinis*). The data collection method was by distributing questionnaires widely. The questionnaires distributed used a Likert scale answer choice at five levels stating the categories and ratings being measured. Answer choice 0 means very low, answer 1 means Good, answer 3 means Very good. The total respondents in this study were 30 respondents. Respondents who filled out the questionnaire were people who had carried out activities directly and were related to the object of this study, the specifications of the respondents can be seen in the following table:

Table 1. Respondent Specifications

Respondent category	Location	Respondents	Total respondents
Fisherman	Lekok Fish Market	4	10
	TPI Rejoso	3	
	TPI Kraton	3	
Collector	Lekok Fish Market	1	4
	TPI Rejoso	2	
	TPI Kraton	1	
MICRO BUSINESS Fish Management	Lekok Fish Market	7	16
	TPI Rejoso	4	
	TPI Kraton	5	

Source: Processed data

The determination of respondents follows the guidelines explaining that the number of respondents for the test is recommended to be at least 30 respondents (Muhsoni *et al.*, 2021). Fishermen, collectors and Micro Businesses which are the reference parameters in determining and seeing how the sustainability status using the RAPFISH method has 3 aspects, namely environmental, social and social.

Based on Table 1 above, it can be analyzed using descriptive analysis to find out the description of respondents who have been measured in several indicators or attributes that have been determined. Analysis of the sustainability of the development of the Pasuruan Regency Coastal Area was carried out using the Multi Dimensional Scaling (MDS) approach called RAPFISH (Hidayah *et al.*, 2020), then strengthened by the Monte Carlo test then to find out the most influential attribute as a lever, Leverage analysis was carried out. Each attribute that has been compiled and filled with existing data conditions is then analyzed using MDS, then the sustainability index of each dimension is obtained, the standard index value that determines sustainability or not can be seen in table 5 (Saragih *et al.*, 2020).

Table 2. Sustainability management status index

Index Value	Sustainability Category
0 – 25	No Sustainability
25 – 50	Less Sustainable
50 – 75	Sustainable Enough
75 – 100	Sustainable

Source: Adapted from the RAPFISH analysis (Saragih *et al.*, 2020)

According to Table 2, an index value of 0–25 indicates a "non-sustainable" condition that requires improvement. An index value of 25–50 reflects a "less sustainable" condition, suggesting that the improvements made have minimal impact on sustainability. An index value of 50–75 falls into the "sustainable enough" category, meaning that the activities or programs implemented have had a sufficient impact on sustainability. Lastly, an index value of 75–100 indicates a "sustainable" condition, where the positive progress achieved has a good impact on sustainability (Chaliluddin *et al.*, 2023).

Sustainability analysis

The analysis of the sustainability of the development of the Pasuruan Regency Coastal Area was carried out using the Multi Dimensional Scaling (MDS) approach called RAPFISH ⁽²¹⁾, then strengthened with the Monte Carlo test then to find out the most influential attribute as a lever, the Leverage analysis was carried out. Each attribute that has been compiled and filled with the existing data conditions is then analyzed using MDS, then the sustainability index of each dimension is obtained, the RAPFISH analysis produces a sustainability index and the distribution of sensitivity values (leverage), from each dimension attribute. The acquisition of the sustainability index value can be measured and confirmed its truth and reliability from the difference between the sustainability index value and the Monte value Carlo .

Fisherman

The scoring data derived from respondent questionnaires, which assessed perceptions across 16 sustainability attributes (detailed in the Appendix), were subsequently analyzed using the RAPFISH software. For the input to the RAPFISH analysis, each attribute was assigned a score based on a predefined ordinal scale ranging from 0 (representing the 'worst' condition or lowest performance) to 2 (representing the 'best' condition or highest performance), following common practices for converting qualitative assessments into quantitative inputs for multidimensional scaling (cf. Sugiyono, 2001). The RAPFISH analysis then aggregated these individual attribute scores through multidimensional scaling to generate an overall sustainability index for the Fishermen category. This analysis yielded a sustainability index value of 55.62. Positioned on the standardized RAPFISH sustainability scale (where 0 = Bad and 100 = Good), this index falls within the 50-75 range, typically indicating a 'fairly sustainable' status (Figure 1) (Jimenez *et al.*, 2020; Atufa *et al.*, 2023). Therefore, while the assessment does not classify the fishermen segment as critically unsustainable, the 55.62 index signifies that significant improvements across various dimensions are needed to achieve a more optimal and robust level of sustainability.

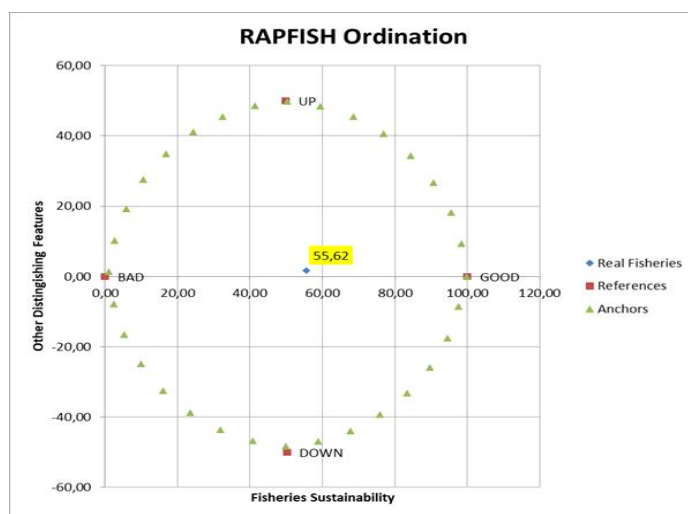
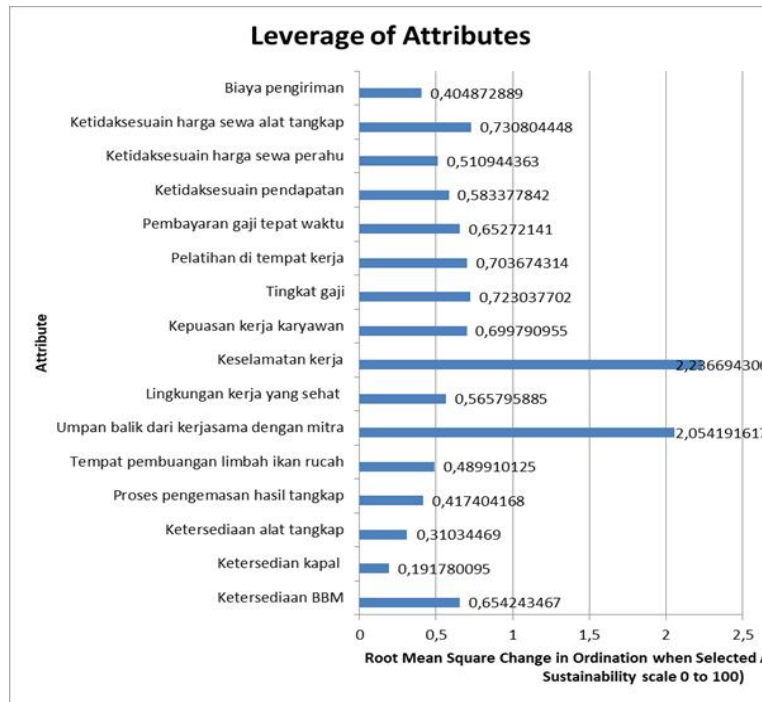


Figure 1. RAPFISH fishermen ordination chart

The RAPFISH ordination analysis for fishermen, visualized in Figure 1, yielded a sustainability index of 55.62. Positioned on the standard RAPFISH scale ranging from 0 (bad) to 100 (good) (Jimenez *et al.*, 2021; Chrispin *et al.*, 2022), this value falls between the 'BAD' and 'GOOD' reference points. This score suggests a 'fairly sustainable' status

for the fishermen category in the research area, indicating moderate performance across the evaluated dimensions (typically including ecological, economic, social, technological, and governance aspects, as employed in various RAPFISH studies like Akhmad Farid *et al.*, 2024; Atufa *et al.*, 2023). However, similar to findings in other small-scale fisheries assessments using this multidimensional framework (Jimenez *et al.*, 2021; Atufa *et al.*, 2023), a score in this mid-range signifies that substantial improvements are necessary. Although not critically unsustainable ('bad'), underlying challenges common in such fisheries – potentially related to socio-economic factors, weak governance, or resource pressures as identified by Jimenez *et al.* (2021) and Atufa *et al.* (2023) – likely contribute to this moderate rating and require targeted management to mitigate risks and achieve optimal long-term sustainability. Therefore, focused strategies aimed at increasing supply chain efficiency, implementing more effective fish resource management, and developing supportive, sustainability-based policies, perhaps informed by integrating fishers' knowledge (Duplisea, 2018), are crucial interventions needed to elevate the sustainability status towards the 'GOOD' benchmark. Addressing these multidimensional aspects strategically holds the potential to make the fisheries sector involving these fishermen more competitive and environmentally sound.



[Attributes on the Figure use Indonesian]

Figure 2. Diagram leverage of attributes analysis results

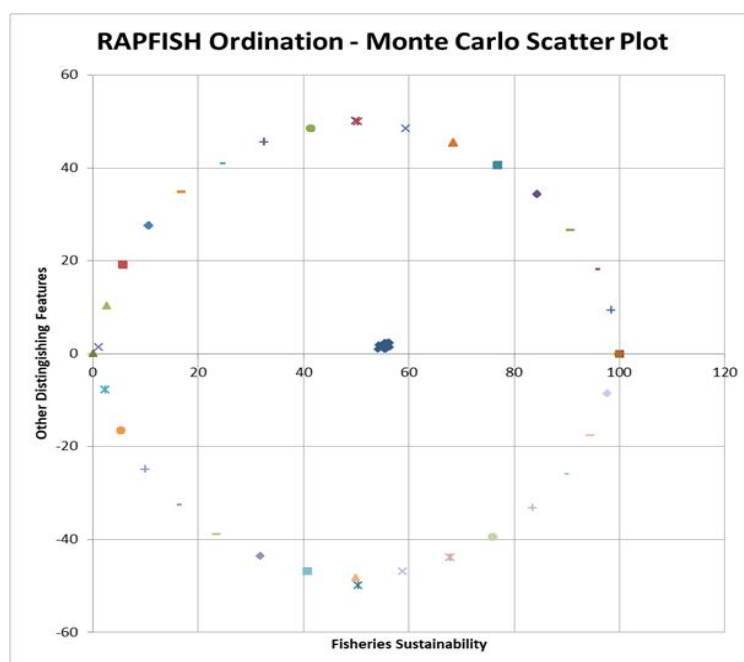


Figure 3. Monte carlo analysis strengthening results on fishermen

The results of the Leverage of Attributes Graph, presented in Figure 2, identify the factors exerting the most influence on fisheries sustainability for fishermen in the research area. The 'work safety' attribute demonstrates the highest leverage value (2.28), closely followed by 'feedback from partner cooperation' (2.05). This indicates that initiatives focused on improving work safety standards and strengthening partner relations are likely to yield the most significant improvements in the overall sustainability of this fisheries sector. Other factors, such as salary levels, job training, and fishing gear price discrepancies, also show considerable influence. In contrast, the 'vessel availability' attribute has the lowest leverage (0.19), suggesting it is less decisive in determining the overall sustainability status compared to other factors. Therefore, management strategies prioritizing improvements related to work safety and partner cooperation are expected to be the most effective interventions.

Figure 3 presents the results of the Monte Carlo simulation performed to evaluate the statistical robustness of the RAPFISH ordination for the fishermen category (as initially shown in Figure 1). This scatter plot displays the outcomes of numerous simulation runs (represented by the dense cluster of dark blue diamond points) where small random variations were introduced into the original attribute scores. The tight clustering observed, centered around the initial fishermen sustainability index of approximately 55.62 (Figure 1), demonstrates a high degree of stability in the MDS ordination. This suggests that the sustainability assessment for fishermen is not significantly sensitive to potential minor variations or uncertainties within the input data. While Monte Carlo techniques are broadly applied to assess reliability and handle uncertainties in various systems, such as evaluating the long-term strength of offshore structures (Gaidai *et al.*, 2018) or analyzing the reliability of stiffened panels (Leheta *et al.*, 2017), its specific application here is to confirm the stability of the multi-attribute sustainability index derived from the RAPFISH analysis. The scattered colored symbols represent the reference points (anchor points) defining the ordination space. Therefore, despite the different application domains in the available references, the Monte Carlo analysis conducted here provides crucial statistical confidence in the assessed sustainability status for the fishermen category.

Collector

The marine and fisheries sector is recognized as a crucial component for achieving economic independence in Pasuruan Regency (BPS, 2023). This presents a significant opportunity for business actors within the tuna commodity sector, including collectors, particularly concerning the sustainability of their operations. Employing the RAPFISH multidimensional framework (Chrispin *et al.*, 2022; Jimenez *et al.*, 2021), the analysis of the collector sustainability index across environmental, social, and economic dimensions yielded a score of 73.50. Based on the standard RAPFISH scale where scores between 50-75 typically indicate 'fairly sustainable' or 'sustainable enough' status (Atufa *et al.*, 2023), this value places the collector segment in a moderately positive sustainability category. Figure 4 visually presents this ordination result.

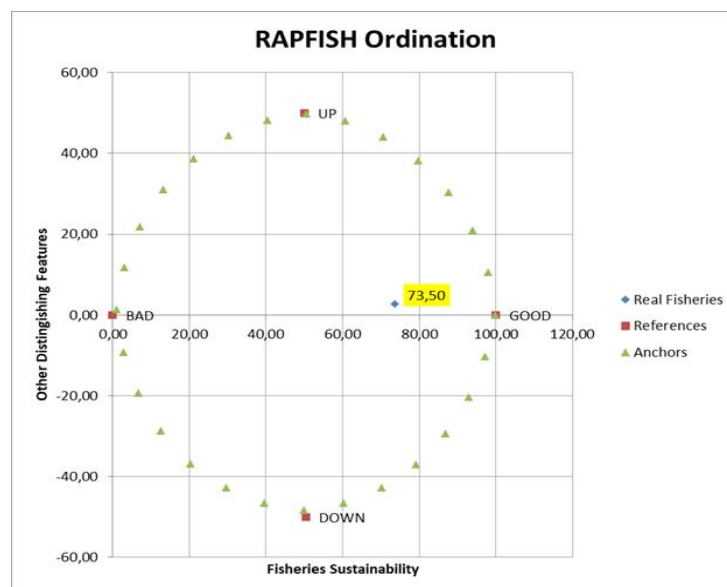
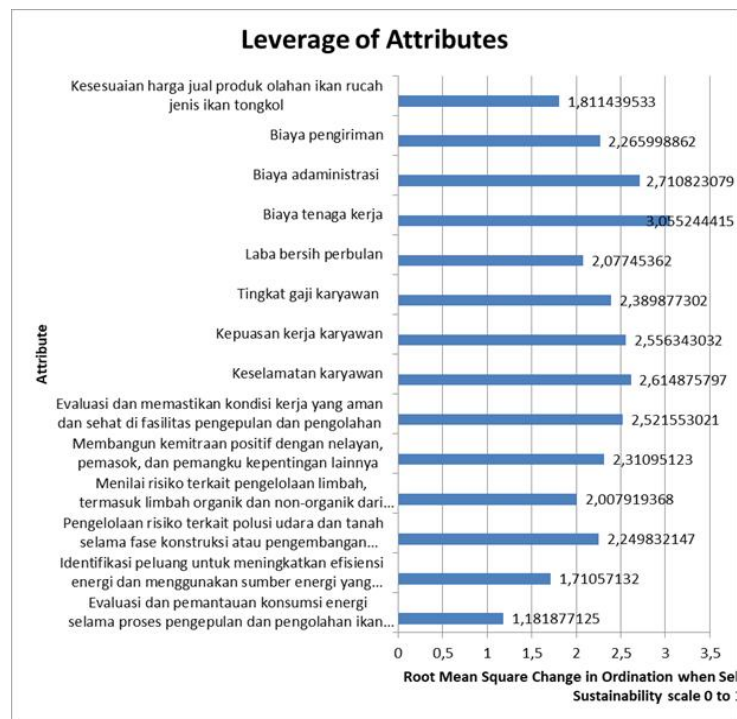


Figure 4. RAPFISH ordination chart collector

The RAPFISH Ordination graph presented in Figure 4 confirms the fisheries sustainability score for collectors at 73.50. This position, notably closer to the 'GOOD' (100) reference point than the 'BAD' (0) point, suggests that the collector segment of the fisheries system exhibits relatively sound practices compared to other segments potentially facing more direct ecological or resource pressures. However, it simultaneously indicates that further improvement is necessary to achieve optimal sustainability. This overall index reflects the complex interplay of performance across various dimensions inherent in the RAPFISH assessment – encompassing ecological, economic, social, technological, and institutional factors (Chrispin *et al.*, 2022; Farid *et al.*, 2024). While the condition appears relatively positive,

identifying the specific aspects that most limit further progress is crucial. Therefore, further analysis using the Leverage technique is essential to pinpoint the most influential factors ('levers') that can be targeted to significantly enhance the sustainability of this sector.



[Attributes on the Figure use Indonesian]

Figure 5. Diagram leverage of attributes analysis results

Figure 5 presents the Leverage analysis results specifically for the collector segment, identifying the attributes with the most significant influence on their sustainability status. The analysis highlights that within the economic dimension, 'labor costs' (*Biaya tenaga kerja*) and 'administrative costs' (*Biaya administrasi*) exhibit the highest leverage values (approximately 3.06 and 2.71, respectively, based on visual inspection of Figure 5). This indicates that fluctuations or inefficiencies related to these operational costs have a disproportionately large impact on the overall economic viability and sustainability of the collectors in Pasuruan Regency. Effective management of these costs is therefore crucial, particularly given that fisheries supply chains, even those involving valuable commodities like tuna, can face challenges related to optimization and integration, potentially impacting profitability at different nodes (Idris *et al.*, 2023). Furthermore, socioeconomic pressures common in small-scale fisheries, such as market access limitations or fluctuating input costs (Jimenez *et al.*, 2020), can amplify the sensitivity to labor and administrative expenses. Thus, these findings pinpoint labor and administrative cost management as critical leverage points where targeted interventions could most effectively improve the economic sustainability of tuna collectors along the Pasuruan coast.

The development of the coastal sustainability status of Pasuruan Regency, which includes TPI Lekok, TPI Rejoso and TPI Kraton, is a special concern in Pasuruan Regency. This is because based on the production of marine fish catches of the type of tuna in Indonesia based on BPS data in 2020, it was 20,907 tons with a transaction value of IDR 457.34 billion. Tuna is in second place with a production value of IDR 423.86 billion with a production volume of this fish reaching 12,995 tons.

Regency is one of the regencies of the province that contributes the most fish production in 2020, East Java contributed marine capture fisheries production of fish processing of 15,702 tons or 62.16% (KKP, 2020). Although the production of marine fish catches of the type of tuna has economic value, the supply chain management system is still less than optimal. Little research on risk mitigation integrates a sustainable supply chain system in Micro Businesses processing fish catches, to consumer preferences regarding the availability of raw materials (Idris *et al.*, 2023).

Figure 6 displays the results of the Monte Carlo simulation conducted to assess the statistical robustness of the RAPFISH ordination for the collector category. The scatter plot visualizes the distribution of sustainability indices generated across numerous iterations where small random variations were introduced into the original attribute scores (represented by the dense cluster of dark blue diamond points). This tight clustering, centered around the original sustainability index for collectors (approximately 73.50, as shown in Figure 4), signifies a high degree of stability in the MDS ordination. This stability indicates that the assessed sustainability status for the collectors is reliable and not unduly influenced by minor uncertainties or noise in the input data. The general principle of using Monte Carlo methods to analyze statistical properties like variance and convergence, even in different fields such as

computer graphics rendering (Singh *et al.*, 2017; Singh *et al.*, 2019), supports its application here to verify the dependability of the RAPFISH outcome. The scattered colored symbols denote the reference anchor points defining the ordination space. Consequently, this Monte Carlo analysis provides crucial statistical confidence in the sustainability assessment determined for the collector segment of the Pasuruan skipjack tuna fishery.

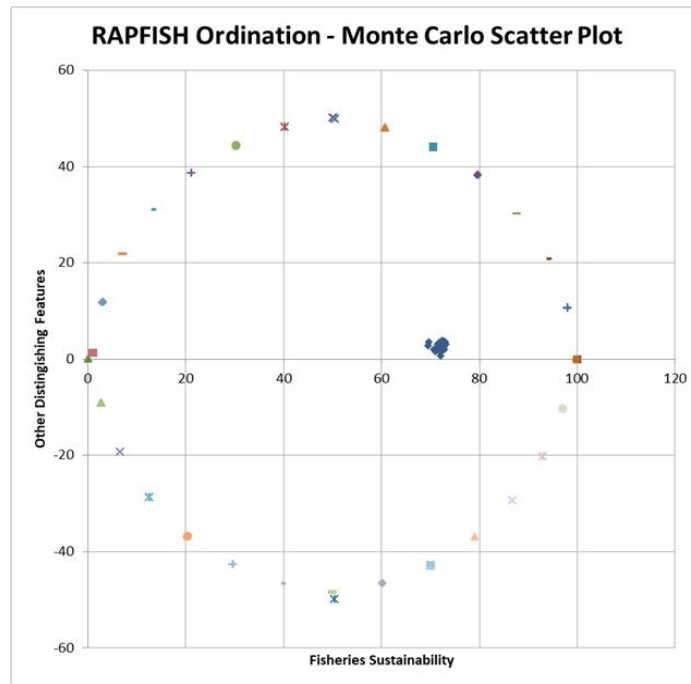


Figure 6. Results of monte carlo analysis amplifier on collectors

Micro and medium enterprises (MICRO ENTERPRISES)

The fish processing business on the coast of Pasuruan Regency is one of the leading commodities from capture fisheries with high selling value (Boceng & Syarif, 2022). However, the process of catching and processing fish products is highly determined by natural conditions such as season and weather. This makes it difficult to predict the quantity and quality of anchovy products produced by fishermen. In addition, the price of anchovy products is also relatively unstable or often fluctuates.

From the scoring data produced in the table above, it is then analyzed using RAPFISH software, which can be seen in the appendix. It can be seen that each individual respondent gets 16 questions each that are asked in the questionnaire, and all of these questions are the same. For each question, a score is then obtained, where the processing of the scoring is a reference from previous research where each scoring has a value from the worst, namely zero (0) to the best, namely two (2) (Chaliluddin *et al.*, 2023). Furthermore, the total obtained is processed using RAPFISH software.

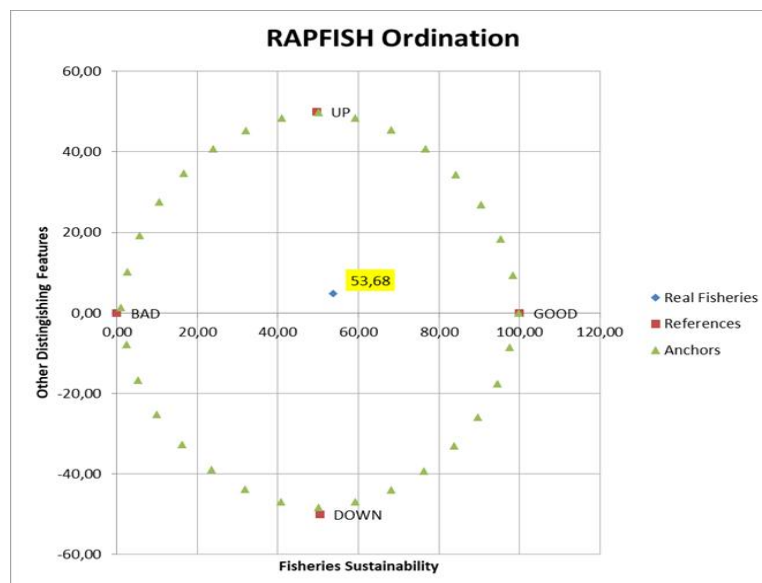
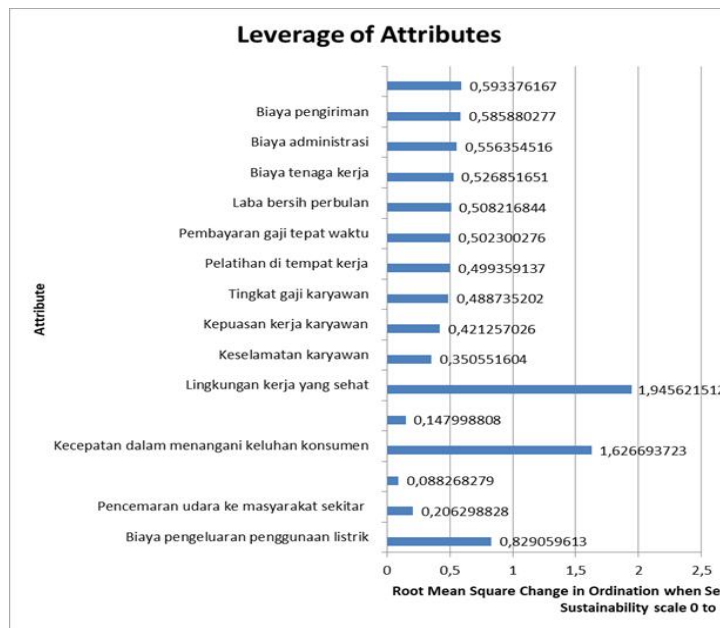


Figure 7. RAPFISH MICRO BUSINESS Ordinance Graph

software makes it possible to find out how much the sustainability index is for the micro and medium enterprises. Then the results obtained from the Rappfish analysis prove that the sustainability index of Micro Enterprises is 55.27. The value of the sustainability index of the micro and medium enterprises is in the range of >50 - 75 (Figure 7). In such conditions, it explains that based on the criteria referred to, the index is quite sustainable.

The RAPFISH Ordination graph presented in Figure 7 displays the sustainability assessment for the micro-business category involved in processing skipjack tuna, yielding an index value of 53.68. Situated midway between the 'BAD' (0) and 'GOOD' (100) reference points on the standard RAPFISH scale (Jimenez *et al.*, 2020; Chrispin *et al.*, 2022), this score indicates a 'fairly sustainable' status. However, this moderate positioning signifies that the micro-enterprise system, while not critically unsustainable, has not yet achieved full sustainability and possesses considerable scope for improvement. This finding resonates with assessments in other data-poor, small-scale fisheries contexts where RAPFISH often reveals moderate sustainability levels constrained by underlying socioeconomic or governance challenges (Atufa *et al.*, 2023; Jimenez *et al.*, 2020). The need for improvement spans multiple dimensions inherent to the RAPFISH framework, including economic viability, social aspects like worker welfare, and environmental management practices (Farid *et al.*, 2024; Chrispin *et al.*, 2022). Therefore, targeted strategies focusing on enhancing supply chain efficiency, improving conditions for workers, and strengthening environmental stewardship are essential to elevate the sustainability performance of these micro-businesses towards the 'GOOD' benchmark in the long term.



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Figure 8. Diagram leverage of attributes analysis results

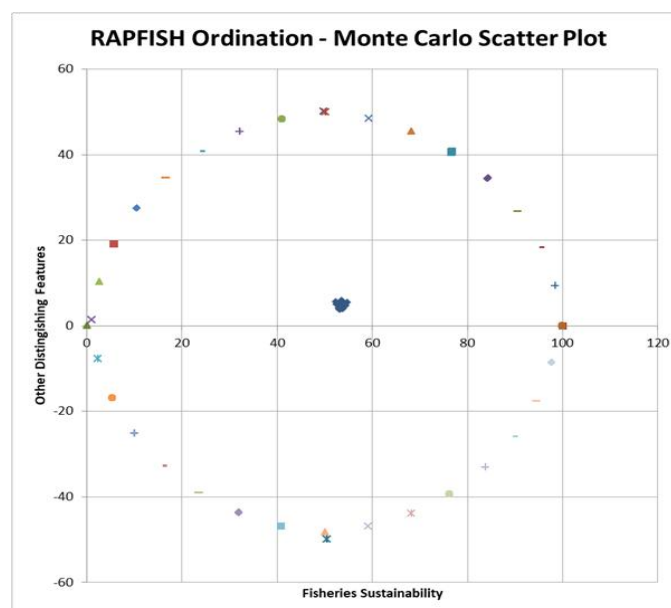


Figure 9. Results of monte carlo analysis amplifier in micro business

The Leverage of Attributes analysis for the micro-business category, depicted in Figure 8, identifies the factors with the most substantial impact on their overall sustainability. Notably, 'healthy work environment' emerges with the highest leverage value (1.94), underscoring the critical importance of providing safe, comfortable, and supportive working conditions for employees within these enterprises. This aligns with broader sustainability assessments where social dimensions, including labor conditions, are recognized as crucial, yet often challenging, aspects in small-scale operations (Jimenez *et al.*, 2020). The second most influential attribute is 'speed in handling consumer complaints' (1.62), highlighting the significant role of customer satisfaction and responsiveness in maintaining market reputation and long-term business viability, especially important for smaller businesses navigating competitive markets. Factors related to specific operational costs (shipping, administration, labor) and certain environmental impacts like air pollution registered considerably lower leverage in this analysis, indicating they are relatively less sensitive drivers of overall sustainability compared to the primary social and market-facing attributes for this specific group. Therefore, these findings strongly suggest that strategies aimed at enhancing the sustainability of tuna processing micro-businesses in Pasuruan should prioritize improvements in workplace conditions and customer service responsiveness as key intervention points.

Figure 9 depicts the results of the Monte Carlo simulation conducted to assess the statistical robustness of the RAPFISH ordination for the micro-business category (corresponding to Figure 7). This analysis involves multiple simulation runs with slight random variations introduced into the input attribute scores, visualized here as the dense cluster of dark blue diamond points. The tight grouping of these points around the original sustainability index for micro-businesses (approximately 53.68 as show figure 7.) demonstrates a high degree of stability in the MDS result. This finding indicates that the calculated sustainability index is reliable and not overly sensitive to inherent uncertainties or minor fluctuations in the data. The application of Monte Carlo simulation to evaluate outcomes under uncertainty and verify design robustness is a common practice across various fields. For instance, it is used to assess the stochastic economic feasibility for micro and small businesses (Lacerda *et al.*, 2020) and to verify the robustness of optimized electronic designs, such as CMOS operational amplifiers (Valencia-Ponce *et al.*, 2021). Applied in this context, the Monte Carlo analysis confirms the dependability of the sustainability assessment for the micro-businesses studied. The scattered colored symbols represent the reference anchor points within the ordination space. Thus, this simulation provides essential statistical confidence in the RAPFISH findings for micro-businesses.

Based on the results of RAPFISH processing consisting of Fishermen, collectors and Micro Businesses with dimensions (environmental dimension, economic dimension, social dimension). The next step is to create a flyover diagram to determine the sustainability index value of the ikan rasak on the coast of Lekok Beach, Pasuruan Regency.

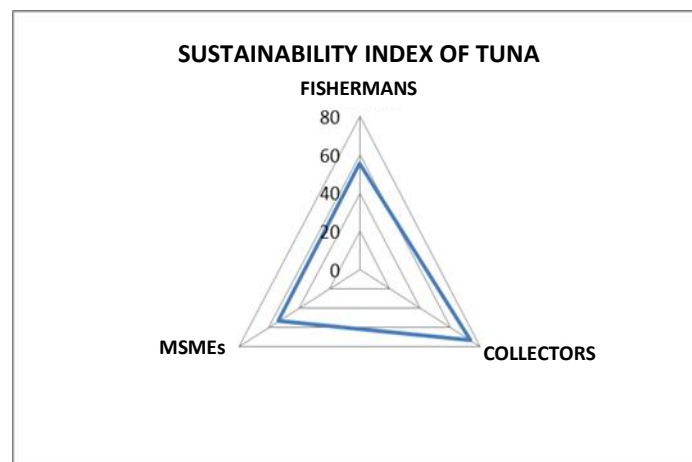


Figure 10. Flyover diagram of the sustainability index values of tuna fish

The Flyover diagram in the Figure 10. shows the Sustainability Index of Skipjack Tuna based on three main categories: fishermen, collectors, and Micro Enterprises for Fish Catch Management. From the visualization, it can be seen that fishermen have the highest sustainability index compared to the other two categories, approaching 80. This indicates that the sustainability aspect in the fisheries sector is better maintained at the fishermen level, possibly due to their direct access to fish resources and relatively traditional and more controlled fishing practices.

Meanwhile, collectors have a lower sustainability index compared to fishermen but still higher than Micro Fisheries Enterprises. This position indicates that collectors have a significant role in the tuna supply chain, but still face several challenges in terms of sustainability, such as catch management practices and distribution systems that may not be optimal. The category with the lowest sustainability index is MICRO ENTERPRISE, which shows that this sector still faces various obstacles, such as limitations in fish processing, supply chain efficiency, and economic and regulatory factors that affect the sustainability of its business.

From these results, efforts to improve sustainability need to be focused on the collector and MICRO BUSINESS sectors, by strengthening environmentally friendly fish management practices, increasing distribution efficiency, and supporting policies that can improve the competitiveness and resilience of small businesses in the skipjack tuna fisheries industry.

Alternative sustainable management strategies

Based on the results of the sustainability status of the description above, the fisheries in Pasuruan Regency, especially in the Lekok sub-district, Rejoso sub-district and Kraton sub-district with tuna fish commodities, then a grouping of the lever factors of each dimension used was made. Tidd *et al.* (2018) explained that the lever factors from the results of the RAPFISH method analysis are problematic matters that can affect the sustainability status of the tunasak fishery. Therefore, the lever factors will be used as a reference or priority in formulating the existing ones. The formulation of the sustainability index is expected to be able to solve existing problems, especially in the tuna fish commodity sector in the environmental, economic and social fields in order to create sustainable tuna fishery development on the coast of Pasuruan Regency. The following is a table of the lever factors of each dimension.

Table 3. Leveraging Factors in Each Dimension

NO	ASPECT	DIMENSIONS	LEVERAGE FACTOR
1	Fisherman	SOCIAL	Work Safety Feedback on cooperation with partners
2	Collector	ECONOMY	Labor Costs Administrative Costs
3	Micro Fisheries Business	SOCIAL	Healthy Working Environment Speed In Handling Consumer Complaints

Source: Data Processing Factors in Each Dimension

Table 3 shows the leveraging factors in the sustainability of the tuna fisheries sector, including fishermen, collectors, and micro fisheries businesses. For fishermen, the main factors in the social dimension are work safety and feedback on cooperation with partners. Work safety is very important considering the risks of work at sea, while good feedback improves efficiency and coordination in the supply chain. For collectors, the leverage factor is more dominant in the economic dimension, namely labor costs and administrative costs. Efficiency in managing these costs will help collectors increase profitability and strengthen the distribution of tuna. In micro fisheries businesses, leveraging factors in the social dimension include a healthy work environment and speed in handling consumer complaints. A good work environment increases worker productivity, while a quick response to consumer complaints can increase customer satisfaction and business competitiveness. Overall, the sustainability of the tuna fisheries sector is influenced by different social and economic factors for each actor in the supply chain. Optimizing these factors can improve the welfare of fishermen, the efficiency of collectors, and the competitiveness of Micro Fisheries Enterprises .

CONCLUSION

This study concludes that the skipjack tuna fishery system within the coastal areas of Pasuruan Regency, specifically encompassing the Lekok, Rejoso, and Kraton sub-districts, demonstrates a 'fairly sustainable' status overall, based on a multidimensional assessment. The analysis revealed varying levels of sustainability across the key actors involved: collectors exhibited the highest sustainability index at 73.50, indicating relatively stronger performance, while fishermen (55.62) and micro-enterprises (53.68) displayed moderate sustainability levels, highlighting areas requiring significant improvement. Crucially, the sustainability performance assessment identified several key leverage factors that exert considerable influence on the system's overall sustainability. These critical indicators include social factors such as work safety, feedback on cooperation with partners, and a healthy work environment; economic elements like labor costs and administration costs; and market responsiveness as measured by the speed in handling consumer complaints. Focusing strategic interventions and policy efforts on these specific leverage points offers the most promising pathway to enhance the long-term viability and resilience of the skipjack tuna fishery in Pasuruan Regency.

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supply chains and serve as a reference for future studies.

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