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Sustainability Status of *Sardinella lemuru* Utilization in the Bali Strait, Indonesia

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ABSTRACT

Sardinella lemuru is a leading commodity in the Bali Strait. However, it is necessary to evaluate the sustainability of fish resource utilization for being exploit in the provinces of East Java and Bali. To maintain the sustainability of the fish, efforts are made to identify problems and produce strategies for managing *Sardinella lemuru* resources and fishing gear. Purposive sampling techniques were employed to collect both primary and secondary data, which were subsequently analyzed using RAPFish multidimensional measurement (MDS). The results of the sustainability analysis of the lemuru fish resource in the Bali Strait show three dimensions with an extremely sustainable status: the ecological dimension (87.681%), the technical dimension (81.619%), and the social dimension (80.318%). The economic dimension has a moderate sustainable status (57.146%). Environmental variability plays an important role in lemuru population availability, but it cannot offset the pressure of overfishing. MDS revealed that lemuru sustainability in the Bali Strait is under pressure originated from various sources. To achieve sustainable status, interventions must be integrated and holistic, addressing more than one dimension. Efforts to improve the situation should include limiting fishing grounds (ecological), increasing the value of products (economic), strengthening the role of fishing communities (social), and improving the management of fishing efforts (technical). This approach provides a clear roadmap for balancing economic benefits with ecological conservation for the future of lemuru resources.

INTRODUCTION

In the context of marine resource management, the sustainable utilization of lemuru (*Sardinella lemuru*) is an important concern, especially in the Bali Strait, where this species comprises a significant portion of the catch of fishermen utilizing the strait's waters. Given lemuru's economic and ecological importance, a thorough understanding of its population dynamics, reproductive biology, and environmental interactions is necessary for the sustainable utilization of fisheries resources **(Willette & Santos, 2012; Labrador *et al.*, 2022)**. Recent studies have shown that population fluctuations are influenced by factors such as climate variability and overfishing

operations. This has led to a focus on the lemuru's ecological and biological parameters **(Setyohadi *et al.*, 2021; Suariningsih *et al*, 2021; Ramos & Roque, 2023)**. It is critical to understand the results of research on fish length at first capture (L_(c50)) and absolute fecundity in order to develop management strategies for endangered fish resources **(Sartimbul *et al.*, 2016; Metillo *et al.*, 2018)**. Additionally, advances in genetic analysis and ecological modeling can inform better management practices, helping us adapt to changing oceanographic conditions and mitigate the risk of overexploiting resources **(Hendiari *et al.*, 2020; Labrador *et al.*, 2022)**. Ensuring the sustainability of the lemuru fishery requires integrating scientific knowledge with sustainable fishing regulations. This is currently a pressing challenge for fisheries policymakers in the waters of the Bali Strait **(Bhuwana *et al.*, 2023; Satyawan *et al.*, 2023)**.

Average lemuru production in the Bali Strait reflects the status of the area's fishery resources. The strait is known for its abundant fish production, especially lemuru, and it is the economic backbone for many local fishermen **(Susilo *et al.*, 2021; Latumeten *et al.*, 2022; Tanjov *et al.*, 2024)**. Research shows that lemuru has significant ecological and economic value. This makes it one of the main targets of the fishing industry in the Bali Strait **(Nugraha *et al.*, 2018; Tanjov *et al.*, 2024)**. Purse seine nets are the main fishing method used to catch lemuru, as they are highly effective in capturing schooling fish in epipelagic waters **(Kosasih *et al.*, 2021; Jatisworo *et al.*, 2022)**. The *Sardinella lemuru* species dominates 90% of the small pelagic fish caught in the region, demonstrating its important role in the Bali Strait fishery **(Sartimbul *et al.*, 2016; Satyawan *et al.*, 2023)**. The Bali Strait's distinctive hydrographic features, influenced by monsoon patterns and upwelling events, increase the productivity of these waters. This increase in productivity contributes to growing lemuru populations. Understanding the dynamics of fish stocks in the area requires an understanding of interactions between environmental factors, such as chlorophyll-a concentration and sea surface temperature **(Sartimbul *et al.*, 2010; Puspasari *et al.*, 2019; Adivitasari *et al.*, 2022)**.

The production of lemuru is influenced by various factors, such as the availability of zooplankton (its main food source) and environmental conditions, such as sea surface temperature and chlorophyll-a **(Ridha *et al.*, 2013; Adivitasari *et al.*, 2022)**. Clear variations in lemuru catches in the Bali Strait were shown to be closely related to climatic phenomena, such as upwelling and the Index of Dipole Oscillations (IOD) **(Adivitasari *et al.*, 2022)**. Additionally, advances in fishing technology using hydroacoustic methods provide a more accurate estimate of the potential availability of lemuru fish, which can support the management of sustainable fisheries **(Pratama *et al.*, 2024)**.

The lemuru catch is related to the volume and effort of fishing operations, which are important factors in understanding the sustainability of fish populations. The research shows that the fishing season is strongly influenced by weather factors, such as the rainy and windy seasons. These factors affect the migration patterns and availability of lemuru in the waters **(Suhery *et al.*, 2023)**. Therefore, fishers must

have a good understanding of the ecological conditions and the best time for lemuru fishing in order to maximize their catch. **(Suhery *et al.*, 2023; Tanjov *et al.*, 2024)**.

This combination of factors suggests that the average production of lemuru in the Bali Strait is determined not only by the fish population itself but also by the complex interplay of various environmental factors and human activities. Further research is necessary to optimize the value of the Bali Strait fisheries, particularly with regard to sustainability and preserving aquatic ecosystems **(Susilo *et al.*, 2021; Adivitasari *et al.*, 2022; Latumeten *et al.*, 2022; Tanjov *et al.*, 2024)**.

Despite its high economic value, rising catch rates have raised concerns about lemuru populations. Without appropriate management strategies, such as implementing fishing restrictions and monitoring fishing quotas, lemuru populations could be threatened, according to research **(Harlyan *et al.*, 2021; Harlyan *et al.*, 2022)**. The Fisheries Management Area (WPP) 573, which encompasses the Bali Strait, underscores the importance of an integrated approach that considers both ecological and economic factors **(Jatisworo *et al.*, 2022; Satyawan *et al.*, 2023)**. Without proper regulation of fishing practices, overexploitation becomes a threat to the long-term viability of the sardine population and the livelihoods that depend on it **(Pertiwi *et al.*, 2023; Satyawan *et al.*, 2023)**. Therefore, effective fisheries management is essential to sustaining lemuru and the surrounding marine ecosystem.

During February–March 2015, potential lemuru fishing grounds were only found in Sembulungan and Pengambengan in the Muncar and Bali Strait waters **(Simbolon *et al.*, 2017)**. Lemuru management should focus not only on demographic parameters (e.g., stock size and catch volume) but also on preserving adaptive variation **(Labrador *et al.*, 2022)**. Lemuru is one of the most important pelagic fish in the Bali Strait and has been reported to be overfished. Various studies have been conducted to understand its population status (**Pertiwi *et al.*, 2023)**. Data on currents, wind speed, waves, and sea level are important supporting data that help fishermen determine fishing areas and conduct fishing activities **(Ghazali & Manan, 2016)**.

MATERIALS AND METHODS

This study used a purposive sampling technique with stratification of fishing gear to assess the sustainability of lemuru resources in the Bali Strait. When assessing the sustainability of fish resources, a reliable method for collecting relevant data on fish populations and the impacts of various fishing practices is to use purposive sampling techniques combined with fishing gear groupings. This approach enhances the representativeness of data obtained in diverse ecological settings and fishing methods by enabling researchers to target specific fishing activity centers with different types of gear more precisely. For example **Yanti *et al.* (2021)** discussed how clustering by gear type can improve sustainability assessments by revealing important fishing-induced factors and resource utilization patterns. These groupings provide a comprehensive picture of the relationships among different fishing methods, fish populations, and environmental health **(Brown *et al.*, 2024)**.

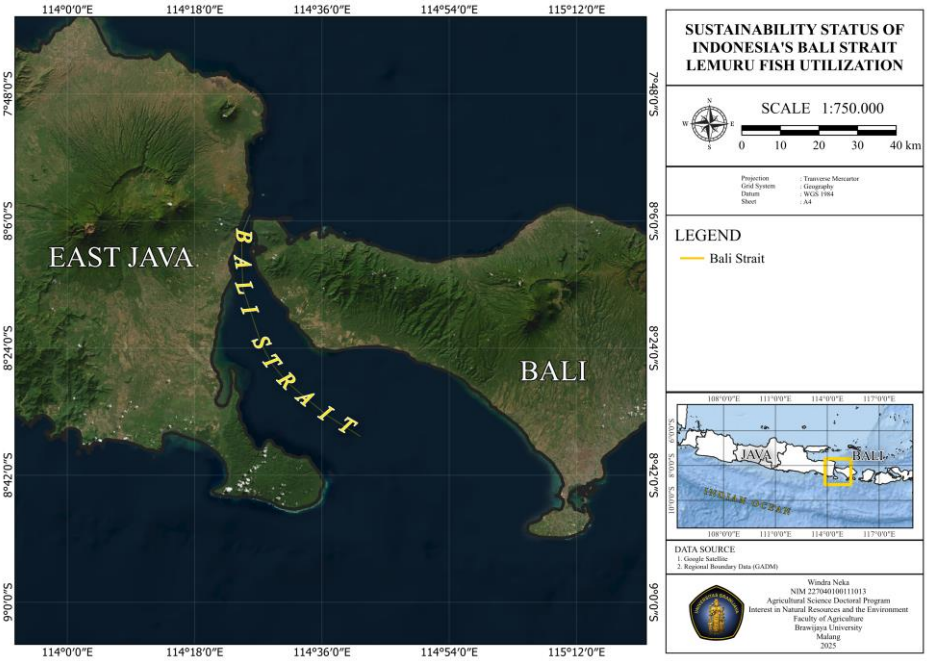

Fig. 1. Research location

Multidimensional scaling (MDS) strengthens this assessment by visualizing the relationships between different sustainability factors, including ecological, economic, and social dimensions **(Hidayanto & Fiana, 2024; Purwanti *et al.*, 2024)**. MDS allows researchers to identify the sensitivity of various sustainability indicators and their interactions. This facilitates a multifaceted approach to fisheries management **(Nikoyan *et al.*, 2023)**. For instance, **Nikoyan *et al.* (2023)**, in their study, demonstrated the effective use of MDS in evaluating commodity sustainability, a methodology that can be adapted for fisheries. Stakeholders can use this methodology to synthesize complex fishery performance data into actionable insights that inform sustainable management practices addressing ecological integrity and community livelihoods **(Anderson *et al.*, 2015; Moreau & Garaway, 2021)**.

In summary, combining purposive sampling with multidimensional scaling (MDS) techniques provides a comprehensive methodological framework for evaluating the sustainability of fish resources. This ensures that management strategies are based on empirical data reflecting the actual complexity of fishing practices.

Table 1. Dimension, attributes and scale assessment of the sustainability of *Sardinella lemuru* in Bali Straits

No.	Dimension	Attribute
1	Ecology	Exploitation status
		Recruitment variability
		Change in T level
		Migratory range
		Range collapse
		Size of fish caught

		Catch < maturity
2	Economy	Profit
		Workforce absorption
		Lemuru fish demand
		Migratory range
		Range collapse
		Size of fish caught
		Catch < maturity
		Discarded bycatch
		Species caught
		Primary production
3	Social	Education level
		Level of conflict
		Number of Fishermen
		Migratory range
		Role of the community
		Business socialization level
4	Technical	Fishing gear selectivity
		Fish handling on board
		Threatens target fish species
		Vessel size
		Auxiliary fishing gear
		Negative impact of fishing gear
		Fisherman safety
		Lemuru catch landing
		Species caught

Source: Modified from **Pitcher and Preikshot (2001)** and **Baeta *et al*. (2005)**.

The steps in the RAPFish MDS analysis of the *Sardinella lemuru* resource utilization in the Bali Strait, as measured by the attributes of the dimensions of sustainability status, are as follows:

1. Perform scoring techniques or assign ranks to each attribute, including scoring other analysis results that reflect the sustainability of the dimensions in question.
2. Using RAPFish software, MDS calculates the distance and rotation to determine the position of the sustainability index between "good," "less," "medium," and "good."
3. The level of sustainability of *Sardinella lemuru* resource utilization is assessed using a sustainability index scale ranging from 0 to 100%. The 0-25 category is considered poor, the 26-50 category is considered fair, the 51-75 category is considered adequate, and the 76-100 category is considered good **(Putri *et al.*, 2023)**.
4. Calculate the magnitude of the S-stress value to assess the goodness of fit in MDS.

5. Conduct a sensitivity analysis (leverage analysis) to determine which attributes have a strong effect on sustainability by examining the magnitude of the root mean square (RMS).
6. Perform a Monte Carlo analysis to evaluate the effect of random errors on the estimation process and to estimate the true value.

RESULTS

Research on the sustainability of *Sardinella lemuru* utilization in the Bali Strait identified various factors affecting its sustainability status through multidimensional scaling (MDS) analysis. MDS allows researchers to interpret complex data and to gain insight into the ecological and social conditions of local fisheries. Research revealed the significant impact of sea surface temperature (SST) dynamics on pelagic fish populations, including lemuru, which depend heavily on environmental conditions for survival and reproduction **(Puspasari *et al.*, 2016; Puspasari *et al.*, 2019)**.

From a climatic standpoint, fishing activity in the Bali Strait is strongly influenced by the seasons. It has been demonstrated that a clear seasonal pattern exists, with the wet and dry seasons affecting the fishing period. The rainy season, which is accompanied by dominant southeast winds, lasts from October to March and contributes to the productivity of fishing, including lemuru **(Suhery *et al.*, 2023**). This finding is relevant for MDS. Understanding this seasonal variability is crucial in forecasting optimal fishing locations and timing.

A relationship was found between sea surface temperature and chlorophyll-a concentration that affects lemuru distribution. Although lemuru catches varied, this study concluded that sea surface temperature and food availability, which is influenced by chlorophyll-a, exhibit a mutually influential distribution pattern **(Adivitasari *et al.*, 2022)**. In the context of sustainability, this suggests that effective management must consider broader environmental factors, such as climate change, that can impact both parameters.

The concentration of chlorophyll-a, a pigment that plays a crucial role in photosynthesis, has been identified as the primary factor influencing the population dynamics of *Sardinella lemuru*. This finding offers significant insights into the functioning of the Bali Strait pelagic ecosystem, underscoring the fundamental relationship between primary productivity and the sustainability of the marine food chain. From an ecological perspective, this relationship underscores the significance of bottom-up control mechanisms in marine food webs. From a management perspective, this knowledge positions chlorophyll-a as a bioindicator for ecosystem-based fisheries management (EBFM).

A more specific approach to fisheries management is expected through the use of satellite data. For example, prior research used satellite data to estimate fishing grounds and found that catch varied significantly based on temperature and chlorophyll-a levels **(Ridha *et al.*, 2013)**. This shows that the utilization of modern technology can help improve sustainable fisheries monitoring and management.

Finally, multi-dimensional scaling (MDS) analysis can provide an integrated picture that assesses the sustainability of lemuru utilization from ecological and social dimensions. This study aims to provide a stronger basis for policy recommendations for sustainable fisheries management in the Bali Strait by collecting and analyzing data from various sources, including environmental indicators, fishing patterns, and the influence of climate change **(Susilo *et al.*, 2021)**. It is expected that when data-driven policies are implemented, lemuru utilization can be conducted responsibly while ensuring the sustainability of the aquatic ecosystem.

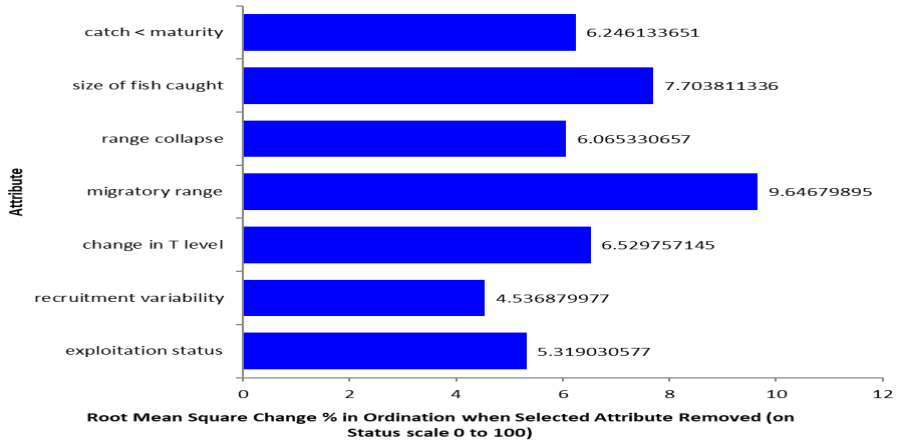

Fig. 2. Leverage value of ecological dimension

The results of the ecological dimension analysis revealed three important factors: lemuru migration, the size of the fish caught, and sea surface temperature. The swimming speed of lemuru during migration was found to depend on the strength of the target fish, depth, and time of day **(Jaya., 2002)**. The migration of lemuru fish in the Bali Strait significantly influences the catch of fishermen using purse seine gear. Lemuru, a main fishery commodity in the region, performs seasonal movements influenced by oceanographic factors such as water temperature, ocean currents, and plankton availability. Large-scale migrations, especially in certain seasons, tend to increase purse seine catches because lemuru gather in large groups that are easily reached by these circular nets. Conversely, catches can drop dramatically when fish migrate to other areas or to depths that purse seine nets cannot reach. These migratory patterns also affect fishing strategies, forcing fishermen to adjust the timing and location of their fishing based on the movements of the fish. Additionally, environmental changes due to human activities or natural phenomena, such as El Niño, can disrupt lemuru migratory patterns, ultimately impacting the productivity of purse seine fishing. Therefore, understanding the dynamics of lemuru migration is essential to optimizing catches while preserving fish stocks in the Bali Strait.

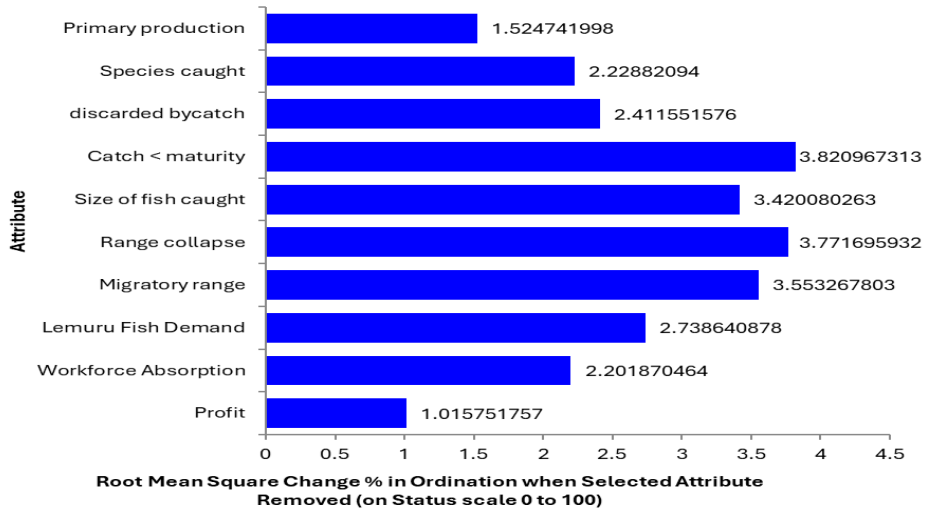

Fig. 3. Leverage value economic dimension

The economic implications of using purse seine gear to catch *Sardinella lemuru*, also known as Bali sardines, are multifaceted and significantly impact the sustainability and profitability of local fisheries. Purse seine operations are a prevalent fishing method in the Bali Strait. They generate sizable sardine catches due to their efficiency in targeting schooling species, which supports the livelihoods of many local fishers **(Puspasari *et al.*, 2019; Apituley *et al.*, 2023)**. Purse seine gear's ability to encircle and capture large biomasses makes it a favored technique, often resulting in sardine catches that comprise a significant portion of the region's total pelagic fish catch **(Davies *et al.*, 2014)**. These species are a source of food and livelihood for local residents **(Neka, 2019)**. While this high volume of catch represents an economic advantage, it also raises concerns about the sustainability of fish stocks amid increasing fishing pressure **(Adhawati *et al.*, 2023)**.

From an economic perspective, relying on purse seine gear requires careful management to prevent overfishing and to ensure the long-term viability of fishing communities, which is critical to their economic stability. **(Harlyan *et al.*, 2021; Hampton *et al.*, 2023)**. Sustainable practices not only protect fish stocks but also secure steady income for fishing businesses, reducing financial risks from stock collapse. For instance, implementing regulations on fish aggregating devices (FADs) can help maintain healthy *Sardinella lemuru* populations, ensuring consistent supply for markets and stable revenue for fisheries. Thus, balancing high catch rates with sustainability measures supports both business profitability and long-term resource availability. Adopting sustainable practices can improve the overall economic performance of fishers by securing fish populations for future harvests. This strengthens the socioeconomic frameworks that depend on these resources **(Song & Shen, 2022; Apituley *et al.*, 2023)**. Integrating effective fisheries management with purse seine practices is essential to maximizing the economic potential of *Sardinella lemuru* while preserving marine biodiversity. Effective fisheries management in purse seine operations is critical to balancing the economic benefits of Sardinella lemuru exploitation with long-term stock sustainability. Overharvesting risks collapsing fisheries, jeopardizing livelihoods and market supply, while underutilization leaves

economic potential untapped. By regulating catch limits and gear use (FAD restrictions), stakeholders can optimize resource utilization ensuring stable incomes for fishing communities and consistent yields for industries dependent on this resource.

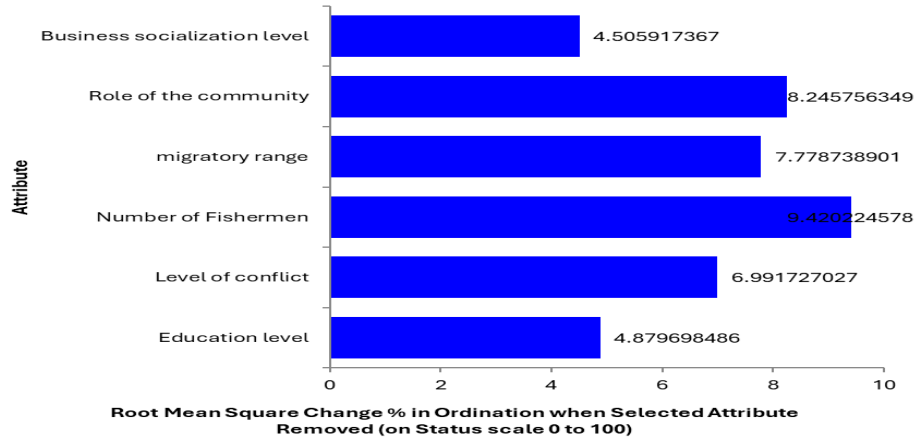

Fig. 4. Social dimension leverage value

The social dimension's sensitivity value significantly contributes to the sustainability of lemuru resources in the Bali Strait by engaging stakeholders and improving community resilience. This dimension encompasses the collective action and social cohesion of local fishing communities, both of which are essential for disseminating sustainable fishing practices and environmentally friendly resource management **(Putra *et al.*, 2021; Ramos & Roque, 2023)**. Effective communication and collaboration among fishers, the government, and non-governmental organizations can lead to informed decision-making and to ensure the sustainable use of lemuru stocks. Integrating local knowledge, particularly concerning optimal fishing times and practices that prevent overfishing, as well as paying attention to lemuru reproductive patterns, can help develop more effective management strategies **(Ramos & Roque, 2023)**.

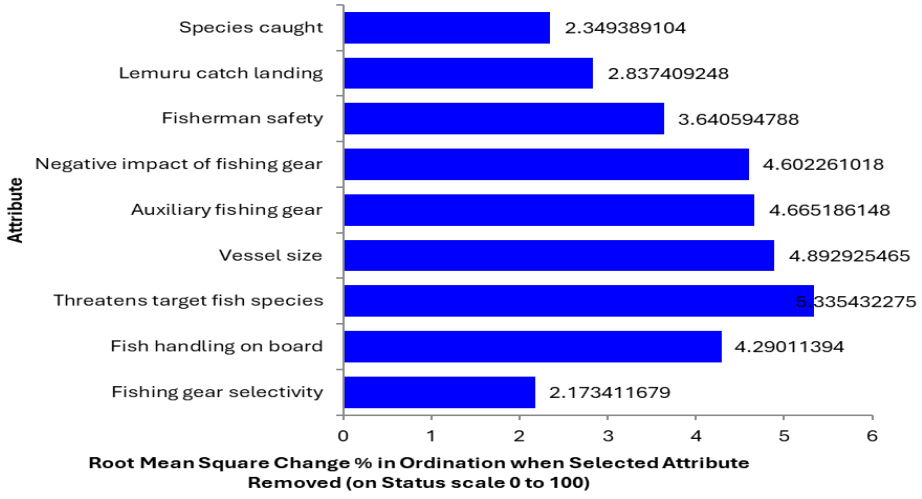

Fig. 5. Technical dimension leverage value

The sensitivity of the technical dimension that explains the dominance of purse seine nets in the *Sardinella lemuru* fishery presents opportunities and challenges for fisheries management and the development of fishing technology, particularly for purse seine nets. Characterized by their ability to enclose entire schools of fish, purse seine nets provide higher catch efficiency values than other fishing methods, such as gill nets or longlines. This makes them the preferred choice for pelagic fishing **(Handegard *et al.*, 2017)**. This efficiency can increase the number of lemuru landings, an economically important fish in the Bali Strait. This would streamline the processing and distribution of fishery products **(Rizkina *et al.*, 2023)**. The sustainability of lemuru resources in the Bali Strait is impacted by the increasing use of purse seine gear, making it an important consideration.

The development of purse seine gear has increased its effectiveness in large-scale pelagic fishing operations. However, there is limited research on the impact of these operations on the sustainability of lemuru resources, or on the possibility that they may be overfished **(Veldhuizen *et al.*, 2018)**. Innovations in gear design that reduce bycatch and increase the survival rates of non-target species are important factors in purse seine development **(Anders *et al.*, 2019)**. Operations involving purse seine gear in coral reef areas require close monitoring to minimize the risk of damaging lemuru spawning habitats **(Mario Sipahutar *et al.*, 2022)**. Engineering purse seine gear focuses on improving the operational efficiency of these nets. This is critical to balancing economic benefits with ecologically sustainable fishing methods and maintaining the sustainability of lemuru resources responsibly **(Adhawati *et al.*, 2023)**. Thus, integrating technological advances in purse seine gear with sustainable fishing operations can improve the economic and ecological sustainability of fisheries in the Bali Strait.

The length and weight of lemuru can be important indicators when determining sustainable harvest targets, especially when linked to gonadal maturity (GML). Lemuru that are not a certain size or gonadally mature are at high risk of being caught before they can reproduce, which reduces the population's ability to maintain itself. Setting a minimum catch size based on length and weight corresponding to gonadal maturity ensures that most lemuru have reproduced at least once before being caught. This helps maintain stock recruitment, prevents population decline, and supports the long-term sustainability of lemuru resources. Additionally, implementing this size-based policy requires strict monitoring of selective fishing gear, such as using appropriate mesh sizes, to ensure that only fish of a certain size are caught. Therefore, managing lemuru fisheries by taking into account biological aspects of reproduction, such as fish length and weight, can be an effective strategy for maintaining the sustainability of the resource. The findings of this study can serve as a concrete catalyst for sustainable development by integrating resource conservation and economic growth. One such integration is through the establishment of fisheries zoning that separates commercial fishing areas from spawning grounds. This, in turn, minimizes exploitation pressure during the critical phase of the lemuru life cycle. The findings of this study offer significant policy implications, which have the potential to

enhance fisheries management at both the local and national levels. The implementation of these findings could promote fishing practices that are in accordance with the principles of the Ecosystem Approach to Fisheries Management (EAFM).

The migration of lemuru fish in the Bali Strait significantly influences the catch of fishermen using purse seine gear. Lemuru fish are one of the region's main fishery commodities and make seasonal movements influenced by oceanographic factors such as water temperature, ocean currents, and plankton availability. Large-scale migrations, especially in certain seasons, tend to increase purse seine catches because lemuru gather in large groups that are easily reached by these circular nets. Conversely, when the fish migrate to areas or depths that purse seine nets cannot reach, catches can drop dramatically. These migratory patterns also affect fishing strategies, forcing fishermen to adjust the timing and location of their fishing trips based on the movements of the fish. Additionally, environmental changes due to human activities or natural phenomena, such as El Niño, can disrupt lemuru migratory patterns, ultimately impacting the productivity of purse seine fishing. Therefore, understanding the dynamics of lemuru migration is essential to optimizing catches while preserving fish stocks in the Bali Strait.

The utilization of bycatch as a strategy to enhance the economic well-being of the community is of paramount importance in mitigating uncontrolled exploitation, particularly within the context of *Sardinella lemuru* fishing in the Bali Strait. The incorporation of sustainable bycatch utilization strategies into fisheries management has the potential to serve as a multifaceted approach, encompassing both ecological protection and economic opportunities for coastal communities. From an ecological perspective, the implementation of selective fishing gear and time-restricted fishing regulations has the potential to mitigate the disruption to ecosystems and bolster the resilience of fish populations. From a socio-economic perspective, the utilization of bycatch through processing into fishmeal, fermented products, or alternative food sources has the potential to diversify fishermen's income streams and to mitigate their reliance on overexploited target species. This dual approach is consistent with the principles of the blue economy, which prioritize minimizing waste and maximizing resource efficiency.

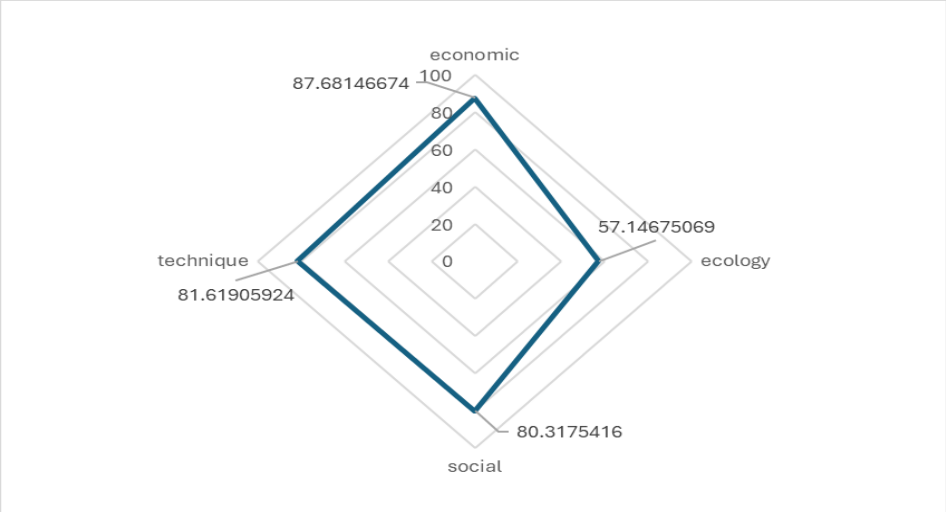

Fig. 6. Multidimensional sustainability of *sardinella lemuru* in Bali Strait

The sustainability of *Sardinella lemuru* (the Bali sardine) in the Bali Strait can be evaluated based on ecological, economic, social, and technological factors, all of which contribute to the species' overall health and viability as a fishery resource. Ecologically, *S. lemuru* plays a significant role in the marine food chain as a primary zooplankton predator, and its population dynamics are closely tied to environmental factors, such as chlorophyll-a concentrations and upwelling events that boost nutrient levels in the Bali Strait **(Puspasari *et al.*, 2019; Suprianto *et al.*, 2021)**. The region's high biodiversity and productivity highlight the importance of effective management practices that consider seasonal variations in fish abundance. These practices ensure that harvest limits align with sustainable yield estimates, preventing overfishing **(Pratama *et al.*, 2024)**. A substantial body of research has identified the necessity for the establishment of substantial guidelines for sustainable fish production and management. This imperative arises as fish stocks confront mounting pressures from exploitation and depletion **(Maiyza *et al.*, 2020; Abdel-Hady *et al.*, 2024)**. For instance, ecological challenges stemming from overfishing necessitate the formulation of effective management strategies that emphasize the maximum sustainable yield (MSY) **(Maiyza *et al.*, 2020; Sarhan, 2021)**. It has been observed that while aquaculture is expanding, there is also a pressing need for improving fishing gear selectivity and regulatory measures to prevent recruitment overfishing, which is crucial for sustaining fish populations **(Warsa & Astuti, 2019; Sarhan, 2021)**.

Table 2. A comparison of multidimensional scaling and the Monte Carlo method made to determine the model's suitability for the sustainable utilization of the *Sardinella lemuru* resource in the Bali Strait

No	Dimention	MDS	Monte Carlo	Reduction	Stress	R square
1	Ecology	87.68147	87.22058	0.460891	0.178662	0.929081
2	Economy	57.14675	56.93451	0.212241	0.138863	0.950869
3	Social	80.31754	80.29008	0.027465	0.189425	0.880902
4	Technique	81.61906	81.5653	0.053761	0.146751	0.933284

CONCLUSION

Multidimensional Scaling (MDS-RAPFish) analysis reveals that the sustainability of *Sardinella lemuru* fisheries in the Bali Strait faces both opportunities and challenges. The ecological, technical, and social dimensions exhibit high sustainability (ranging from 80.318 to 87.681%), while the economic dimension lags at a moderate level (57.146%). This reflects an imbalance between exploitation and long-term viability. Environmental variability influences population availability; however, overfishing remains a critical threat, necessitating urgent management interventions. Enhancing sustainability requires implementing a holistic strategy that includes spatial fishing restrictions (ecological), value-added processing (economic), community-based fisheries governance (social), and optimized fishing effort regulation (technical). Only through integrated, multidimensional policies can the Bali Strait's *Sardinella lemuru* fisheries achieve true sustainability, ensuring ecological resilience and socioeconomic benefits for East Java and Bali.

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