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OPTIMIZING JULUNG-JULUNG (*Hemiramphus* sp.) FISHERY USING SURPLUS PRODUCTION MODELS IN EASTERN SERAM

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ABSTRACT

The julung-julung (Hemiramphus sp.) fishery in eastern Seram waters is an important livelihood resource for coastal communities, yet it is increasingly exposed to high exploitation pressure driven by intensified fishing and coastal habitat degradation. This study assesses the stock status and identifies optimal management strategies using a surplus production modelling approach. Catch (tons) and fishing effort (number of trips) data from 2014–2024 were analyzed using the Schaefer and Fox models. Model comparison showed that the Fox model provided a better fit to the observed data, with an R^2 of 76.0%, compared with 73.3% for the Schaefer model. Based on the Fox model, the estimated maximum sustainable yield (MSY) was 945.7 tons per year, with an optimal fishing effort (Eopt) of 2,365 trips per year. The declining trend in catch per unit effort (CPUE), despite continued increases in fishing effort, indicates reduced fishing efficiency and suggests that the stock is already experiencing overfishing. These results demonstrate that the julung-julung fishery in eastern Seram waters is under overexploitation and requires urgent management intervention. Effort regulation aligned with Eopt, together with ecosystem-based and participatory management approaches, is recommended to support recovery and long-term sustainability. The findings provide evidence-based guidance for strengthening policy development and management of small-scale, data-limited tropical fisheries, particularly those facing similar ecological and socioeconomic pressures.

Keywords: *Hemiramphus sp., MSY, CPUE, Fox model, fisheries management*

INTRODUCTION

Recent ecological investigations have underscored that the degradation of coastal ecosystems—particularly mangrove forests and seagrass meadows—has exerted a measurable and adverse influence on the abundance and spatial distribution of julung-julung (*Hemiramphus* spp.) populations in East Seram. Empirical evidence, derived from interviews with local fishers, indicates a substantial decline in stock abundance ranging between 30% and 50% over the past two decades, primarily attributed to the degradation of critical habitats (Pelasula *et al*. 2023). The julung-julung fishery itself represents a vital economic activity for coastal communities in East Seram Regency, contributing significantly to both livelihoods and local fish supply chains. This species is characterized by its high economic value and steady demand at both local and regional markets. However, the uncontrolled escalation of fishing effort in the absence of adequate regulatory measures threatens not only the sustainability of julung-julung stocks but also the broader integrity of the coastal ecosystem. Similar patterns of overfishing and resource depletion have been widely documented across tropical marine ecosystems, where intensified exploitation has led to notable reductions in commercially important fish populations (Andersen *et al*. 2024; Sumaila & Tai 2020; Tsikliras *et al*. 2023).

The julung-julung (*Hemiramphus* sp.) fishery in East Seram represents a typical small-scale fishery that is vital for providing food, employment, and income to coastal communities (Zeller *et al*. 2021; Hridoy *et al.* 2025). However, this fishery also faces significant management challenges, particularly due to data scarcity and the complexity of its social-ecological dynamics (Martínez-Ortiz *et al*. 2015; Garmestani *et al*. 2023). In such contexts, understanding the stock status through appropriate models is critical for informing sustainable management. Local community involvement can complement scientific assessments, as their traditional ecological knowledge contributes valuable insights for refining science-based policies (Aswani *et al.* 2018; Malfatti *et al*. 2023). Therefore, applying surplus production models alongside community-informed management strategies—such as gear regulations and seasonal closures—offers a promising approach for optimizing the julung-julung fishery and ensuring its sustainability (Alexander *et al.* 2018; Butler *et al*. 2020; Chambon *et al*. 2025).

To support science-based management policies, it is essential to assess the status of fish stocks, particularly using methods suitable for data-limited situations. The surplus production model, developed by Schaefer and Fox, is a quantitative method widely employed to estimate maximum sustainable yield (MSY) and other key parameters such as carrying capacity (K) and intrinsic growth rate (r) (Pedersen & Berg 2016; Barua *et al*. 2023; Kokkalis *et al*. 2024). This model utilizes the relationship between catch and fishing effort data to estimate resource capacity. It has been applied to various species in tropical and subtropical fisheries, although it has limitations concerning assumptions and data accuracy (Santos *et al*. 2018; Zhang *et al*. 2018).

Although surplus production models are widely used to estimate stock status and inform management decisions, they have been criticized for neglecting ecosystem factors and environmental dynamics (Pedersen & Berg 2016; Ito *et al.* 2023; Kokallis *et al.* 2024). Such limitations underline the need to interpret model results cautiously and, where possible, complement them with ecological and spatial considerations. In the context of the julung-julung (*Hemiramphus* sp.) fishery in East Seram, applying the precautionary principle is essential, given the risk that overfishing could not only deplete stocks but also disrupt community structures and trigger trophic cascades (Bundy *et al*. 2016; Serpetti *et al*. 2017; Surma *et al*. 2018). Incorporating the knowledge of local fishers and strengthening the capacity of coastal communities can further support the development of adaptive and context-specific management strategies that align with both the surplus production model outcomes and the ecological realities of the fishery (Malfatti *et al*. 2023; Campbell *et al*. 2024).

The julung-julung (*Hemiramphus* sp.) fishery in East Seram currently operates with limited and fragmented scientific data on catch, fishing effort, and seasonal patterns. This lack of comprehensive information constrains the ability to manage the fishery sustainably and to determine its optimal exploitation level. To address this gap, the study applies surplus production models to available catch and effort data in order to estimate the maximum sustainable yield (MSY) and optimal effort levels. The resulting benchmarks are intended to support evidence-based, locally relevant fishery policies that optimize resource use while balancing ecological sustainability and socioeconomic benefits.

METHODS

Time and location of research

The research was conducted in the waters surrounding Keffing to Garogos Island, located in the East Seram Regency of Maluku Province (Figure 1), situated within the Indonesian Fisheries Management Area (WPP) 715 and 714. This WPP encompasses the waters of the Seram Sea and Banda Sea, which is an important fishing ground for small pelagic species, including julung-julung (*Hemiramphus* sp.).

The research site, specifically, serves as a primary fishing ground for julung-julung (*Hemiramphus* spp.), targeted by local fishermen utilizing giob net (a local name for mini purse seine). The research was conducted from January to March 2025, coinciding with the northeast monsoon season, when fishing activities are optimal due to favorable sea conditions and higher catch rates. This time frame was selected to ensure representative data during the active fishing period.

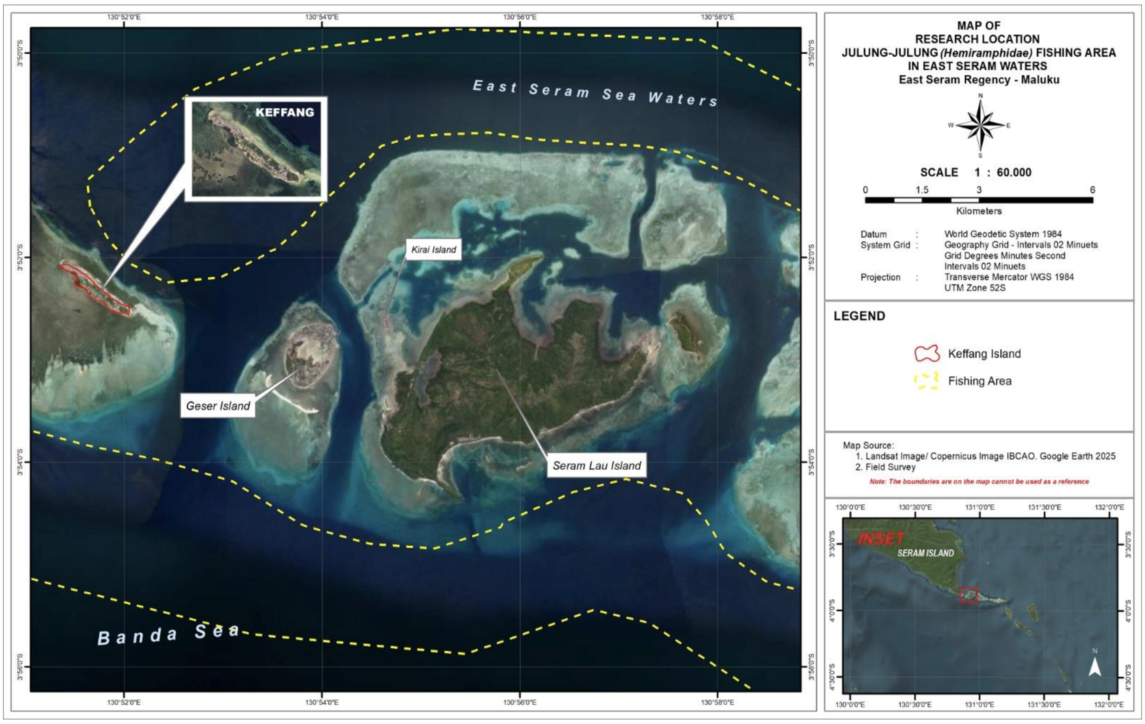

Figure 1 The map of the research location in East Seram, situated within the Indonesian Fisheries Management Area (WPP) 715 and 714.

Type and method of data collection

This study employed a descriptive-quantitative approach using a historical-survey method. Primary data on the annual number of fishing trips, fishing units, and landed catch were collected through a combination of methods to ensure data accuracy and triangulation (Creswell & Plano Clark 2018). Structured and semi-structured interviews with key informants were used to obtain quantitative data on fishing effort (trips and units) and catch records. Focus group discussions (FGDs) with fishers and local stakeholders were conducted to validate the interview data, capture consensus on historical trends, and explore contextual factors influencing the fishery. Field observations were carried out to directly record fishing activities and verify reported practices and numbers. Informal document searches, such as reviewing logbooks and local records, supplemented the primary data and allowed cross-checking of information obtained from respondents. The use of multiple complementary methods was necessary to overcome data gaps, reduce bias, and increase the reliability and validity of the findings (Yin 2018).

The main respondents consisted of 15 owners of local mini purse seine which is also known as giob net. Respondents were purposively selected based on their direct experience and consistent use of the gear during the 2014–2024 period. Additionally, key informants, including fishing group leaders, village heads, and fish collectors, were engaged to enhance the socio-economic and technical perspectives. The selection of informants was based on their involvement in the practice of julung-julung fishing and their strategic roles within the local fishing community.

Data validation was achieved through triangulation among respondents and cross-verification with collectors. Furthermore, secondary data were obtained through informal document searches, which included reviewing personal notes of fishers, informal logbooks, and evidence of fisheries transactions. These documents provided complementary information to validate and cross-check the primary data on fishing effort, catch volumes, and fishing practices. Voice recordings were used only as a supporting tool to document responses during interviews and FGDs, ensuring accurate transcription. Quantitative data were derived from structured responses and validated through triangulation with observations and documents.

Data analysis

Stock assessment was performed utilizing a straightforward surplus production model predicated on catch and fishing effort data. Two models were employed in this study: the Schaefer model (linear-quadratic) and the Fox model (exponential).

The fundamental equations of each model are as follows:

(1) $Y = aE - bE^2$ [Schaefer model]

where Y represents the catch (tons), E denotes the fishing effort (trips), and a, b are the regression parameters to be estimated.

(2) $\ln(Y/E) = a - bE$ [Fox model]

In where ln(Y/E) is the catch per unit effort (CPUE), and a, b are regression parameters.

Both models were utilized to calculate critical biological parameters, specifically:

MSY (Maximum Sustainable Yield):

$MSY = \frac{a^2}{4b}$ (Schaefer model)……..…………(1)

$MSY = E_{opt}.e^{(a-1)}$ (Fox model)……………(2)

Optimal effort:

$E_{opt} = \frac{a}{2b}$ (Schaefer model)...……………….(3)

$E_{opt} = \frac{1}{b}$ (Fox model)................……………(4)

The estimation was conducted using a linear regression approach with Microsoft Excel software. The goodness-of-fit test was conducted to evaluate the model's fit through the coefficient of determination (R^2) value and significance testing of regression parameters. The selection of the optimal model was determined based on the highest R^2 value and the consistency of the biological parameters with the characteristics of julung-julung as a small pelagic species.

RESULTS

Catch and effort trends

Data on fishing units, trips, and julung-julung catch were obtained from secondary sources, including local fisheries office records, fishers' logbooks, and landing site transaction reports. These were complemented by primary qualitative data gathered through interviews, focus group discussions (FGDs), field observations, and informal document reviews to ensure completeness and accuracy. Analysis of those data presented in the Table 1, which reveals a discernible upward trend in both the number of fishing units and the fishing effort from 2014 to 2024. In 2014, the number of fishing units was limited to six, with a total of 1,188 trips. This figure gradually increased, reaching 15 units and 2,850 trips by 2024. Notably, the escalation in fishing effort is particularly pronounced post-2020, with the number of fishing units rising sharply from nine in 2020 to 14 in 2021, accompanied by an increase in effort exceeding 50%. This surge in effort signifies an intensification of julung-julung fishing activities in the Keffing waters of East Seram.

Table 1 Data on fishing units, trips, and julung-julung catch (2014–2024)

Years	Fishing units	Effort (trips)	Catch (ton)
2014	6	1,188	877.5
2015	7	1,386	1,023.75
2016	7	1,379	789.6
2017	7	1,365	776.44
2018	8	1,560	887.36
2019	8	1,520	721.28
2020	9	1,710	811.44
2021	14	2,590	1,171.24
2022	14	2,716	1,133.86
2023	14	2,730	764.4
2024	15	2,850	828

Source: Local Fisheries Office records, fishers' logbooks, and landing site transaction reports (2014–2024).

However, it is important to note that increased effort does not consistently correlate with enhanced catch volumes. For instance, in 2016 and 2017, despite a relatively high effort exceeding 1,365 trips, the catch volumes decreased to 789.6 tons and 776.44 tons, respectively. Similarly, in 2023 and 2024, although the effort reached its peak for the decade at 2,730 and 2,850 trips, the catch volumes declined to 764.4 tons and 828 tons. The highest catch volume was recorded in 2021 at 1,171.24 tons, coinciding with an increase in effort following the pandemic. This pattern suggests a decline in fishing efficiency and potential overexploitation of fish stocks, necessitating an evaluation of effort effectiveness within the framework of fisheries sustainability.

CPUE analysis

The first and second figures illustrate the relationship between fishing effort and CPUE (Catch Per Unit Effort), analyzed using two surplus production model approaches: the Schaefer model (linear) and the Fox model (logarithmic exponential). Both graphs demonstrate a downward trend in CPUE as effort increases, indicating a decline in fishing unit productivity due to high fishing pressure on fish resources.

In the Schaefer model graph, the relationship between effort and CPUE is depicted as a linear regression line with the equation y=-0.1971x+883.06 and a determination value R^2=0.7332. This model assumes that the decrease in CPUE with effort is linear until it reaches zero, reflecting a simple yet widely used approach in initial stock estimation. The negative regression coefficient indicates that each one-unit increase in effort will proportionally reduce CPUE by 0.1971 tons per trip.

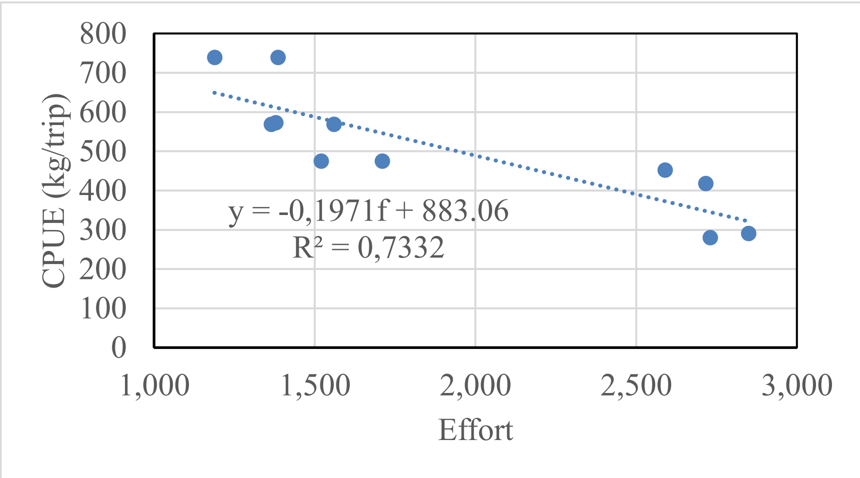

Figure 2 The relationship between effort and CPUE (Catch Per Unit Effort) Schaefer model

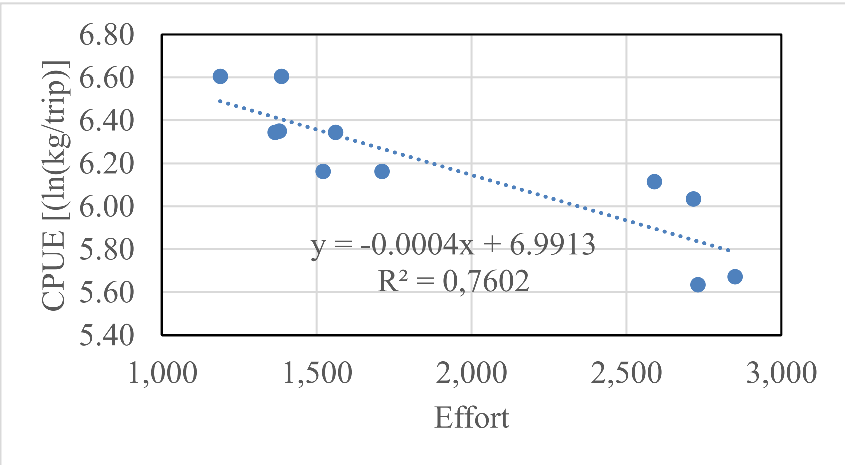

Figure 3 The relationship between effort and CPUE (Catch Per Unit Effort) Fox model

In contrast, the graphs of the Fox model employ a logarithmic transformation and suggest that the decline in CPUE follows an exponential pattern. Although the equation used appears similar, Fox's approach is more suitable if the decline in CPUE is not constant but rather decreases sharply at low effort and then levels off at high effort. Based on the curve's shape and the fit to the data, the Fox model offers a more conservative and realistic approach for a resource that has been intensively exploited. Therefore, in the context of sustainability, the Fox model is more recommended for describing the stock dynamics of julung-julung in Keffing waters.

Surplus production model estimates

Utilizing the results derived from the surplus production model analysis, both the Schaefer and Fox methodologies were employed to estimate the biological parameters of the fishery and ascertain the maximum sustainable yield (MSY) (Table 2). The Schaefer model yielded an MSY of 1,060.1 tons, with an optimal effort (Eopt) of 2,328 trips and a maximum buffer capacity (K) of 4,656. Conversely, the Fox model indicated an MSY of 975.5 tons, with Eopt at 2,401 trips. Notably, the Fox model does not explicitly calculate K, as its logarithmic function form does not provide a maximum effort value akin to the Schaefer model.

In selecting the most suitable model, the criteria generally include the coefficient of determination (R^2) value, alongside the biological and realistic alignment with the analyzed fishery conditions. The results revealed that the Schaefer model had an R^2 of 73.3%, whereas the Fox model exhibited an R^2 of 76.0%, indicating that the Fox model offered a superior fit to the CPUE and effort data. Consequently, the Fox model was deemed the more appropriate model to describe the dynamics of the julung-julung resource in the study area, as it not only provides a conservative estimate of MSY but also demonstrates a higher statistical fit.

Table 2 Analysis result of Schaefer and Fox model

Model	Schaefer	Fox
a	883.06	6.99
b	-0.197	-0.0004
r^2	73.3%	76.0%
K	4,482.5	-
f_{MSY}	2,241 trips	2,365 trips
Y_{MSY}	989.3 ton	945.7 ton

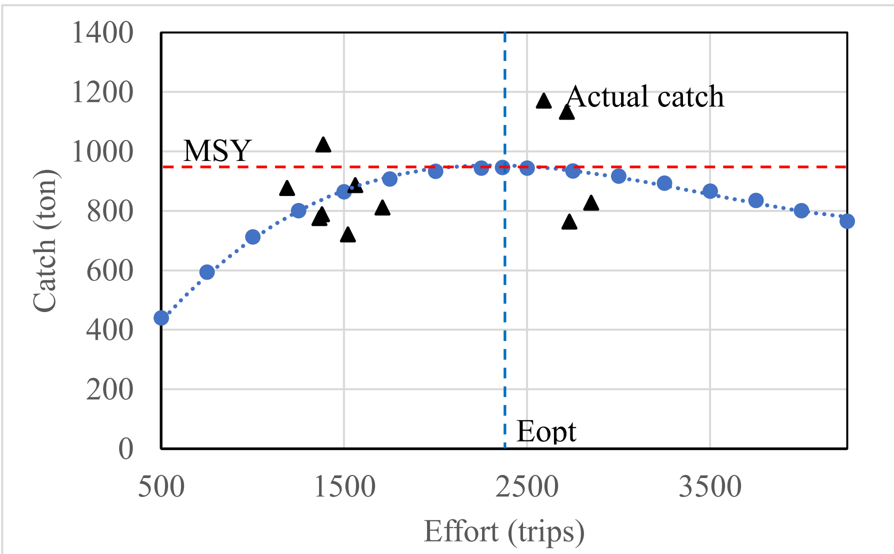

Figure 4 Catch and effort relationship of fox model

The Figure 4 illustrates the relationship between catch and effort as modeled by the Fox surplus production model. The blue curve demonstrates an exponential increase to a peak, followed by a decline as effort intensifies, consistent with the Fox model's characteristics. The apex of this curve signifies the Maximum Sustainable Yield (MSY), representing the highest catch that can be sustainably achieved, which in this analysis occurs at approximately 2,365 trips, as indicated by the dashed blue vertical line.

The triangles on the graph denote actual catch data derived from field observations. The majority of these data points lie below or near the curve, suggesting a reasonable fit with the model's predictions. However, beyond the optimal effort level (Eopt), the catch exhibits a declining trend, indicative of overfishing as effort continues to rise. This underscores the Fox model's significance as a foundation for management strategies, emphasizing the necessity of restricting effort to not surpass the Eopt threshold to sustainably preserve fish stocks.

DISCUSSION

Interpretation of model results

The analysis utilizing the Fox surplus production model revealed that the Maximum Sustainable Yield (MSY) for julung-julung in Eastern Seram waters is 945.7 tons, with an optimal effort (Eopt) of approximately 2,365 trips. When juxtaposed with recent actual effort values, which have approached or surpassed the Eopt, it can be inferred that the julung-julung fishery may have reached the threshold of sustainable exploitation or may even be experiencing overexploitation. This observation aligns with Edgar *et al*. (2018), who noted that numerous global fisheries fail to maintain catches below biologically safe thresholds due to inadequate regulation and high utilization pressure. Tu *et al*. (2018) further emphasized that a reduction in the average size of individuals caught serves as an indicator of exploitation pressure, a phenomenon also observed in a local study on Eastern Seram waters, where the size of fish caught has diminished over time.

Despite its structural limitations, such as not accounting for age or size structure, the surplus production model remains a valid approach for medium-data stocks like this one (Kokkalis *et al*. 2024). Froese *et al*. (2017) also confirmed that models such as Fox and Schaefer are effective in providing biological reference estimates when comprehensive biomass or size data are unavailable. Moreover, the results indicating that fishing effort is nearing the maximum recommended level suggest that careful management of the widow rockfish fishery is warranted.

Drivdal & Van Der Sluijs (2021) proposed that in situations of uncertainty, precautionary measures such as effort limitation or the establishment of conservation areas should be considered to prevent further damage to the stock. Ben-Hasan *et al*. (2021) highlighted that exploitation exceeding the regenerative capacity of fish can lead to double overfishing (growth and recruitment overfishing), resulting in a long-term decline in biomass and population productivity. Therefore, adaptive management through effort reduction, monitoring of the spawning season, and the application of selective fishing gear is necessary. A local study by Rumakat *et al.* (2024) reported that the region’s management status is “moderate,” emphasizing the need for improved gear regulation, fisher education, and habitat protection. This contextual information reinforces the relevance of optimizing the julung-julung fishery in accordance with ecosystem-based management (EBM) principles, even though this study did not collect or analyze primary EAFM data.

Implications for fisheries management

The findings from various studies underscore the significance of implementing effort restrictions and adaptive management strategies to ensure the long-term sustainability of fisheries, including the julung-julung fishery in Eastern Seram waters. Effort restrictions, such as limiting fishing mortality and employing spatial management measures like marine protected areas (MPAs), have proven effective in enhancing the productivity and profitability of spatially heterogeneous multispecies fisheries (Costello 2024). When these measures are combined with other management tools, such as catch limits and limited entry, they have been particularly successful in maintaining or increasing fish abundance and biomass (Selig *et al*. 2016).

Adaptive management strategies are vital for addressing the challenges posed by climate change and other environmental stressors. Climate-ready fisheries necessitate the integration of climate factors into stock assessments and increased flexibility in decision-making (Lomonico *et al*. 2020). Simulations of mass mortality events in fish populations have demonstrated that adaptive approaches, such as temporary reductions in fishing mortality, can mitigate economic impacts and ensure sustainable resource use (Buttay *et al*. 2023).

In conclusion, the studies suggest that a combination of effort restrictions and adaptive management strategies is essential for the long-term sustainability of fisheries. Key elements for successful implementation include strong local leadership, high community involvement, and governance capacity (Selig *et al*. 2016). Additionally, the use of spatially-explicit multi-species bio-economic modeling approaches, such as SMART, can aid in evaluating the potential benefits of different management scenarios and support decision-making processes (Russo *et al*. 2019).

Limitations of the study

Surplus production models (SPMs) have a number of limitations that can affect their precision and applicability in the management of fisheries resources, including the julung-julung (Hemiramphus spp.) fishery. SPMs tend to simplify complex ecosystem dynamics by assuming fish populations as a single homogeneous stock, without accounting for age structure, spatial distribution or interspecies interactions (Kokkalis *et al*. 2024). This simplification has the potential to result in inaccurate predictions, especially in tropical coastal ecosystems such as Keffing Island that are characterized by high food web complexity and spatial dynamics. In addition, SPM's reliance on historical catch data is problematic, especially if these data are incomplete or contain recording errors due to changes in fishing techniques, inconsistent reporting, or lack of science-based monitoring (Kokkalis *et al*. 2024). This can lead to biases in the estimation of important biological parameters such as MSY, r, and K.

The estimated MSY and optimal effort levels for the julung-julung fishery were derived using surplus production models (SPMs). While SPMs are often criticized for their simplicity and inability to capture environmental variability or long-term regime shifts (Wu *et al*. 2021; Kotzur *et al.* 2021), they remain relevant for data-limited or data-moderate fisheries (Pedersen & Berg 2016), such as in this study. These findings offer a baseline for science-based management, but future assessments should integrate ecosystem considerations, account for potential non-stationarity in productivity, and adopt more robust estimation approaches with diagnostic evaluations (Craig & Link 2023; Kokkalis *et al*. 2024).

Recommendations for future research

Future research in fisheries management, including in the julung-julung (Hemiramphus spp.) fishery, needs to be directed towards the integration of ecosystem-based approaches and the incorporation of environmental variables to improve resource sustainability and resilience (Liu *et al*. 2015; Loos *et al*. 2022; Jiang and Ding 2025). A key agenda is to strengthen the implementation of Ecosystem-Based Fisheries Management (EBFM) through the development of ecosystem science, modeling and analysis capable of representing the relationships between ecological components and their responses to climate change, habitat degradation and socio-economic dynamics (Townsend *et al*. 2019). In this context, there is a need to further explore how the integration of ecosystem models can be operationalized within existing fisheries management frameworks, including procedural challenges between management jurisdictions.

The strengthening of interdisciplinary approaches is also an urgent need in the management of medium-data stocks such as the Keffing sculpin. Research teams that incorporate spatial-temporal, ecosystem and socioeconomic dimensions are needed to respond to contemporary challenges such as climate change and data limitations (Goethel *et al*. 2022). Future studies should focus on improving data collection protocols, including the development of standards for sharing confidential data among stakeholders, to promote research progress and more robust information-based management.

Furthermore, the incorporation of local knowledge from fishers and fishing industry actors into marine science and decision-making processes is a promising research direction (Baker *et al*. 2023). Future research efforts should develop effective methods to integrate data, perspectives and experiences of fisheries businesses into fisheries science systems. Such collaborative approaches are believed to enrich understanding of fisheries and ecosystem dynamics, improve the validity of managerial decisions and strengthen the legitimacy of management policies.

Thus, future research priorities should be directed towards developing integrated approaches that incorporate ecosystem services, stakeholder participation and adaptive management strategies. This includes the application of Management Strategy Evaluation (MSE) as a unifying element to bridge fisheries modeling disciplines, support scenario-based decision-making, and ensure inclusion of multiple interest groups (Goethel *et al*. 2022). Through such a research approach, fisheries management is expected to transform in a more proactive, transparent and adaptive manner in the face of ecological and social uncertainty.

CONCLUSIONS

This study reveals that the julung-julung (Hemiramphus spp.) fishery in the waters of Keffing Island, East Seram, is approaching or may have already exceeded sustainable exploitation thresholds. Using a surplus production modeling approach, particularly the Fox model, the estimated Maximum Sustainable Yield (MSY) was 945.7 tons, with an optimal fishing effort (Eopt) of 2,365 trips per year. The Fox model demonstrated a better fit (R^2 = 76.0%) compared to the Schaefer model. The observed increase in fishing effort without a corresponding rise in catch volume indicates a decline in fishing efficiency and signals potential overfishing. These findings highlight the urgency of implementing evidence-based fisheries management strategies to sustain small-scale coastal fishery resources.

SUGGESTION

Based on the findings, it is recommended to control fishing effort below the Eopt threshold through science-based, locally tailored trip limits, adopt adaptive ecosystem-based management (EAFM) that accounts for socio-ecological and environmental dynamics, integrate fishers' ecological knowledge to strengthen governance, and conduct regular monitoring of CPUE, catch, and ecological conditions to guide sustainable use.

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