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Bioeconomic Analysis of Blue Swimming Crab (*Portunus pelagicus*) Fishery Landed at PPN Karangantu, Banten, Indonesia

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ABSTRACT
The blue swimming crab (*Portunus pelagicus*) holds significant commercial value. This study aimed to assess the population characteristics of the species in Banten Bay using five surplus production models: Gordon Schaefer, Fox, Walter Hilborn, Schnute, and Clarke Yoshimoto Pooley (CYP). Among these, the CYP model demonstrated the highest coefficient of determination (R^2), reaching 96.52%. Based on this model, the maximum sustainable yield (MSY) was estimated at 79,743.483 kg/year, with a corresponding fishing effort (Fmsy) of 3,670 trips/year. The bioeconomic analysis revealed that the actual fishing effort exceeded both Fmsy and Fmey, indicating that the crab population is fully exploited and economically overfished. Moreover, fishing effort in Banten Bay has continued to rise annually, with a notable increase in 2022 and 2023, surpassing the threshold established under the MSY regime. To ensure sustainable management, this study recommends optimizing resource utilization under the maximum economic yield (MEY) regime. This approach would reduce fishing effort and operational costs while maximizing economic returns compared to MSY and open-access scenarios. Specifically, fishing effort should be restricted to 79,698.565 trips per year to regulate the annual increase in exploitation and safeguard the long-term sustainability of *P. pelagicus* in Banten Bay.

INTRODUCTION

Banten Bay is a principal hub for *rajungan* (Portunus pelagicus) production in Indonesia and reflects a fishing culture that incorporates local wisdom in the sustainable use of marine resources **(Daris *et al.*, 2022)**. However, these traditional practices face considerable challenges in adapting to global market dynamics and increasingly stringent fisheries regulations **(Laksono *et al.*, 2023; Setyaningrum *et al.*, 2025)**. Small-scale crab fisheries must balance ecosystem sustainability with the economic needs of fishing households while simultaneously adjusting to policy shifts and market fluctuations **(Qomariyah *et al*., 2023; Masyhadi *et al*., 2024; Maulana *et al*., 2024; Setioko *et al*., 2024)**. Examining the interactions between global economic pressures, local ecological conditions, and fishermen's adaptive strategies is therefore critical for shaping effective and sustainable fisheries governance **(Madduppa *et al*., 2021)**.

A key component of crab fisheries management is a comprehensive understanding of population dynamics, as high fishing intensity can reduce wild stock abundance **(Susanto *et al*., 2019; Shafeeq *et al*., 2024)**. Research on recruitment, growth, mortality, and environmental influences provides the scientific foundation for assessing the sustainability of crab resource utilization **(Tirtadanu & Chodrijah, 2019; Wagiyo *et al*., 2019; Arofah *et al*., 2024)**. Growth data, in particular, is essential for determining the minimum catch size and estimating the time required for crabs to reach harvestable size **(Sanchirico *et al*., 2016; Gebremedhin *et al*., 2021; Yeşilyurt *et al*., 2022; Ervinia *et al*., 2023)**.

This study aims to evaluate the exploitation status of *rajungan* in Banten Bay and apply bioeconomic modeling to analyze both the biological and economic aspects of crab fishing, with an emphasis on sustainability. Specimens for analysis were obtained from fishermen's catches and landed at the Nusantara Fishing Port, Karangantu, Serang Regency, Banten Province.

Five bioeconomic models will be employed to assess the sustainability of crab fishing by examining fishing effort and catch production data from local fishermen. Regression analysis will be used to identify the model that best determines the optimal fishing levels needed to ensure both stock sustainability and economic profitability. A comparative analysis will then be conducted between current conditions and the model outcomes to formulate strategies for optimizing the exploitation of *rajungan* resources in Banten Bay.

The findings of this research are expected to provide a comprehensive understanding of the current exploitation status, the degree of resource utilization, and appropriate strategies for managing crab fisheries. Ultimately, this work will contribute to the development of sustainable exploitation frameworks for *rajungan* in Banten Bay.

MATERIALS AND METHODS

1. Location and time of research

This study was conducted at the Nusantara Fishing Port, Karangantu, in Serang Regency, Banten Province, focusing on blue swimming crabs (*Portunus pelagicus*) landed from the waters of Banten Bay and the northern area around Panjang Island. Data collection was carried out over a six-month period, from September 2024 to February 2025.

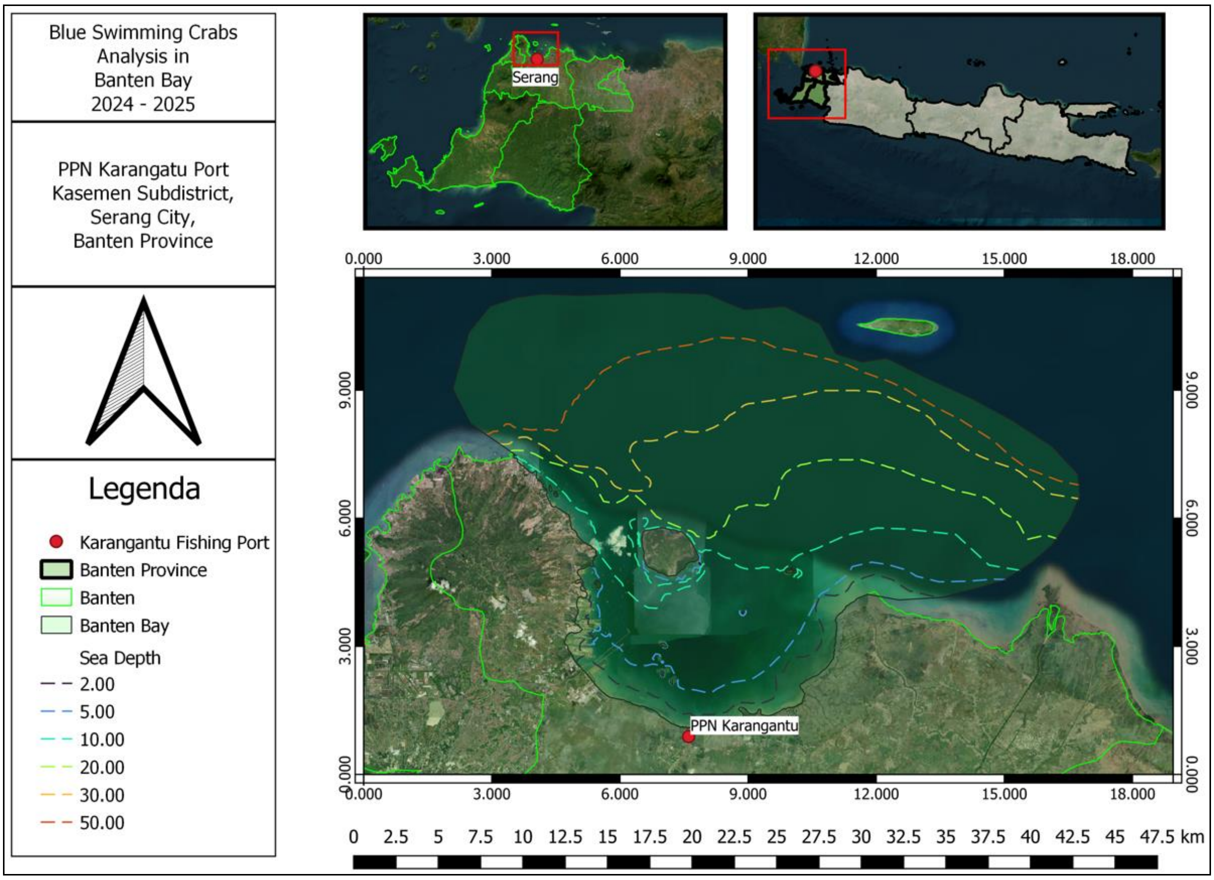

Fig. 1. Research location at Karangantu Fishing Port, Banten

2. Resources and implements

The primary subject of this study was the blue swimming crab (*Portunus pelagicus*) harvested by local fishermen. The resources and implements used in the research included writing instruments for data recording, questionnaires to obtain information from fishermen, a map of the Karangantu region to identify fishing grounds, and documentation equipment such as cameras and recorders to support field observations and data validation.

3. Categories of data sources

This study utilized secondary data obtained from the Nusantara Fishing Port (PPN) Karangantu, Serang, Banten Province. The dataset comprised time-series records of fishing effort, catch volume, and market prices of *rajungan* spanning the years 2017 to 2024. For analytical consistency and reliability, only data from 2017 to 2023 were employed, providing a robust basis for assessing long-term trends in fishing activities, production levels, and economic dynamics within the study area.

4. Methods of data collection

A time-series approach was employed to collect *rajungan* fishery data, relying on secondary sources from the official records of PPN Karangantu, which is responsible for fisheries statistics documentation. Data were systematically compiled over a seven-year period (2017–2023) at regular annual intervals to ensure continuity and reproducibility in temporal analysis.

The primary variables collected included: (1) crab production data, quantified in tons, representing actual catch; (2) fishing effort data, expressed in standardized units, reflecting the intensity of fishing activities; and (3) the percentage of maximum sustainable yield (MSY), indicating the extent of crab resource utilization relative to sustainable capacity.

Data collection was conducted through archival searches and review of official documentation, with stratification based on fishing gear types. Two main types of gear were recorded: gillnets (69 units) and traps (33 units). The compiled data were subsequently arranged into a chronological time-series format to facilitate the analysis of trends, seasonal fluctuations, and production variations during the study period. The time-series methodology was chosen for its ability to provide a comprehensive overview of the temporal dynamics of crab fisheries.

5. Data analysis

Standardization of fishing equipment

Fishing gear standardization was carried out using catch per unit effort (CPUE) as the benchmark. The type of gear with the highest average CPUE was designated as the standard fishing gear and assigned a fishing power index (FPI) value of 1. Other fishing gear types were standardized into equivalent fishing gear units by calculating the ratio of their CPUE values relative to that of the standard gear. This standardization process ensured that fishing effort from different gear types could be objectively compared, thereby providing a uniform basis for evaluating fishing productivity.

$$FPI = \frac{CPUE_i}{CPUE_{standard}} \quad \text{.........(i)}$$

Keterangan:

FPI : *Fishing Power Index*

$CPUE_{standard}$: *Catch Per Unit Effort* standard

$CPUE_i$: *Catch Per Unit Effort* alat tangkap *i*

Model of production surplus

The analytical approach used to assess fish stock dynamics in Banten Bay was a bioeconomic method based on surplus production models. The concept of production surplus is fundamental in fisheries science, where population growth is driven by the annual recruitment of new individuals, while reductions are caused by natural mortality and fishing exploitation **(Mohsin *et al*., 2020; Parent *et al*., 2024)**. In this framework, the surplus production model represents fish population dynamics as the difference between natural production and total mortality, expressed mathematically as:

$$Fish\ popuation_{t+1} = Fish\ population_t + Produktion - Mortality \quad \text{.........(ii)}$$

This approach necessitates harvest and effort data, which are two categories of information typically gathered and disseminated in fisheries statistics. In this model, if production surpasses natural mortality, the population will grow; conversely, if death surpasses production, the population would diminish. This study employs a logistic model formulated by **Gordon (1954)**, **Fox Jr. (1970)**, **Schnute (1977)**, **Clarke *et al.* (1992)** and **Hilborn and Walters (1992)** to estimate three biological parameters, specifically:

r : The growth rate of fish stocks in optimal conditions

K : Environmental carrying capacity

q : Fishing gear coefficient

The logistic model is subsequently formulated as follows:

$$\frac{dx}{dt} = rx\left(1 - \frac{x}{K}\right) \quad \text{....(iii)}$$

When fisherman endeavors to capture fish, the catch may be documented as follows:

$$h = qxE \quad \text{.....(iv)}$$

In the long-term equilibrium:

$$\frac{x}{K} = \frac{qE}{r} \quad \text{........(v)}$$

$$h = qE\left(1 - \frac{qE}{r}\right) \quad \text{....(vi)}$$

The bioeconomic framework applied in this study was derived from surplus production models commonly used in fisheries assessments, specifically the Schaefer, Fox, Walter-Hilborn, Schnute, and Clarke-Yoshimoto-Pooley (CYP) models. The Gordon-Schaefer (GS) and Fox models employ simple linear regression analysis, relying on only two variables in their evaluation. In contrast, modified versions of the GS model—such as the Schnute, Walter-Hilborn, and CYP models—utilize multiple linear regression techniques to provide a more comprehensive estimation **(Kristiana *et al*., 2021)**.

Among these, the Schnute model was chosen as the primary approach for predicting the Maximum Sustainable Yield (MSY), or the maximum level of fishing production that can be sustained without depleting the stock. Implementation of the surplus production models relied on annual time-series data of catch and fishing effort for blue swimming crab (*Portunus pelagicus*) in Banten Bay. Through this modeling approach, sustainable catch levels were estimated to ensure resource utilization without compromising the resilience of the wild population.

The bioeconomic model is based on surplus production, represented by the following formula:

Fish growth (X) during period t:

$$F(X) = Xt + 1 - Xt \quad \text{.....(vii)}$$

$$= \frac{dX}{dt}$$

$$= r.X$$

r represents the Intrinsic Growth Rate, whereas x denotes the biomass or fish population.

The natural growth of fish can be calculated using logistic growth, as follows:

$$\frac{dy}{dx} = r.X.(K - X)$$

$$\frac{Dy}{dx} = r.X.\left(1 - \frac{X}{K}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ldots \text{(viii)}$$

Description:
r = Intrinsic Growth Rate
X = Populasi
K = Carrying Capacity

Fishing operations in the form of fish exploitation can also be computed using the following formula:

$$h = f(X.E)$$

$$h = q.X.E\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\text{(ix)}$$

Description:
Q = *Catch*ability Coefficient
E = *Effort*

The growth function is as follows:

$$\frac{Dy}{dx} = r.X.\left(\frac{K}{X}\right) - h$$

$$\frac{Dy}{dx} = r.X.\left(\frac{K}{X}\right) - q.X.E$$

In equilibrium $\frac{dx}{dt} = 0$

$$r.X. = \left(1 - \frac{K}{X}\right) - q.X.E = 0\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(x)}$$

This function depicts the link between catch (C) and fishing effort (E). When E is at MSY:

$$\frac{dh}{dE} = \alpha - 2\beta = 0$$

$$EMSY = \frac{\alpha}{2\beta}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(xi)}$$

The value of h when MSY conditions apply:

$$h = \alpha.EMSY - \beta.EMSY^2$$

$$h = \left(\frac{\alpha}{2\beta}\right) - \left(\frac{\alpha}{2\beta}\right)^2$$

$$h = \frac{\alpha^2}{2\beta} - \frac{\alpha^2}{4\beta}$$

$h = \frac{2\alpha^2}{4\beta} - \frac{\alpha^2}{4\beta}$

$hMSY = \frac{\alpha^2}{4\beta}$………………………………………………………………………………………….(xii)

MEY calculations incorporate the fish price element and fishing costs. The equation delineating the link between catch and fishing effort, articulated in terms of price, is as follows:

$C_{R =} Price\ (\alpha E - \beta E^2)$…………………………………………………………………………(xiii)

Description:

$C_{R =}$ Income dependent on catch

$\alpha = q.K$

$\beta = q2.K/r$

To determine accumulated expenditures, the capture effort can be multiplied by the expense incurred for a single trip's catch. The formula for estimating fish growth is as follows:

$F(X_r)Price.r.X.(1 - \frac{K}{X})$

Xr represents the revenue derived from fish growth.

The subsequent formula calculates the effort value in relation to the income generated from fishing, as well as the overall incurred costs:

$E = (K - X).\frac{r}{q.K}$

$TC_X = c.(K - X).\frac{r}{q.K}$…………………………………………………………………………...(xiv)

Description:

TC_X = Total accumulated costs from fishing activities

c = Costs incurred depending on effort for each fishing trip

To determine the effort value inside the MEY framework, the equation presented in the aforementioned formula may be utilized:

$NR_E = price.(\alpha E - \beta E^2)$

$\frac{\alpha NR_E}{\alpha E} = price.(\alpha - 2\beta E) - c$

If:

$\frac{\alpha NR_E}{\alpha E} = 0$

$price.(\alpha - 2\beta E) = c$

$E_{MEY} = \frac{(price.\alpha) - c}{2.price.\beta}$……………………………………………………………………………(xv)

Descriptions:

NR_E = Maximum Profit/MEY

E_{MEY} = effort required to achieve maximum profit.

To ascertain the value of hMEY, the total catch equation is employed and the effort value is replaced with the effort corresponding to maximum profit:

$h_{MEY} = \alpha E_{MEY} - \beta.(E_{MEY})^2$ ....(xvi)

To ascertain the effort value in the OA regime, the subsequent formula may be employed:

$E_{OA=} \frac{\alpha.price-c}{\beta.price}$

The production formula inside the OA regime may also utilize the total catch equation.

$h_{OA} = \alpha.E_{OA} - \beta.(E_{OA})^2$ ....(xvii)

This study employed various models to determine the biological parameters r, K, and q, including:

Gordon-Schaefer = CPUE = α + βE...(xviii)

Fox = *ln*(CPUE) = α + βE..(xix)

Where:

α = q . K

$\beta = \left(\frac{q^2.K}{r}\right)$

q = *catchability coefficient*

r = *intrinsic growth rate*

K = *Carrying Capacity*

Schnute = $ln\,ln\left(\frac{U_{t+1}}{U_t}\right) - 1 = a - b\left(\frac{U_t+U_{t+1}}{2}\right) - \gamma\left(\frac{E_t+E_{t+1}}{2}\right)$.............................(xx)

Walter-Hilborn = $\frac{U_{t+1}}{U_t} - 1 = a - \beta\, U_t - \gamma E_t$...(xxi)

Where:

α = r

$\beta = \frac{r}{qk}$

γ = q

CYP = $ln\,ln\,U_{t+1} = a\,Ln(qk) + \beta\,Ln(U_t) - \gamma\,(E_t + E_{t+1})$.............................(xxii)

Where:

$\alpha = \frac{2r}{(2+r)}$

$\beta = \frac{(2-r)}{(2+r)}$

$$\gamma = \frac{q}{(2+r)}$$

RESULTS

In this study, gillnets were utilized as the standard fishing apparatus with a fishing power index of 1 **(Sanders & Morgan, 1976)**, succeeded by traps with a fishing power index of 0.87849408 (Table 1).

Table 1. Standardization of fishing gear

Fishing gear	FPI
Gill net	1
Bubu	0,87849408

Equations for determining production value, effort, and economic rent within MSY, MEY, and OA frameworks are illustrated in Table (2).

Table 2. Formulations for H, E, and π across each management regime in the WH, Schnute, and CYP models

Variable	Management regime		
	MSY	MEY	OA
Biomass (X)	$\frac{K}{2}$	$H_{MEY} - q(E_{MEY})^2$	$H_{OA} - q(E_{OA})^2$
Catch (h)	$\frac{r \times K}{4}$	$\left(\frac{(r \times K)}{4}\right) \times \left(1 + \left(\frac{Cost}{-q \times \frac{K}{Price}}\right)\right) \times \left(\left(1 - \left(\frac{Cost}{-q \times \frac{K}{Price}}\right)\right)\right)$	$\left(\frac{r \times Cost}{-q \times Price\ K}\right) \times \left(1 - \left(\frac{Cost}{-q \times \frac{K}{Price}}\right)\right)$
Effort (E)	$\frac{r}{(2 \times -q)}$	$\left(\left(\frac{r}{2 \times -q}\right)\right) \times \left(1 - \left(\frac{Cost}{-q \times \frac{K}{Price}}\right)\right)$	$\left(\left(\frac{r}{-q}\right)\right) \times \left(1 - \left(\frac{Cost}{-q \times \frac{K}{Price}}\right)\right)$
Rente (π)	$(p\ x\ H_{MSY}) - (c\ x\ C_{MSY})$	$(p\ x\ H_{MEY}) - (c\ x\ C_{MEY})$	$(p\ x\ H_{OA}) - (c\ x\ C_{OA})$

Table (2) presents three fisheries management regimes derived from the bioeconomic models of Walter-Hilborn, Schnute, and Clarke-Yoshimoto-Pooley (CYP), which incorporate catch (H), fishing effort (E), and economic rent (π) as key variables within different analytical frameworks. The maximum sustainable yield (MSY) regime seeks to achieve the highest sustainable catch without compromising crab populations. In this model, the optimal catch level is expressed as $a^2/4b$, with fishing effort defined as $a/2b$, where parameter *a* represents the intrinsic growth potential and *b* reflects the environmental carrying capacity. The MSY approach emphasizes biological sustainability, with economic rent defined as the difference between total revenue and fishing costs; however, it does not fully maximize economic outcomes **(Harlyan *et al*., 2021; Jurado-Molina *et al*., 2021; Negrei & Ladaru, 2023)**. The formulation of effort and catch within this framework follows the Gordon-Schaefer model, where sustainable yield is optimized at a biomass equivalent to 50% of carrying capacity **(Seijo *et al*., 1998; Lleonart & Merino, 2010)**.

In contrast, the maximum economic yield (MEY) regime applies the effort formulation (p·a − c) / 2·p·b, where *p* denotes price and *c* represents cost. This model produces a higher optimal biomass (BMEY > BMSY) at a sustainable exploitation level, thereby maximizing economic returns **(Belharet *et al*., 2020)**.

Open-access (OA) conditions, described by the equation (p·a − c) / p·b, often lead to overfishing and drive economic rent toward zero due to excessive competition. Such conditions exemplify the "tragedy of the commons," placing long-term crab stock sustainability at risk.

The structural differences among these three regimes demonstrate how management strategies strongly influence both sustainability and profitability. Research further shows that MEY can yield profits up to 10.7 times higher than current levels, making it a preferred benchmark among economists for its ability to maximize profits while minimizing overexploitation risks **(Pan, 2021)**.

Table (3) presents the formulas used for calculating production, effort, economic rent, and biomass under these management regimes.

Table 3. Formulations for H, E, and π corresponding to each management regime in the GS model, Fox

Variable	Management regime		
	MSY	MEY	OA
Catch (H)	$\frac{a^2}{4b}$	$aE_{MEY} - b(E_{MEY})^2$	$aE_{OA} - b(E_{OA})^2$
Effort (E)	$\frac{a}{2b}$	$(p.a - c)/2.p.b$	$(p.a - c)/p.b$
Rente (π)	$(p\ x\ H_{MSY}) - (c\ x\ E_{MSY})$	$(p\ x\ H_{MEY}) - (c\ x\ E_{MEY})$	$(p\ x\ H_{OA}) - (c\ x\ E_{OA})$

Table (3), which presents the Gordon-Schaefer and Fox models, integrates both biological and economic dimensions across three fisheries management regimes, illustrating the progression of biomass (X), catch (H), fishing effort (E), and economic rent (π) under each scenario. This model builds upon **Gordon**'s **(1954)** pioneering framework, which combined biological and economic variables to represent the exploitation of renewable resources. Schaefer subsequently refined this framework three years later by incorporating biological dynamics, allowing the analysis of different equilibrium conditions, including maximum sustainable yield (MSY), maximum economic yield (MEY), and open-access (OA) equilibrium **(Parent *et al*., 2024)**.

The inclusion of economic variables such as costs and pricing within the MEY and OA regimes demonstrates the enduring relevance of surplus production models in fisheries management. Their simplicity and relatively modest data requirements make them especially useful for practical applications. The Fox model, which assumes a Gompertz relationship between population growth rate and biomass, often provides more precise estimates than alternative approaches **(Su & Liu, 1998; Nurdin *et al*., 2020)**.

1. Criteria for assessing bioeconomic models

Selecting an appropriate bioeconomic model is essential for achieving sustainable fisheries resource management. This study evaluated several traditional models to determine the most suitable approach for the characteristics of the available data and the specific conditions of the fishery under study. The models assessed include Gordon-Schaefer, Fox, Walter-Hilborn, Schnute, and Clarke-Yoshimoto-Pooley, each of which applies different assumptions and mathematical formulations to describe fish population dynamics and their associated economic dimensions **(Pinnegar *et al*., 2021; Singh & Weninger, 2023)**.

Regression analyses of these models were conducted using Microsoft Excel. The primary criterion for evaluating model performance was the coefficient of determination (R^2), which measures the proportion of variation in the dependent variable explained by the model. A higher R^2 value indicates a stronger explanatory power and better fit between the model and empirical data. Thus, comparing R^2 values across models allows researchers to identify the model with the greatest predictive accuracy and the closest alignment with observed fishery conditions **(Dutta *et al*., 2025)**.

A comparative analysis of the five models provides a robust scientific foundation for determining the most effective bioeconomic approach, which can inform efficient and sustainable fisheries resource management strategies. In each model, the values of R^2 vary, and specific criteria are applied to assign the symbols corresponding to these values in order to facilitate interpretation.

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Table 4. Outcomes of the coefficient of determination analysis for each model

Model	R^2
Gordon Schaefer	52.28%
Fox	63.92%
Walter Hilborn	64.96%
Schnute	23.58%
Clarke Yoshimoto Pooley	96.52%

The analysis of the coefficient of determination (R^2) in the bioeconomic management of the blue swimming crab (*Portunus pelagicus*) reveals notable variability in the predictive capacity of bioeconomic parameters across the three management regimes: Maximum sustainable yield (MSY), maximum economic yield (MEY), and open access (OA). The R^2 value indicates the extent to which a model accounts for data variability. As shown in Table (4), the Clarke-Yoshimoto-Pooley (CYP) model achieved the highest R^2 value among the models assessed.

The CYP model demonstrated superior performance with an R^2 value of 96.52%, capturing nearly all variability in the empirical data with exceptional precision. This model provides a realistic framework for estimating the maximum sustainable yield (MSY), allowable biological catch (ABC), and the associated fishing effort, while also incorporating bioeconomic variables to determine the maximum economic yield (MEY) **(Mamdouh-Lotfy *et al*., 2025)**. Its dual capability—addressing both biological sustainability and economic optimization—makes the CYP model particularly effective for generating management recommendations. Moreover, its high predictive accuracy underscores its reliability in forecasting the bioeconomic conditions of blue crab fisheries under different management scenarios in Banten Bay.

Evaluating the effectiveness of fisheries resource management requires a comparison of current conditions against the optimal management scenarios outlined by fisheries bioeconomic theory. This study considers three regimes: MSY, MEY, and OA, each reflecting distinct objectives and management philosophies. The MSY regime seeks to optimize long-term harvests while maintaining population sustainability, focusing primarily on biological productivity. The MEY regime, in contrast, prioritizes maximizing net economic profit by balancing catch yields with operational costs, thereby producing the highest possible economic rent. Meanwhile, the OA regime represents unrestricted exploitation, which typically results in overfishing and reduces economic rent to zero.

To assess these regimes, four critical parameters were analyzed: stock biomass (X), representing the status of the wild population; catch (H), reflecting the level of exploitation; fishing effort (E), indicating the intensity of fishing activities; and economic rent (π), denoting the net economic benefit derived from fishing. Comparing the prevailing conditions to those under each regime provides insights into the current state of fisheries management in Banten Bay, while also identifying opportunities for improvement through adjustments in management strategies.

A detailed comparison of the outcomes for each regime is presented in Table (5).

Table 5. Comparison of empirical data with maximum sustainable yield, maximum economic yield, and optimal allocation regimes

Parameter	MSY	MEY	OA	Actual
X	78,090.65	79,944.02	3,706.75	
H	79,743.48	79,698.57	7,390.74	87,633.65
E	3,670.24	3,583.14	7,166.27	13,310.29
Economic rent	4,177,705,174.27	4,180,175,685.77	-	4,064,854,258.69

According to the bioeconomic framework, the status of fishery resource management can be classified into regimes defined by specific biological and economic criteria, each reflecting different trade-offs between sustainability and profitability. These regimes are summarized in Table (5).

Under the MSY regime, production (H) reaches 79,743.48 kg/year, the highest among all regimes, at a fishing effort (E) of 3,670.24 trips/year. MSY represents the threshold where fishing activity achieves its peak prior to the onset of overfishing. Any catch volume exceeding this level reduces the stock's recovery capacity, jeopardizing long-term sustainability. This condition is referred to as biological overfishing.

In the MEY regime, the fishing fleet achieves maximum profit, with economic rent values surpassing those of other regimes. However, the production level is lower than that at MSY, and the required fishing effort is also the lowest among regimes. This outcome reflects the principle of diminishing marginal returns in fisheries production. The MEY point represents the optimal balance between yield and profitability. When fishing effort exceeds MEY, profits begin to decline, a condition termed economic overfishing.

In the OA regime, fishing effort is at its highest, but profit falls to zero. OA occurs when total operating costs equal annual revenues. Under this condition, both economic and biological overfishing take place. Excessive fishing effort reduces the stock's replenishment capacity while simultaneously eroding profitability due to excess capacity in the fleet. Such circumstances threaten the long-term sustainability of crab fisheries in Banten Bay.

The relationships among these three regimes—MSY, MEY, and OA—are illustrated in Fig. (2).

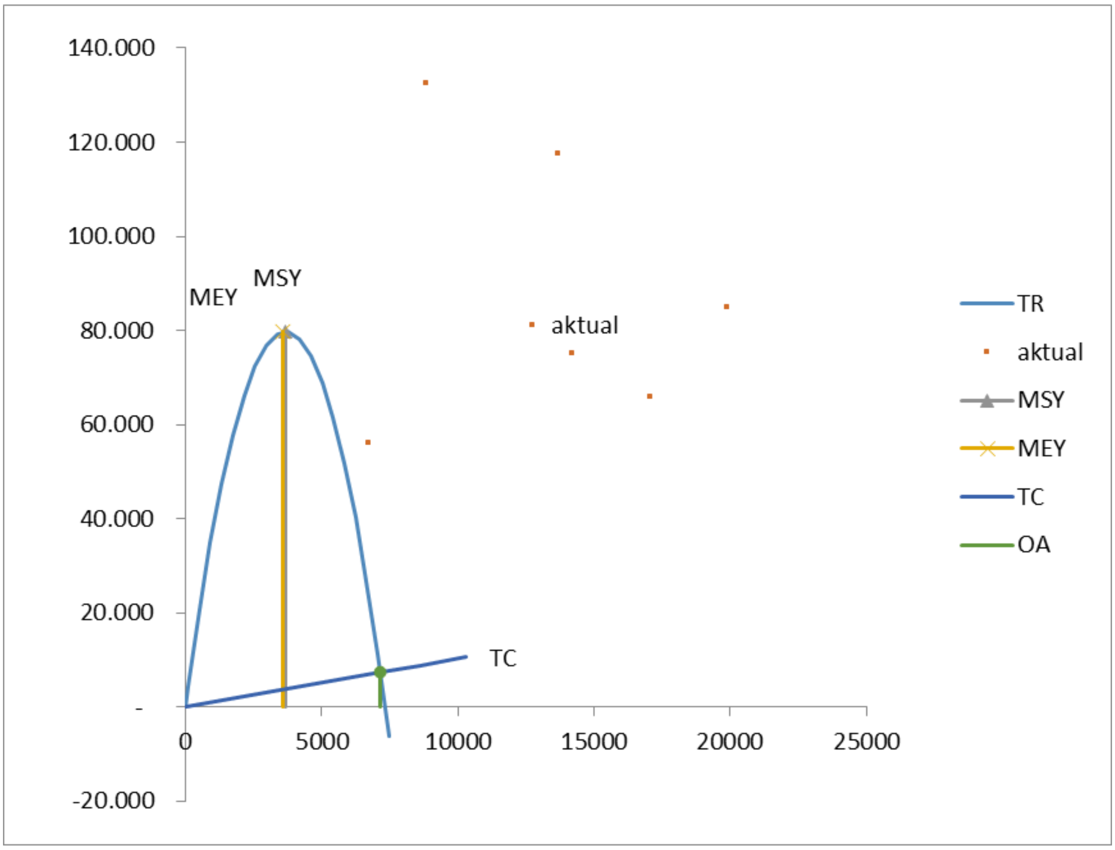

Fig. 2. Production and effort graph in the Clarke Yoshimoto Pooley model

The fisheries bioeconomics graph illustrates substantial variability in the current state of the fishery, as reflected by the wide dispersion of data points across different levels of fishing effort. Most actual observations are concentrated between 12,000 and 20,000 trips annually, showing that real fishing practices have exceeded all recommended optimal benchmarks, including maximum economic yield (MEY), maximum sustainable yield (MSY), and even the open access (OA) equilibrium. This condition signals severe overcapacity, where fishing intensity has surpassed the carrying capacity of the resource. Such overexploitation indicates the presence of economic overfishing, in which the operational and maintenance costs of fishing fleets outweigh the revenues from catches, threatening both the economic stability of fishing households and the ecological sustainability of crab stocks in Banten Bay.

From 2017 to 2023, production levels and fishing effort consistently remained above MEY and MSY thresholds. The elevated distribution of production points, particularly those lying above the MEY economic rent curve, can be explained largely by fluctuations in crab prices influenced by variations in size, weight, and quality. Larger and higher-quality crabs fetch premium prices, enabling fishers to temporarily secure profits greater than the average market value used in the bioeconomic model. However, such advantages are not sustainable, as variability in production and effort also reflects the instability of the fishery, which remains vulnerable to both biological and economic pressures.

Despite these short-term market-driven gains, it is evident that fishing activity has repeatedly exceeded sustainable limits, with several years recording production and effort levels well beyond the MSY threshold. This underscores the urgent need for effective control measures, as continued overexploitation places the fishery at risk of long-term stock depletion and declining profitability. Continuous monitoring and regulation of fishing effort are therefore essential to align actual practices with sustainable management regimes.

To illustrate these challenges in greater detail, annual records of fishing effort, production levels, and utilization status have been systematically compiled and are presented in Table (6), providing an important reference for evidence-based fisheries policy development.

Table 6. Actual shrimp production and fishing effort annually from 2017 to 2023

Years	Crab		% of MSY	
	Production	Effort	Production	Effort
2017	56,146.00	6,750.91	56	63
2018	132,648.00	8,831.16	132	82
2019	117,537.60	13,683.94	117	127
2020	75,147.08	14,218.12	75	132
2021	81,235.19	12,755.33	81	119
2022	84,939.38	19,881.18	84	185
2023	65,782.28	17,051.39	65	159

The utilization status of the *rajungan* fishery between 2017 and 2023 reveals dynamic fluctuations in both production and fishing effort. In 2017, utilization levels based on production and effort were classified as moderately overexploited, with catches reaching 50–70% of the maximum sustainable yield (MSY). The following two years, 2018 and 2019, marked a critical turning point as production exceeded the MSY threshold. In 2018, landings peaked at 132,648kg, or approximately 132% of MSY, reflecting intense harvesting pressure that extended beyond biologically sustainable limits. In subsequent years, production exhibited variability, with notable increases during 2021–2022, followed by a sharp decline in 2023, when catches fell to just 65% of MSY.

This declining production trend contrasts with the steady increase in fishing effort over the same period. From 2017 to 2023, fishing effort consistently rose, despite minor fluctuations after 2019. Importantly, fishing effort consistently exceeded the MSY threshold across all seven years. Yet, from 2019 onward, production levels remained below MSY, highlighting a persistent imbalance between fishing intensity and the productive capacity of the resource. This mismatch indicates that the *rajungan* fishery in Banten Bay has entered a state of overfishing, where the number of vessels and trips surpasses the natural capacity of the crab population to replenish itself.

Empirical evidence of this overexploitation is reflected in the production trend for 2017–2023. The sharp increase in landings leading up to 2018, followed by a gradual but sustained decline, illustrates that while fishing effort has continued to intensify, the stock's resilience has weakened over time. If left unmanaged, this trajectory risks further depletion of *rajungan* populations, diminished economic returns, and long-term disruption of the ecological balance within Banten Bay's coastal ecosystem.

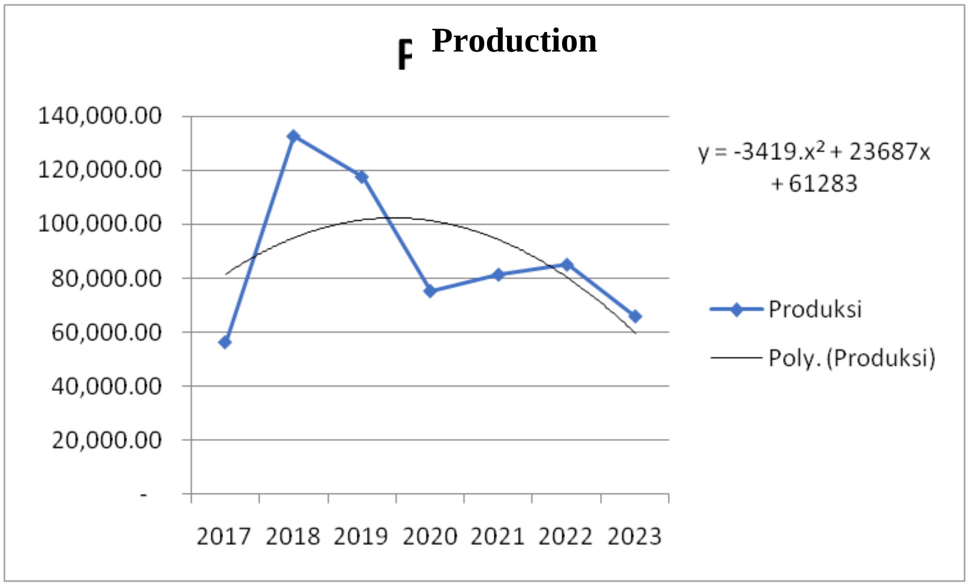

Fig. 3. Crab production in Banten Bay from 2017 to 2023

The crab production graph reveals a pattern of pronounced volatility, culminating in a declining trend toward the end of the observation period. In 2017, *rajungan* production began at a relatively modest level of approximately 55,000 units. The following year, production rose sharply, reaching a peak of more than 135,000 units in 2018—an increase of nearly 150% compared to 2017.

After this peak, production entered a period of gradual decline. In 2019, output fell to about 120,000 units, followed by a steep decrease in 2020 to around 75,000 units. A modest recovery occurred in 2021, with production climbing to 80,000 units; however, this growth was short-lived. Output reached only 85,000 units in 2022 before plummeting further in 2023 to 65,000 units—well below the production level recorded in 2017.

The polynomial trend line depicted in the graph, represented by the equation $y = -3419x^2 + 23687x + 61283$, illustrates an inverted curve. This pattern indicates that crab production in Banten Bay initially increased but then steadily declined toward the end of the observation period. Such a trajectory reflects multiple underlying challenges, including overfishing pressure, environmental degradation, and shortcomings in management implementation.

Fishing effort serves as a critical metric in fisheries dynamics, quantifying the intensity of fishing activities within a defined region and timeframe. It is typically expressed in units such as the number of trips, operating hours, or the quantity of gear deployed. The fishing effort graph for Banten Bay, covering the period 2017–2023, follows the power equation $y = 6740x^{0.513}$. This dataset provides a key indicator of the exploitation pressure placed on crab resources and offers valuable insights into the scale of fishing activities in the region, as shown in Fig. (4).

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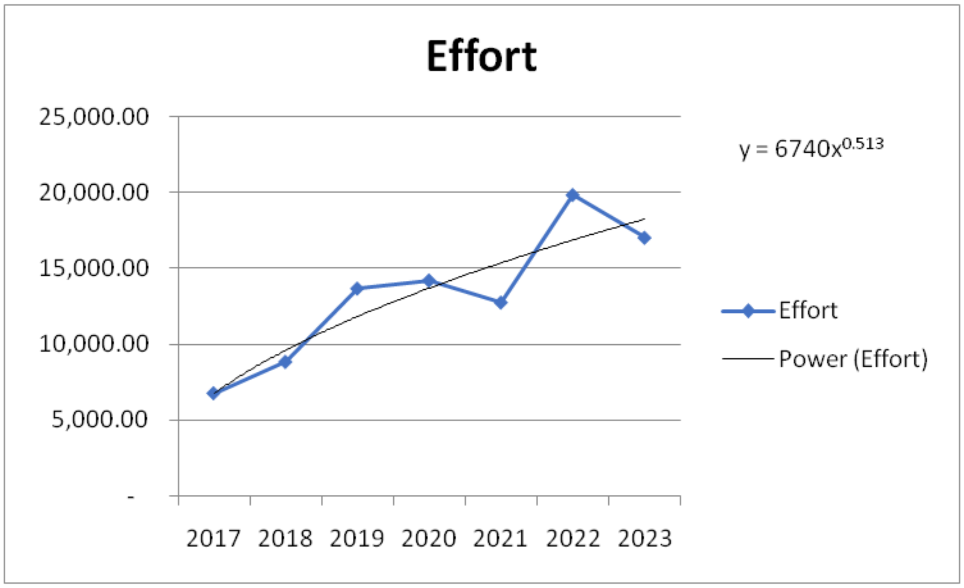

Fig. 4. Effort of crab fishing in Banten Bay from 2017 to 2023

The intensity of fishing activity has consistently and significantly increased, exerting adverse effects on the crab population. In 2017, fishing effort was recorded at approximately 7,000 units and rose to 9,000 units in 2018, marking a 28.6% increase. By 2022, effort surged to a maximum of 20,000 units. This escalation in fishing pressure has had profound consequences. The rapid increase in the quantity and variety of fishing gear has intensified pressure on existing stocks, leading to a sharp decline in crab populations and a reduction in the average size of catches. These conditions have forced fishing zones to extend farther from landing bases **(Kunsook *et al*., 2014)**.

Fig. (4) illustrates a pronounced escalation in crab fishing effort between 2017 and 2023, characterized by a positive linear trend that reflects a steady and concerning rise in fishing intensity. Effort increased from 6,750 trips in 2017 to 17,051 trips in 2023, signaling a level of exploitation that threatens the sustainability of the fishery. The peak effort was observed in 2022, exceeding three times the effort recorded in 2019. Such an increase demonstrates that, in the absence of adequate regulation, fishing intensity is likely to escalate further, resulting in both economic and ecological overfishing. This situation underscores the fact that fishing pressure on blue crabs remains insufficiently controlled, highlighting the urgent need for direct effort regulation and continuous monitoring to prevent further stock depletion. Overfishing inevitably reduces the potential yield available in future years, creating long-term risks for both the resource and dependent communities.

Given these conditions, a comprehensive bioeconomic study is essential to identify effective management strategies capable of mitigating excessive pressure on crab resources. To achieve this, an assessment incorporating five key variables is required:

fishing effort intensity (number of trips), catch productivity (kg), total revenue, total operational costs, and net profit margin, as summarized in Table (7).

Table 7. Results of the bioeconomic analysis of the blue crab fishery resource

Activity	F (Trip)	Y (kg)	TR (Rp.)	TC (Rp.)	Profit (Rp.)
OA	7.166	7.391	406.490.779	406.490.779	-
MSY	3.670	79.743	4.385.891.587	208.186.413	4.177.705.174
MEY	3.583	79.699	4.383.421.075	203.245.390	4.180.175.686
Actual	13.310	87.634	4.819.850.593	754.996.334	4.064.854.259

Description:
F (Trip): Effort in 1 year (trip); Y (kg): Production in 1 year (kg); TR: Total income from catches in 1 year; TC: Total costs accumulated in 1 year of fishing.

Substantial disparities are evident in the economic and biological outcomes across different fisheries management scenarios. Under the open access (OA) condition, economic equilibrium occurs at a fishing effort of 7,166 trips, yielding a minimum output of 7,391 kg. Total revenue, amounting to Rp 406,490,779, is equal to total costs, resulting in zero economic profit (economic rent = 0). This condition represents a bioeconomic equilibrium in which resources are exploited to a point where fishing operations merely cover operational expenses without generating profit.

The maximum sustainable yield (MSY) scenario demonstrates biological optimization, requiring a relatively low fishing effort of 3,670 trips while producing a substantially larger output of 79,743 kg. This level of production generates total revenue of Rp 4,385,891,587 and incurs costs of Rp 208,186,413, resulting in a profit of Rp 4,177,705,174. In contrast, the maximum economic yield (MEY) scenario reflects economic optimization, with fishing effort reduced to 3,583 trips and production at 79,699 kg. This condition achieves more efficient operational costs of Rp 203,245,390 while generating the highest profit of Rp 4,180,175,686.

Current fishing conditions indicate economic overfishing, with fishing effort reaching 13,310 trips—approximately 3.7 times higher than the MEY level. Although production amounts to 87,634 kg and total revenue reaches Rp 4,819,850,593, operational costs are disproportionately high at Rp 754,996,334. Consequently, the resulting net profit of Rp 4,064,854,259 is lower than both MEY and MSY scenarios.

This reduction in profitability demonstrates that excessive fishing intensity diminishes economic efficiency by Rp 115,321,427 (relative to MEY) and simultaneously threatens the long-term sustainability of crab stocks. These findings underscore the urgent need for fisheries management strategies based on sustainable effort limits.

The comparison among OA, MSY, and MEY scenarios highlights the trade-offs between biological sustainability and economic efficiency. The OA regime, although representing an unrestricted equilibrium, results in the lowest production and generates no economic rent, rendering it economically and ecologically unsustainable. By contrast, both MSY and MEY offer more favorable outcomes. Among them, MEY emerges as the most optimal management regime, as it maximizes economic profit with lower fishing effort and operational costs, while maintaining production levels nearly equivalent to MSY.

Therefore, implementing MEY-based management is strongly recommended. This approach not only enhances economic returns for fishing communities but also reduces fishing pressure, thereby supporting the long-term ecological sustainability of *rajungan* resources in Banten Bay.

DISCUSSION

This study applies a bioeconomic modeling approach and reveals substantial differences in the performance of classical models, with the Clarke-Yoshimoto-Pooley (CYP) model producing the most reliable outcomes. The CYP model achieved a coefficient of determination (R^2) of 96.52%, demonstrating its strong ability to explain variability in the data. By integrating both biological indicators (e.g., MSY and ABC) and economic indicators (e.g., MEY), this model provides a robust foundation for formulating crab management strategies in Banten Bay.

An evaluation of the three management regimes—MSY, MEY, and OA—shows that the *rajungan* fishery in Banten Bay has exceeded sustainable thresholds. Between 2017 and 2023, fishing effort consistently surpassed the optimal level, while production followed an erratic pattern marked by a downward trend. Production peaked in 2018 at 132% of MSY but declined sharply to 65% of MSY by 2023. These findings suggest that overfishing has led to both stock depletion and reduced economic efficiency.

The bioeconomic analysis further indicates that although current fishing practices generate the highest revenue, net profit is lower than under the MSY regime. With 13,310 fishing trips, the fishery yields only Rp 4.06 billion in net profit, whereas the MSY scenario requires just 3,583 trips to produce Rp 4.18 billion. This demonstrates that increased fishing effort does not necessarily translate into higher profitability, and that management efficiency is vital to maintaining both economic viability and resource sustainability.

Unregulated escalation of fishing effort has placed considerable pressure on crab stocks, as evidenced by declining catch sizes and the displacement of fishing operations to more distant grounds. These conditions highlight a state of overcapacity within the fishing fleet, in which fishing capacity surpasses the stock's natural regeneration rate. Without decisive management intervention—such as imposing effort restrictions and enforcing stricter oversight—this situation will accelerate the depletion of crab resources and undermine the long-term sustainability of the fishery sector in Banten Bay.

CONCLUSION

The bioeconomic analysis of the blue swimmer crab (*Portunus pelagicus*) fishery at Karangantu PPN demonstrates that the Clarke-Yoshimoto-Pooley (CYP) model provides the most accurate representation of stock dynamics and economic performance, as reflected by its superior coefficient of determination compared to other surplus production models. Evaluation of the three management regimes—open access (OA), maximum sustainable yield (MSY), and maximum economic yield (MEY)—reveals that current fishing practices have surpassed sustainability thresholds. This is evident from excessive fishing effort, unstable production levels, and declining economic efficiency.

Among the scenarios, the MEY regime emerges as the most favorable management option. It maximizes net economic benefits while requiring lower levels of fishing effort and maintaining production nearly equivalent to MSY. This finding underscores that adopting MEY-based management would generate dual advantages: reducing operational costs and fishing effort for fishermen, while simultaneously safeguarding the long-term sustainability of crab stocks.

Accordingly, future management of *rajungan* resources in Banten Bay should prioritize MEY-oriented policies. These include regulating fishing effort through restrictions on the number of trips, enhancing fisheries data collection and monitoring systems, and strengthening fishermen's capacity to adopt sustainable practices. By implementing these measures, the fishery can evolve into a more resilient, efficient, and sustainable system that ensures ecological preservation while supporting socio-economic well-being.

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