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Bioeconomic Management of Mackerel Tuna (*Euthynnus affinis*) in Tulungagung Regency: Evaluating MSY, MEY, and Open Access Regimes

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ABSTRACT

The species *Euthynnus affinis* has been reported as a dominant catch in Tulungagung Regency, comprising an average of 36 percent of total landings between 2017 and 2023. Despite its abundance, the fishery is identified as fully exploited and inefficiently managed. This study provided the first application of the Fox surplus production model in the region to analyze the bioeconomic performance of *Euthynnus affinis* fisheries under three management regimes: Maximum Sustainable Yield (MSY), Maximum Economic Yield (MEY), and Open Access (OA). Both biological and economic parameters were assessed using primary and secondary data. The analysis revealed that actual catches remain below the MSY level, indicating that biological overfishing has not occurred. The MEY regime produced the highest economic rent with minimal fishing effort, demonstrating the most economically efficient and sustainable option. In contrast, the OA regime resulted in zero rent and excessive fishing effort. Dynamic optimization analysis using a 10% discount rate was employed to simulate long-term profitability under different management scenarios. The findings support the establishment of MEY-based policies, including fishing effort limits and quota allocations, and provide evidence-based recommendations to enhance the sustainability and economic viability of tuna fisheries in Tulungagung Regency.

INTRODUCTION

Fisheries and oceans are recognized for their significant contribution to the global economy, particularly in terms of food security, employment, and livelihoods **(Funge-Smith & Bennett, 2019)**. Capture fisheries are reported to account for approximately

53% of the total fish-based food supply, benefiting millions of people worldwide, especially in developing countries **(FAO, 2020)**. With the growing demand for fish driven by population growth and shifting dietary preferences, increased pressure has been placed on marine fish populations, raising concerns regarding the sustainability of fisheries in the long term **(Saleh *et al.*, 2022)**. In response to these concerns, the need for sustainable fisheries management has been prioritized by governments, with efforts directed toward aligning economic development with marine resource conservation **(Cochrane, 2000)**.

Tulungagung Regency in East Java represents a strategic fisheries area in Indonesia, yet its bioeconomic management has received limited scientific attention compared to other regions such as Bitung, Pati, or Banyuwangi, where tuna fisheries have been more intensively studied and managed. While these regions have adopted various fisheries management strategies, Tulungagung despite its 61.47km coastline and proximity to productive Indian Ocean fishing grounds lacks comprehensive bioeconomic assessments. This study focuses specifically on *Euthynnus affinis* (mackerel tuna), a large pelagic species that consistently dominates local landings, contributing an average of 36% of total catches between 2017 and 2023. *Euthynnus affinis* was selected due to its high economic value, ecological significance, and vulnerability to overfishing, making it a priority species for sustainable management. Moreover, this study aligns with Indonesia's national fisheries development agenda under the Ministry of Marine Affairs and Fisheries (MMAF), which emphasizes the implementation of measurable quotas, fishing effort regulation, and economic efficiency. The research also directly supports the achievement of Sustainable Development Goals (SDG) 14, particularly targets 14.4 and 14.7, which aim to restore fish stocks and increase economic benefits from sustainable marine resource use. By applying a bioeconomic framework in Tulungagung for the first time, this study provides critical insights to support science-based policy-making and regional fishery governance reform.

Fishing activities in the regency are concentrated in the Indian Ocean, and significant fish resources, particularly tuna (*Euthynnus affinis*), have been recorded, with a production volume of 3,345 tonnes in 2023 **(KKP, 2024)**. Besuki Sub-district has been identified as a key tuna (*Euthynnus affinis*) landing site, especially at Popoh Beach Fishing Port, where the species has dominated local catches, constituting an average of 36% of total catches by Besuki fishermen between 2017 and 2023 **(DKP Jawa Timur, 2024)**.

Despite the abundance of marine resources, challenges such as the full exploitation of large pelagic species like tuna (*Euthynnus affinis*) and inefficient management practices have been encountered by the capture fisheries sector in Tulungagung Regency. To address these challenges, comprehensive assessments incorporating biological and economic indicators, including maximum sustainable yield (MSY), maximum economic yield (MEY), and optimal fishing effort, have been recommended **(Hoshino *et al.*, 2018)**.

Bioeconomic models have been employed as valuable tools in the assessment of fisheries and the formulation of management strategies. Through these models, critical reference points such as MSY and MEY can be estimated to support sustainable exploitation **(Wong *et al.*, 2021; Tunca *et al.*, 2022)**. The integration of such approaches has been aimed at supporting policy makers in developing long-term and comprehensive fisheries management frameworks **(Fulton *et al.*, 2014)**. In Indonesia, sustainable development in the marine and fisheries sector has been promoted to achieve a "triple win"—ocean health, ocean wealth, and ocean prosperity alongside the Sustainable Development Goals (SDGs). The use of bioeconomic models has been regarded as an effective means to incorporate both biological and economic parameters into fisheries management decisions **(Anderson & Seijo, 2010; Castro *et al.*, 2018)**. These models have been used to simulate interactions among fish populations, fishing effort, and economic variables, providing insights into management strategies that maximise ecological sustainability and economic gains **(Prellezo *et al.*, 2012; Lancker *et al.*, 2019)**. Various management interventions, such as catch quotas, effort limits, and seasonal closures, have been evaluated through bioeconomic modeling to forecast their long-term impacts **(Dichmont *et al.*, 2010; Fulton *et al.*, 2011)**. By doing so, decision-makers have been equipped with alternatives to achieve sustainable outcomes that align environmental and economic objectives **(Castro & Lechthaler, 2022)**. However, while such models have been widely adopted globally, limited application has been observed in Tulungagung Regency due to constraints in data availability. Existing studies have been focused primarily on socioeconomic evaluations, including business performance and income contributions **(Kushendarto *et al.*, 2018; Farizi *et al.*, 2024)**, whereas bioeconomic analyses for optimal fisheries management remain scarce.

The importance of this study has been framed within the context of fisheries resource management. It has been initiated in response to the dynamic nature of fisheries production, which has shown signs of stagnation or decline in capture fisheries, in contrast to the consistent growth observed in aquaculture, a trend also reported by the KKP. The full exploitation status of large pelagic fish resources, such as tuna (*Euthynnus affinis*), has been acknowledged. The status can be tracked using published methods **(Primyastanto *et al.*, 2025)**. The focus on Tulungagung Regency has been deemed relevant, as the region is recognized as a major contributor to East Java and Indonesia’s capture fisheries production **(KKP, 2024)**. Within the regency, Besuki Sub-district has been confirmed as a significant source of income in the capture fisheries sector, in accordance with findings by the local Fisheries Service **(Dinas Perikanan Kabupaten Tulungagung, 2024)**. Furthermore, the high economic value of the tuna (*Euthynnus affinis*) fishery at both regional and national levels has been underscored **(DKP Jawa Timur, 2024)**. Through academic references, the role of this research in enriching understanding of sustainable fisheries resource management by integrating biological and economic considerations has been reinforced. The objective of this study was to examine the bioeconomic utilization of tuna (*Euthynnus affinis*) fisheries resources in Tulungagung Regency, with a particular focus on determining the optimal management regime among maximum sustainable yield (MSY), maximum economic yield (MEY), and open access (OA). The findings are expected to provide new insights and supplementary data for the formulation of optimal fisheries management strategies based on bioeconomic analysis in Tulungagung Regency, where such research is currently limited. Additionally, this study is expected to contribute valuable perspectives for balancing economic development with the conservation of marine resources in tuna fisheries management.

MATERIALS AND METHODS

In this quantitative research, both static and dynamic bioeconomic models were applied using the Fox Model framework. Primary data were collected using a census sampling technique, targeting the entire population of active purse seine fishers operating from Popoh Beach Fishing Port during the study period. This approach was selected over stratified random sampling to ensure comprehensive coverage and eliminate sampling bias, considering the relatively small and well-defined population of 12 purse seine units. Given the homogeneity of vessel types, gear used, and target species (*Euthynnus affinis*), census sampling provided a more accurate and inclusive representation of actual fishing activities.

To ensure the reliability and accuracy of the primary data obtained through structured interviews and questionnaires, a triangulation method was employed. This included cross-checking interview responses with fishers, logbooks, daily landing records, and port authority documentation. Additionally, direct field observations were conducted during landing operations to validate reported fishing effort, gear deployment, and catch composition. This multi-source validation process ensured data consistency and minimized recall bias from respondents.

Time series data covering the years 2017 to 2023 encompassing catches, fishing effort, gear types, vessels, fishermen, and fish species were used. The research focused on vessels greater than 5 GT employing purse seine gear. The data collection survey was conducted from October 2024 to December 2024. Popoh Beach Fishing Harbor was selected as the main research location, being the primary fishing base for purse seine operations.

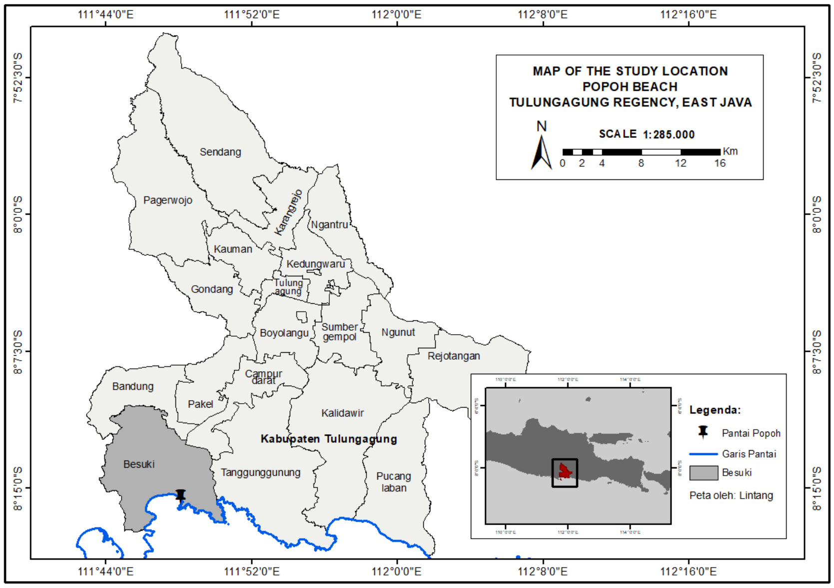

Fig. 1. Map of the study area

The bioeconomic model applied in this study was specifically focused on static and dynamic modeling based on the Fox model. Prior to the bioeconomic analysis, a biological analysis was conducted to estimate intrinsic growth rate (r), fishing power coefficient (q), and environmental carrying capacity (K), as outlined in equation (1). This biological analysis was performed to evaluate fish stock potential and to identify optimal fishing levels. A surplus production approach was adopted as the methodological basis. The estimation of biological parameters was carried out using function algorithms derived from the model developed by published method **(Fox Jr. 1970)**, which is referred to as the Fox model. The mathematical expression of the Fox model was denoted accordingly.

The calculation of the growth factor (z) value based on environmental parameters and catch was obtained with the equation:

$$z = \left[\left(-\frac{a}{b}\right) - \left(\frac{U_t + U_{t+1}}{2}\right)\right] \quad \ldots\ldots(1)$$

Calculation of the biomass stock value at a certain time in the Fox model was obtained using the equation:

$$x = \left[\left(\frac{z}{U_t}\right) + \left(\frac{1}{\beta}\right)\right] \quad \ldots\ldots(2)$$

Where, z is the growth factor, U_t the actual catch at time period t and β is the population growth parameter. The estimated catch (y) was calculated using the following equation:

$$y = \left[\left(\frac{z}{U_{t+1}}\right) + \left(\frac{1}{\beta}\right)\right] \quad \ldots\ldots(3)$$

From equations 1, 2, and 3, the value of the fishing power coefficient (q) can be calculated to measure the ability of fishing gear to catch available fish by calculating the natural logarithm, the calculation of the q value is obtained by the equation:

$$q = \left[\prod_{t=1}^{n} \left|\frac{ln\left(\frac{x}{y}\right)}{z}\right|\right]\frac{1}{t} \qquad \text{..................................(4)}$$

The calculation of environmental carrying capacity (K) was obtained from the comparison between the intercept value (α) and the value of the capture capacity coefficient (q), then the K value was obtained by the equation:

$$\mathrm{K} = \frac{\alpha}{q} \qquad \text{....................................(5)}$$

The natural growth rate of the fish population or intrinsic growth (r) was obtained by the equation:

$$r = \frac{Kq^2}{\beta} \qquad \text{.....................................(6)}$$

After obtaining the value of biological parameters, the model was then entered into the estimation of economic parameters. Based on the estimation previously stated, the economic parameters that affect the static bioeconomy of the fox model were divided into two categories: input cost estimation and output price estimation. The fishing cost used was the average of the operational cost of fishing costs, which includes the cost of fuel oil, oil, and ice. The average fishing costs and output prices during the study period were calculated based on the formula **(Haryanto *et al.*, 2025)**:

$$c_t = \frac{1}{n}\left(\sum_{i=1}^{n} c_i\right)\left(\frac{CPI_t}{CPI_e}\right)x100$$

$$p_t = p\left(\frac{CPI_t}{CPI_e}\right)x100$$

Where:

p_t = Real fish price in year t (in rupiah, IDR)

p = Nominal fish price in the current year (in rupiah, IDR)

c_t = Average nominal fishing cost (in rupiah per year per respondent)

n = Number of respondent fishermen (individuals)

CPI_t = Consumer price index in period t

CPI_e = Consumer price index in the study period

The Fox model is characterised by biomass growth following a Gompertz growth model, and CPUE declining with fishing effort following a negative exponential pattern. The Fox exponential model has two assumptions: the population is considered non-extinct, and the population is the sum of individual fish. The results of the Fox model **(Nguyen, 2011)** are shown in Table (1):

Table 1. Management regime calculations from the fox bioeconomy

Variable	Bioeconomy Analysis		
	Maximum Sustainable Yield	Maximum Economic Yield	Open Access
Catch per unit (h)	$E_{t}.\ exp^{(a+bEt)}$	$\dfrac{\frac{c}{p} - exp^{-1+\alpha+w}}{b}$	$\dfrac{c(\ln c - \ln p - \alpha)}{pb}$
Effort (E)	$\dfrac{-1}{b}$	$\dfrac{-1.w}{b}$	$\dfrac{\ln c - \ln p - \alpha}{b}$
Economic Rent (π)	$p.h_{MSY} - c.E_{MSY}$	$p.h_{MEY} - c.E_{MEY}$	$p.h_{OA} - c.E_{OA}$

The above approach is a static model approach. The approach is static because it does not take into account time in its analysis, so it is necessary to take a dynamic approach that moves following various changes in both internal and external factors. In analyzing dynamic optimization, it is bridged by the use of a discount rate with the equation:

$$\delta = \ln(1+r) \quad \text{..........................(14)}$$

Based on the equation above, the dynamic optimal values for biomass, production and economic rent can be found through the equation:

$$x^* = \frac{K}{4}\left[\left(1 + \frac{c}{pqk} + 1 - \frac{\delta}{r}\right) + \sqrt{\left(\frac{c}{pqk} + 1 - \frac{\delta}{r}\right)^2 + \frac{8c\delta}{pqKr}}\right] \quad \text{............(15)}$$

$$h^* = \frac{x}{c} \times \left(pqx - c\left[\delta - r\left(1 - \frac{2x}{k}\right)\right]\right) \quad \text{.............(16)}$$

$$E^* = \frac{h^*}{qx^2} \quad \text{.........................(17)}$$

$$\pi = ph^* - cE^* \quad \text{.......................(18)}$$

Based on the formulated approach, the estimation of the Fox Bioeconomic Model was carried out through several stages **(Fauzi, 2005)**. Initially, production and fishing effort data were compiled into a time series format. Subsequently, a stationarity test was conducted to evaluate the consistency of the data over time. Biological parameters were then estimated using multiple regression analysis, applying the Ordinary Least Squares (OLS) method via RStudio 2023.12.1. The OLS equation adopted for the estimation followed the formulation provided by published article (**Gujarati & Porter, 2009)**.

To ensure the estimated parameters qualified as the Best Linear Unbiased Estimator (BLUE), classical assumption tests were performed. These included multicollinearity testing, where the presence of perfect linear relationships among independent variables was assessed although in models with a single independent variable, intercorrelation is inherently absent. Heteroscedasticity testing was conducted to determine whether variance remained constant over time; in this context, the Breusch-Pagan test was applied to detect any variance irregularities **(Gujarati & Porter, 2009)**. Autocorrelation was also examined, with the Durbin-Watson test employed to identify any correlation between consecutive observations. Additionally, normality of residuals was tested using the Shapiro-Wilk test to confirm whether the residuals followed a normal distribution **(Gujarati & Porter, 2009)**.

Economic parameter estimation was carried out by identifying values such as the price per kilogram or tonne and the cost of harvesting per trip or per day at sea. These economic figures were adjusted to real terms using the Consumer Price Index (CPI). Optimal values were then calculated based on established formulas, and this process was facilitated by Microsoft Excel 2016, which was also used to generate graphical outputs.

Lastly, contrast analysis was performed by comparing actual data with the estimated modeling results. The comparison involved evaluating the average production of actual catches and the actual units of fishing effort over the study period under different management regimes, in order to assess the alignment between the modeled outcomes and real-world conditions.

RESULTS AND DISCUSSION

An important step in bioeconomic modeling begins with the linear regression exercise to determine bioeconomic parameters. The Ordinary Least Squares (OLS) model used in this study underwent a comprehensive evaluation to ensure that it fulfils the classical assumption criteria. The identification process starts with calculating the catch per unit fishing effort (CPUE). After calculating Catch Per Unit Effort (CPUE), the next step was to estimate biological parameters including natural growth rate (r), catchability coefficient (q), and environmental carrying capacity (K).

The fox algorithm method forms the basis of the biological parameter estimation. The application of the Fox algorithm approach effectively uses the natural logarithm value of CPUE at one particular time, denoted as time t. The model effectively shows no sign of heteroscedasticity and autocorrelation, as evidenced by the P-value > α in the Breusch-Pagan and Durbin-Watson tests. In addition, the model is also normally distributed, as evidenced by the P-value > α in the Shapiro-Wilk normality test (Table 2).

Table 2. Ordinary least squares estimation results of the fox algorithm bioeconomic model

	Estimate	Std. Error	t value	Pr(>|t|)
lncpue	0.5807057	0.2760195	2.104	0.0893
Et	-0.0005681	0.0001487	-3.821	0.0124*

Residual standard error: 0.3508 on 5 degrees of freedom
Multiple R-squared: 0.7449, Adjusted R-squared: 0.6939
F-statistic: 14.6 on 1 and 5 DF, p-value: 0.01235
Durbin-Watson test, DW = 2.718, p-value = 0.8427
Shapiro-Wilk normality test, W = 0.89266, *P*-value = 0.2888
Breusch-Pagan test, BP = 0.0030689, df = 1, *P*-value = 0.9558

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

In Table (2), the biological parameters were estimated using the Fox Algorithm model. The natural growth rate (r) was estimated at 57.8965517, indicating that the tuna (*Euthynnus affinis*) resources in Tulungagung waters have the capacity to grow at a rate of 57.90 per cent annually in the absence of fishing or human interference. The fishing gear ability coefficient (q) was determined to be 0.056640393 tonnes per trip, which signifies that each unit increase in fishing effort corresponds to an additional catch of 0.056640393 tonnes of *Euthynnus affinis* per trip. Meanwhile, the environmental carrying capacity (K) was estimated at 10.2525016 tonnes per year, representing the maximum biomass of *Euthynnus affinis* that the environment can sustain annually, considering factors such as food availability, fish size, and population growth.

These biological parameters play a crucial role in bioeconomic analysis as they reflect the ecological and reproductive dynamics of *Euthynnus affinis* in Tulungagung waters. Once the estimations of the parameters r, q, and K were obtained, they were subsequently used to calculate the fish stock (x), optimal catch (h), and optimal fishing effort under maximum sustainable yield (MSY) conditions, all based on the Fox Algorithm estimation model.

Table 3. Biological and economic parameters of tuna (*Euthynnus affinis)*

Biological Parameter	Unit	Value
Intrinsic Growth (r)	% per month	57.8965517
Coefficient of Capture (q)	1/ unit *effort*	0.056640393
Enviromental Carrying Capacity (K)	Tons	10.2525016
Economic Parameter		
Operational Costs	IDR/Trip	IDR 2,149,170
Fish Price	IDR/Ton	IDR 10,292,504.69

Source: Primary Data, 2025 (Processed)

The subsequent phase in the bioeconomic modeling framework involved the estimation of economic parameters, which encompassed fishing costs and fish prices. These parameters were derived from both secondary sources and primary data collected through interviews with 12 purse seine fishers. The nominal fishing cost, representing the average operational expenses such as fuel, ice, and supplies, was determined to be IDR 2,149,170 per trip. Meanwhile, the nominal price of tuna (*Euthynnus affinis*) was established at IDR 10,293 per kg, based on the production value and quantity of *Euthynnus affinis* landed at Popoh Beach Fishing Port over the past seven years and supplemented by interview responses from fishers and sellers. Using these economic parameters (c and p), the revenue function (total revenue), cost function (total cost), and actual economic rent defined as the difference between total revenue and total cost were calculated.

The final stage of the study comprised the analysis of the bioeconomic model of *Euthynnus affinis*, integrating both biological and economic factors to assess the species' exploitation level relative to optimal sustainability thresholds. This analysis evaluated three distinct fishery management regimes: Maximum sustainable yield (MSY), maximum economic yield (MEY), and open access (OA).

As presented in Table (4), under actual conditions, production was recorded at 1,023 tonnes with an effort level of 1,628 trips. In comparison, MSY conditions yielded a higher production level of 1,154 tonnes with a corresponding effort of 1,760 trips. This comparison reveals that actual production remains below the MSY level, indicating that overfishing either biologically or economically has not yet occurred within the Popoh PPP region. Moreover, the high productivity under actual conditions, despite a lower fishing effort than that required for MSY, suggests efficiency in current fishing practices.

Under MEY conditions, fishing effort was significantly lower than MSY, at just 175 trips, producing 936 tonnes of *Euthynnus affinis*. MEY was identified as the optimal regime for maximizing net profit with minimal fishing effort, although the resulting production was lower than both MSY and actual conditions. In contrast, OA conditions should be avoided due to the risk of overexploitation, excessive fishing effort, reduced catches, and the absence of economic rent. Under OA, total revenue equals total cost ($\pi = 0$), thereby eliminating profits and threatening the long-term sustainability of the fishery.

Table 4. Bioeconomic analysis of tuna (*Euthynnus affinis)* under MSY, MEY and OA management regimes

Parameter	Actual	Management Regimes		
		MSY	MEY	OA
Production (Ton)	1,023	1,154	936	723
Effort (Trip)	1,628	1,760	175	4,058
Economic Rents	7,541,259,172	8,647.907309	9,906,650,781	

Source: Primary Data, 2025 (Processed)

Table (4) presents a comprehensive comparative analysis of three fishery management regimes for *Euthynnus affinis*. The catch parameter, denoted by h, represents the quantity of catch derived from the utilisation of *Euthynnus affinis* resources. Under the MSY regime, a sustainable catch level of 1,154 tonnes was achieved. The actual catch is lower than this threshold, indicating that the fishery has not yet experienced biological overfishing. This parameter essentially defines the maximum allowable catch that ensures the long-term sustainability of the stock. The highest catch was observed under MSY conditions, followed by the MEY and OA, respectively. These results highlight the critical role of the MSY regime in balancing resource utilization with the biological preservation of *Euthynnus affinis*. Under OA conditions, high fishing efforts can lead to overexploitation **(Jueseah *et al.*, 2020)**. Although MSY aims to maintain fish populations at sustainable levels, it remains vulnerable to overfishing without effective management **(Memon *et al.*, 2015; Hilborn *et al.*, 2020)**. Implementing MSY targets can improve yield, enhance food security, and alleviate pressure on fishery resources **(Elleby *et al.*, 2025)**.

The fishing effort parameter, denoted by E, plays a crucial role in determining sustainable management practices. The highest fishing effort was recorded under OA conditions with 4,058 trips, followed by the MSY regime with 1,760 trips, and finally the MEY regime with only 175 trips. The actual effort level, which is lower than both MSY and OA, suggests that the *Euthynnus affinis* stock in Tulungagung waters is currently underexploited. The MEY regime's minimal effort aligns with optimal economic recommendations, underlining the importance of balancing economic efficiency and resource conservation. MEY represents the most economically efficient scenario, achieving maximum profit with the least effort **(Cabral *et al.*, 2019; Jurado-Molina *et al.*, 2021)**.

The economic rent, denoted by π, measures the net economic benefit from harvesting *Euthynnus affinis*. The highest economic rent was achieved under the MEY regime, amounting to IDR 9,906,650,781, indicating the most favourable outcome for fishery management. The MSY regime followed with an economic rent of IDR 8,647,907,309. In contrast, the OA regime produced an economic rent of zero. In this scenario, revenues merely cover fishing costs, with no additional profits. This reflects the common pool problem under OA, where unlimited access leads to increased competition and diminished economic returns. The zero-profit condition under OA highlights the importance of regulated access to prevent overexploitation and economic inefficiency **(Abidin *et al.*, 2024)**.

These findings support the fundamental principles of fisheries economics: MEY represents the optimal point where profits are maximised without compromising stock sustainability, while MSY focuses on maintaining long-term biological productivity. Although MEY results in slightly lower yields than MSY, it provides higher economic benefits. The disparity between MEY and MSY outcomes underscores the inherent trade-off between economic efficiency and biological sustainability **(Andrew *et al.*, 2007; Dichmont *et al.*, 2010; Yanti *et al.*, 2021)**. In contrast, unmanaged open-access fisheries are prone to overexploitation, leading to intense competition and reduced profitability **(Campbell *et al.*, 2012)**. Policy interventions such as fishing taxes or access fees may be necessary to stabilise fishery dynamics and prevent resource depletion **(Sarkar *et al.*, 2023)**.

Table 2. Dynamic optimization of fishery resources

δ	x*	H*	E*	π
0	6.700	134.415	354.214	733,640,488.10
0.05	6.697	134.456	354.442	733,640,183.26
0.10	6.695	134.495	354.660	733,639,325.50
0.20	6.691	134.567	355.066	733,636,238.41
0.40	6.684	134.694	355.786	733,626,042.13
0.60	6.678	134.803	356.408	733,612,347.82
0.80	6.672	134.900	356.955	733,596,541.25
1	6.667	134.985	357.445	733,579,454.60

Source: Primary Data, 2025 (Processed)

Table (5) shows the optimal biomass, fishing effort, production and profit of tuna (*Euthynnus affinis*) with discount rates ranging from 0 to 100 per cent. When there is no fishing effort, a very high biomass is possible. The ideal biomass is relatively high when the discount rate is zero. When the discount rate is increased, fish biomass continues to fall until it reaches a critical level. This study recommends that purse seine vessels should regulate fishing effort until it reaches optimal conditions so as to obtain the optimal level of economic rent while maintaining the sustainability of the existing tuna (*Euthynnus affinis)* resources in the waters of Tulungagung Regency in a 10 percent discount rate scenario to take into account long-term economic benefits, ensuring sustainable fisheries management while maximizing profits.

The optimal profit decreases as the discount rate increases, as it is affected by fishing licences causing a decrease in profit, which becomes very low at a discount rate of 1. A larger discount rate, such as lower fish stock investment, indicates a higher rate of return on investment, which may make harvesting more practical in the future **(Hossain & Arnason, 2014)**. The magnitude of the discount rate has a large influence on the optimal fishing policy **(Pascoe *et al.*, 2019)**. High discount rates increase the fallacy of fishery restrictions such as open entry, whereas low discount rates are associated with less intense fishing pressure **(Clarke *et al.*, 1992)**. Optimal profits continue to decline as the discount rate (δ) is increased from 0 to 100 per cent **(Dutta *et al.*, 2025)**. According to research, fisheries are considered depleted when $\delta > 2r$, and overfished when $\delta > r$**(Newton *et al.*, 2007; Hossain & Arnason, 2014)**.

CONCLUSION

The study confirmed that the actual catch of *Euthynnus affinis* remained below the MSY level, indicating no biological overfishing. Under MEY conditions, fewer trips were required to achieve optimal profit while maintaining sustainability. In contrast, OA conditions led to normal profits only, with high effort and increased competition among fishers. As discount rates increased, biomass, production, and profits declined, while fishing effort rose. A 10% discount rate was considered suitable to balance long-term benefits and sustainability.

Several policy implications were identified. First, production quotas and effort should be set according to MEY for economic efficiency and resource sustainability. Second, effective monitoring and enforcement must be ensured to prevent overfishing. Third, sustainable practices, such as selective gear and accurate reporting, should be promoted. Fourth, fishing access should be limited through licensing to reduce competition. Fifth, collaboration with research institutions should be strengthened to improve management models. Lastly, policies must be adapted continuously to respond to ecological and economic changes.

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