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ESTIMATING SUSTAINABLE EFFORT RATES FOR SKIPJACK TUNA FISHERIES LANDED AT YOGYAKARTA'S COASTAL FISHING PORT USING THE FOX MODEL

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ABSTRACT

This study aims to estimate the fishing effort for skipjack tuna (Katsuwonus pelamis) landed at Sadeng Coastal Fishing Port, Yogyakarta, under three management conditions: Maximum Sustainable Yield (MSY), Maximum Economic Yield (MEY), and Open Access Equilibrium (OAE), using the Fox model. The Fox model includes a key variable that helps balance ecological sustainability with economic profitability, ensuring the long-term viability of both the fishery and the livelihoods it supports. The skipjack tuna assessed in this study were caught using purse seines in the Indian Ocean south of Yogyakarta. Catch and fishing trip data from 2015 to 2021 were analyzed using the Fox bioeconomic model, a development of the Gordon-Schaefer model. The research was conducted from March to May 2022. Under MSY conditions, the estimated catch (CMSY) was 493,012 kg with an effort (EMSY) of 170 trips per year, yielding an annual profit of IDR 4,768,675,442. Under MEY conditions, the estimated catch (CMEY) was 474,424 kg with an effort (EMEY) of 127 trips, resulting in a higher annual profit of IDR 5,071,245,038. Under OAE conditions, the estimated catch (COAE) was 337,761 kg with an effort (EOAE) of 363 trips per year. Based on the Fox model, the current fishing effort is at 70% of EMSY, indicating that the skipjack tuna fishery in this area is not overfished.

Keywords: *Bioeconomic, E_{MSY}, purse seine,Sadeng, Indian Ocean*

INTRODUCTION

The limited ability of fish population to generate threatens the sustainability of existing fish populations (Karman *et al*. 2016). Skipjack tuna is one of the important large pelagic fish. It is an export commodity that is used and targeted by fishermen throughout the year using various types of fishing gear in some regions of Indonesia (Herwaty *et al*. 2021; Hutajulu *et al*. 2023; Mardlijah *et al*. 2021; Yeka *et al*. 2022; Zainuddin *et al*. 2022). The abundance of many fish species, particularly skipjack tuna, makes Indonesia an archipelago country with a great potential in the fisheries sector. Skipjack tuna is a fast migrating and cosmopolitan species often found in tropical and subtropical waters such as the South Java Sea, Bali, and Lombok (Amiluddin *et al*. 2020; Satria & Kurnia 2017). It is necessary to ensure the continued existence of Skipjack tuna, which is a fish species that is heavily exploited in Indonesia. Stock assessment can be used to assess skipjack tuna resources to determine their sustainable potential, optimal effort, and utilization. The activities to utilize stock without causing a population decline (Fadhilah *et al*. 2019). Several bioeconomic determine the appropriate proportion of the number and fishing effort not to disturb the population.

This research was carried out to estimate fishing trips and catch of skipjack tuna (*Katsuwonus pelamis*) landed in Sadeng Coastal Fishing Port (CFP) Yogyakarta under the conditions of Maximum Sustainable Yield (MSY), Maximum Economic Yield (MEY), and Open Access Equilibrium (OAE) with Fox-model approach. The MSY aims to balance resource utilization for long-term sustainability, while the MEY aims to balance ecological sustainability with economic profitability. While OAE occurs when total sustainable revenue equals total costs, there is no incentive for additional entry or exit into the fishery.

An estimate of the fishing effort tolerated under the precautionary principle is necessary to create appropriate fisheries management policies (Rees *et al*. 2022). Regulators have the power to consider this policy when increasing or decreasing the number of vessels or fishing trips in certain fishing zones under their authority. This strategy is especially significant in areas where management policies are not based on scientific judgments (Kraak *et al*. 2010).

At Sadeng CFP Yogyakarta, skipjack tuna (*Katsuwonus pelamis*) is the most common species landed (Dewi *et al*. 2023). Sadeng waters, which fall under Fisheries Management Area (FMA) 573, can provide habitat for economically important fish such as skipjack tuna, the region's second-largest commodity (Wahyuningrum *et al*. 2012; Nikijuluw 2017; Wijopriono 2012). Based on data from Pusat Informasi Pelabuhan Perikanan (PIPP)/Center for Fishing Port Information in 2021, during 2015-2021, this port's skipjack landing totaled 6,611,819 kg, or 37 percent of the total landings of 17,961,471 kg. Yogyakarta Special Region Province caught 6,867,034 kg of skipjack tuna over 15 years, with purse-seine vessels in Sadeng CFP being responsible for 96% of the catch. This research describes the use of the Fox model to determine the status of the skipjack tuna fishery in Yogyakarta, which has not been conducted in the area yet. The Fox model and the Gordon-Schaefer model, both surplus production models, are chosen based on the fishery's specific characteristics and management strategy objectives. If there are multiple gears or species involved in the fishery, the Fox model could provide a better fit. The yield curve produced by the Fox model approaches zero only at high levels of effort, which differs from that of the Gordon-Schaefer model.

The Fox model is one of the bioeconomic models used to estimate the level of effort by determining the values of Maximum Sustainable Yield (MSY), Maximum Economic Yield (MEY), and Open Access Equilibrium (OAE). Calculating effort rate improves sustainable fisheries management. Fox developed the Fox bioeconomic model and used the equilibrium concept to model a fishery over the long term (Fox 1970; Supriatna *et al.* 2015; Yoshimoto & Clarke 1993). The smart and sustainable bioeconomic represents a comprehensive perspective, in which economic, social, environmental, and technological dimensions are considered simultaneously (D'Amico *et al*. 2022)

METHODS

Data collections

This research requires data on catch, effort, fishing costs, and income. It utilized landed data in production (kg) and effort data (trips) for skipjack tuna landed at Sadeng CFP between 2015 and 2021 and conducted from March to May 2022. Skipjack tuna caught in the period in Sadeng CFP was 6,611,819 kg (Table 3) and that used purse seine of 30 GT to 80 GT was 3,402,206 kg (Table 4) which was from the Center for Fishing Port Information. The research utilized this data to calculate further, using field observations and published reports. The fishing grounds of the purse seine were distributed as shown in Figure 1, which is spread over a 2-degree square mile.

Data analysis

Several models are used in fisheries, including Schnute growth, Clarke-Yoshimoto-Pooley, Gordon-Schaefer, and Fox. The Schnute growth model is a general growth model, including numerous specific models as special cases. It is used to calculate the growth of various organisms, i.e. plants and fish. Assessing the status of fishery stocks is done using a bioeconomic model known as the Clarke-Yoshimoto-Pooley (CYP) model. In the fishing industry, the maximum sustainable yield can be computed using both the Gordon-Schaefer model and the Fox model, both of which are bioeconomic models. The Gordon-Schaefer model is based on stable environmental conditions and is designed as a

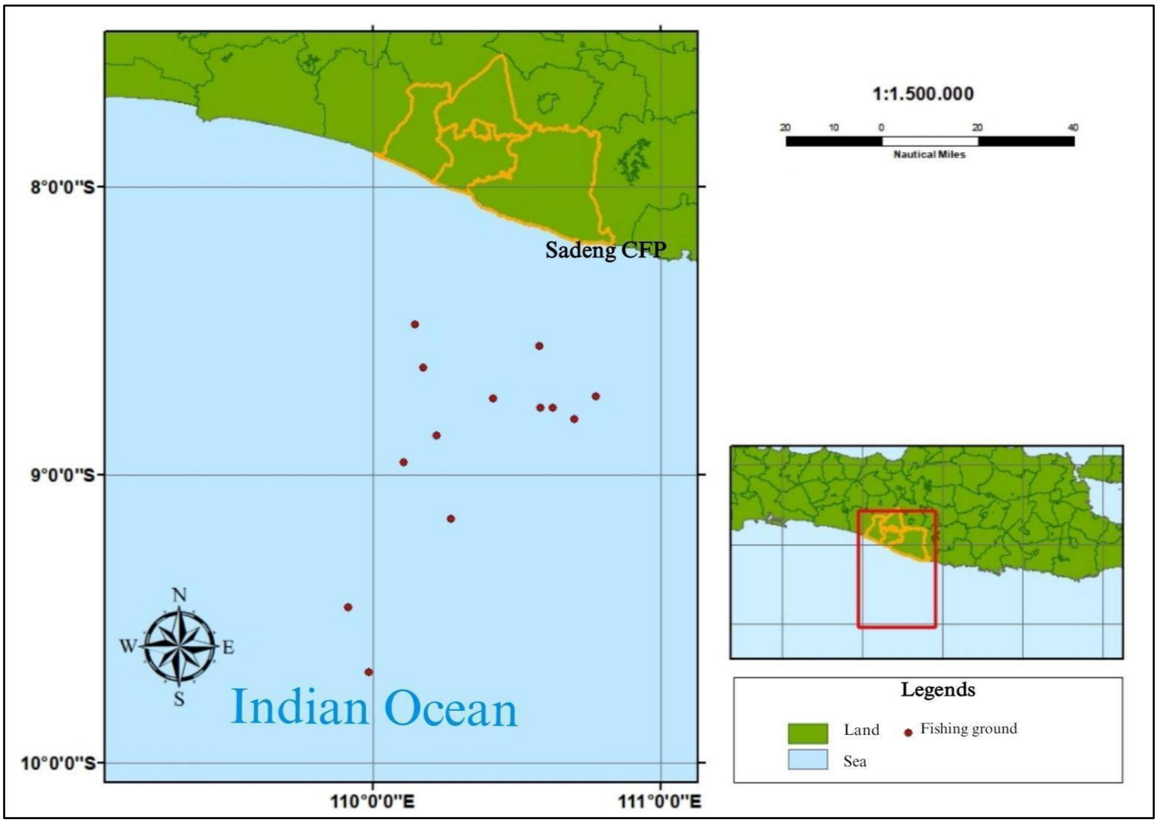

Figure 1 Map of research locations and locations the fishing ground fishing vessel of 30 to 80 GT

one-stock model. The Fox model is more flexible and can be used to model multi-species fisheries, and in this research, we compare both of them.

The Fox model was used in the bioeconomic analysis of skipjack tuna resources at Sadeng CFP Yogyakarta to estimate the value of Maximum Sustainable Yield (MSY), Maximum Economic Yield (MEY), and Open Access Equilibrium (OAE). The bioeconomic model is based on a theory that contrary to the Gordon-Schaefer bioeconomic model, there is a decreasing rate of fishing effort. The Gompertz growth model is adhered to by this model, where the population is considered to be made up of non-extinct fish individuals, even if the stock is significantly depleted (Ghosh *et al*. 2014). The MSY and OAE can be calculated mathematically using the formula in Table 1. The MEY can then be estimated using graphical simulation.

The Gordon-Schaefer model assumes a population that grows logistically, with fast growth at the beginning, and then slows down as effort increases. In this model, the catch is a parabolic function of effort, and the formulas for estimation are given in Table 2.

Table 1 Formula to estimate MSY and OAE of Fox model (Nabunome 2007)

	MSY	OAE
Catch (C)	$E.\,Exp\,(\gamma 0 + \gamma 1\ E)$	$\frac{Ln\,c - Ln\,p - j}{\gamma 1}$
Fishing effort (E)	$-\frac{1}{\gamma 1}$	$\frac{c(Ln\,c - Ln\,p - j)}{p.\gamma 1}$
Total revenue (TR)	$C_{MSY}.\ p$	$C_{OAE}\ .\ p$
Total operational cost (TC)	$c\ .\ E_{MSY}$	$c\ .\ E_{OAE}$
Benefit (п)	$TR_{MSY} - TC_{MSY}$	$TR_{OAE} - TC_{OAE}$

With:
$\gamma 0$: intercept
$\gamma 1$: slope of the trend line
p : price
c : average cost of total revenue

Table 2 Formula to estimate MSY, MEY, and OA of Gordon-Schaefer

	MSY	MEY	OAE
Catch (C)	α / 4β	$\alpha E_{MEY} - \beta(E_{MEY})^2$	$\alpha E_{OAE} - \beta(E_{OAE})^2$
Fishing effort (E)	α / 2β	(pα – c) / (2pβ)	(pα – c) / (pβ)
Total revenue (TR)	$C_{MSY} . p$	$C_{MEY} . p$	$C_{OAE}. p$
Total operational cost (TC)	$c . E_{MSY}$	$c . E_{MEY}$	$c . E_{OAE}$
Benefit (п)	$TR_{MSY} - TC_{MSY}$	$TR_{MEY} - TC_{MEY}$	$TR_{OAE} - TC_{OAE}$

Fishing costs consist of fixed costs, which include depreciation of investment items per trip and maintenance costs per trip, as well as variable costs and non-fixed costs, such as the operational costs of fishing per trip. In the research of bioeconomic models, costs are based on the assumption that only fishing factors are taken into account and are considered constant, so in this research, fishing costs are defined as variable costs per trip and are considered constant (Lam *et al*. 2011). The formulae to estimate the effort rate are as follows:

$$\mathrm{ER} = \frac{\mathrm{E_i}}{\mathrm{E_{MSY}}} \times 100\% \quad \text{.......................................(1)}$$

With :
ER: effort rate (%)
E_i: actual effort in the year i
E_{MSY}: effort at MSY level

To know the peak, normal, or off-season, data from the Center for Fishing Port Information of Sadeng by purse seine of 30 GT to 80 GT from 2015 to 2021 was used to determine the fishing season according to Figure 2. The determination of fishing season is based on the average percentage in the Times Series Analysis. The procedure is as follows

$$u = \left(\frac{1}{m}\right) + \sum_{i=1}^{m} u_i \quad \text{…………………………(2)}$$

With :
U : monthly average CPUE per year
U_i : monthly CPUE
m : number of months (12)

Then calculated U_r, rasio between U_i and U in percent

$$u_r = \frac{u_i}{u} \times 100\% \quad \text{……………………………..….(3)}$$

Calculated season index (SI_i) according to year of data (t)

$$SI_i = \frac{1}{t} + \sum_{i=1}^{t} u_r \quad \text{………………….………….(4)}$$

RESULTS

Fish Production of Sadeng CFP

The research took place at Sadeng CFP in Yogyakarta Special Region Province.The volume and value of skipjack tuna catch are in Table 3.

During 2015-2021, Sadeng CFP produced skipjack tuna with a total weight of 6,611,819 kg and an estimated value of IDR 108,514,512,000. This production represents 96% of the total skipjack tuna catch in Yogyakarta Special Region Province. Table 3 shows that production can vary depending on the year. In 2017, there was a production of 1,685,198 kg with a value of IDR 24,943,088,000, while in 2016, there was a production of 374,736 kg with a value of IDR 6,020,450,000. The production for 2015-2021 totaled 944,546 kg and the average cost was IDR 15,502,073,143.

Between 2015 and 2021, skipjack tuna caught with purse seines produced an average of 486,029 kg on an annual basis. This accounted for 40% of the total purse seine catch and 51% of the total skipjack production at Sadeng CFP. The highest production was 887,524 kg in 2017 with IDR 13,010,644,000 while the lowest production was 187,368 kg in 2016 with IDR 3,010,225,000. These were caught by purse seiners sized from 30 to 80 GT, with a duration of 2 weeks on average. The numbers are shown in Table 5.

Fishing Costs

In bioeconomic analysis, the average total cost incurred by each sampled fishing fleet is used to calculate the cost of fishing. Five purse seines with 30 GT to 80 GT at Sadeng CFP were employed as the source of the fishing cost samples used in this research, which served as a standard for the bioeconomic calculation.

Table 3 Volume and value of skipjack tuna catch at Sadeng CFP (2015-2021)

Years	Volume (Kg)	Value (IDR)
2015	510,639	11,655,860,000
2016	374,736	6,020,450,000
2017	1,685,198	24,943,088,000
2018	964,230	15,397,188,000
2019	807,956	13,846,296,000
2020	1,395,534	23,061,406,000
2021	873,526	13,590,224,000
Average	944,546	15,502,073,143
Total	6,611,819	108,514,512,000

Table 4 Skipjack tuna production using purse seines from 30 to 80 GT (Center for Fishing Port Information 2015-2021)

Year	Volume (Kg)	Value (IDR)
2015	510,014	11,645,860,000
2016	187,368	3,010,225,000
2017	887,524	13,010,644,000
2018	482,115	7,698,594,000
2019	403,978	6,923,148,000
2020	373,822	6,219,649,000
2021	557,385	8,731,709,000
Average	486,029	8,177,118,423
Total	3,402,206	57,239,829,000

Table 5 The fishing fleet of Sadeng CFP

Year	GROSS TONNAGE			
	<5 GT (OBM)	5 GT-10 GT	10 GT-20 GT	30 GT-80 GT
2015	184	29	12	5
2016	245	6	38	8
2017	245	8	38	8
2018	250	6	38	8
2019	250	6	38	8
2020	250	6	38	8
2021	250	6	38	5

Table 6 Fishing costs

No.	Vessel' Name	Fishing Cost (IDR)
1	Restu Putra	35,629,556
2	Restu Putra 01	27,990,667
3	Restu Putra 02	32,379,556
4	Viona 01	43,282,333
5	Inka Mina 647	25,532,333
	Average (C)	32,962,889

The fishing costs incurred by each fishing fleet variables, which are adjusted to the needs of each fleet because they have different vessel sizes and engine capacities that will affect the amount of fuel and supplies needed in one fishing trip. Data from Table 6 shows that the average cost of fishing using purse seine at Sadeng CFP is IDR 32,962,889. The percentage of skipjack caught at Sadeng CFP was 40% of the total number of fish. The cost to catch skipjack tuna using purse seine gear was estimated at 40% of the average (Table 6), IDR 13,238,579 per trip.

Income

The income generated from product sales before deducting the total production costs is known as operating income. The income from capture fisheries is highly influenced by the current selling price of fish at that time. In addition, income can be affected by three fishing seasons that can happen in a year, which are the peak season, normal season, and off-season. Analysis of income per trip is used to determine the standard price or price (p) for further calculations.

The fishing season is determined based on the calculation of the Fishing Season Index (FSI) with the criteria, if the FSI > 100% then it is categorized as the fishing season (peak), but if the FSI value < 100% then it is categorized as off fishing season if FSI = 100% then it is categorized as the normal season (Hamka and Rais 2016). The average month's FSI was 40% lower than January's 60%. Based on the production data of Sadeng CFP capture fisheries in 2015-2021, the fishing season pattern can be seen in Figure 2.

From Figure 2 it can be interpreted that the peak fishing season is in five months of the year namely March, August, September, October, and December, the normal season is in May while the off-season is in six months namely January, February, April, June, July and November. This study was conducted from March to May 2022, it seemed off-season.

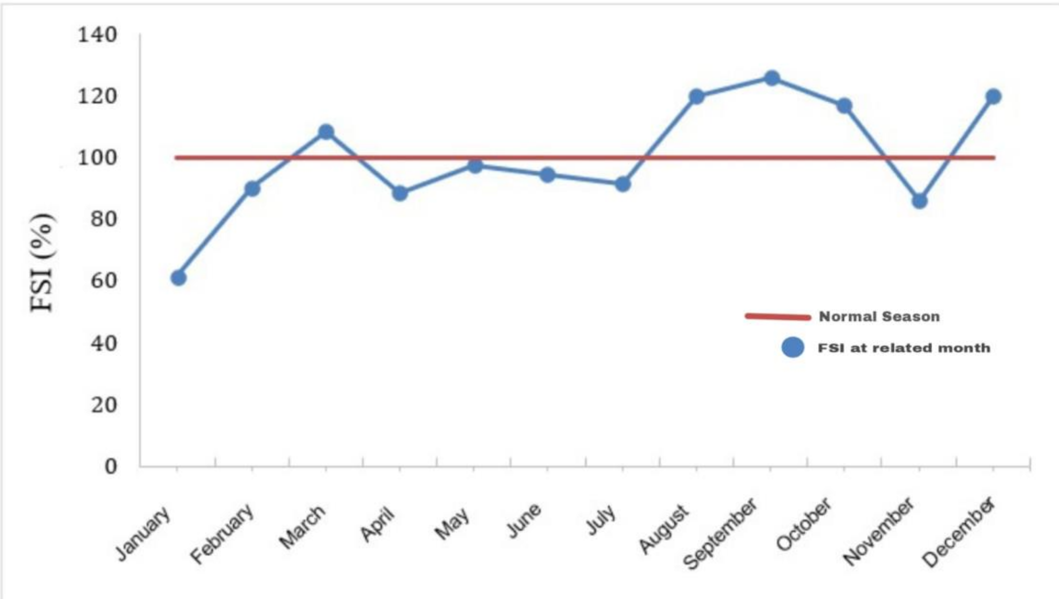

Figure 2 Fishing season index (%) at Sadeng CFP

Table 7 The average income per season

Season	Average catch (Kg)	Average income (IDR)
Peak	14,449	173,388,000
Normal	8,641	132,850,894
Off	4,274	81,206,000
Total	27,364	387,444,894
Average fish price (*p*)		14,233

Table 7 shows the average catch and income of purse seiners sampled in three seasons. In the peak season, the catch reached 14,449 kg with a revenue of IDR 173,388,000, in the normal season the average catch was 8,641 kg with a revenue of IDR 132,850,894, while in the off-season, the catch was 4,274 kg with a revenue of IDR 81,206,000. Based on three fish prices, IDR 14,233 was the average.

Fox Model and Gordon-Schaefer Model Analysis

The Fox model is a bioeconomic model, like the Gordon-Schaefer model, but it also takes into account the decreasing rate of fishing effort. In the Gordon-Schaefer model, the fishing effort is always constant, as Fadhilah *et al*. 2021). The application of the model in this research produced the results shown in Table 8.

The Fox model had less CMSY than the Gordon-Schaefer model (19.5%), but both benefits were 20.2%. In C_{MEY} conditions and benefits were also less than 15.6% and 16.1% (Table 8 and Table 9). This indicates that the Fox model changes the catchability coefficient due to behavioral factors, and it adheres to a precautionary approach.

Maximum Sustainable Yield

Maximum Sustainable Yield (MSY) is a condition of optimal utilization of fish catches in a body of water, but still in a sustainable condition and does not threaten fish populations (Homero *et al*. 2020). Based on the bioeconomic analysis of skipjack tuna fisheries in Sadeng waters using the Fox model, the catch under Maximum Sustainable Yield (C_{MSY}) conditions is estimated at 493,012 kg per year, with an effort value under Maximum Sustainable Yield (E_{MSY}) conditions of 170 trips per year. The C_{MSY} value obtained explains that the highest production level or maximum catch of skipjack in these waters has not yet fallen into the category of overfishing which can threaten its population. Overfishing occurs when actual production exceeds the C_{MSY} value (Ahmed *et al*. 2007; Barman *et al*. 2022).

Maximum Economic Yield

The estimated catch (CMEY) per year is 474,424 kilograms based on Fox model calculations, and there are 127 fishing trips per year. Under these conditions, the estimated profit value obtained is IDR 5,071,245.038. A detailed explanation of this situation can be found in Figure 3. Skipjack tuna resource management can be provided when MEY is in a balanced condition (Auliyah *et al*. 2021; Pan 2021).

Open Access Equilibrium

Open access to waters is a characteristic of them, and if uncontrolled, it can lead to overexploitation and endanger fish resources. Overfishing is caused by the growing number of fishing vessels and the use of fishing gear that is not selective and harmful to the ecosystem (Bambang & Wijayanto 2019). According to the bioeconomic analysis of the Fox model (Figure 3), the OAE value does not reach zero but only gets closer to zero with each additional trip. This means that when

Table 8 Results of the bioeconomic calculation of the Fox model.

	MSY	OAE	MEY
C (kg)	493,012	337,761	474,424
E (Trips)	170	363	127
TR	IDR 7,017,098,348	IDR 4,807,399,676	IDR 6,752,544,573
TC	IDR 2,248,422,907	IDR 4,807,399,676	IDR 1,681,299,535
π	IDR 4,768,675,441	IDR 0	IDR 5,071,245,038

Table 9 Results of the bioeconomic calculation of the Gordon-Schaefer model.

	MSY	OAE	MEY
C (KG)	559,179	269,041	548,245
E (TRIPS)	168	289	145
TR	IDR 7,958,872,958	IDR 3,829,291,358	IDR 7,803,238,663
TC	IDR 2,225,914,270	IDR 3,829,291,358	IDR 1,914,645,679
Π	IDR 5,732,958,688	IDR 0	IDR 5,888,592,983

the utilization effort exceeds the OAE point, the fishing effort does not benefit economically (Squires & Vestergaard 2013), or in other words, the profit value is equal to IDR 0. This situation often leads to the over-exploitation of fish stocks as well as the long-term sustainability of the fishery.

DISCUSSION

Table 8 provides the catch for maximum sustainable yield (CMSY) conditions, with 493,012 kg/year being caught, and the effort value (EMSY) for each trip is 170 trips per year. The catch value under Maximum Economic Yield (C_{MEY}) conditions is 474,424 kg per year and the effort value (E_{MEY}) is 127 trips per year. The catch in the Open Access Equilibrium (C_{OAE}) condition is 337,761 kg per year and the effort value (E_{OAE}) is 363 trips per year. For more detail, it can be seen from the following Fox model catch-effort and balance graph in Figure 3 and Figure 4.

The Fox model balance graph (Figure 4) shows that TR_{MSY} is greater than TR_{MEY} and TC_{MSY} is greater than TC_{MEY}, but the MEY profit is greater than the profit generated during MSY conditions, so the value of Total Revenue (TR_{MEY}) is greater at IDR 6,752,544.573. Under

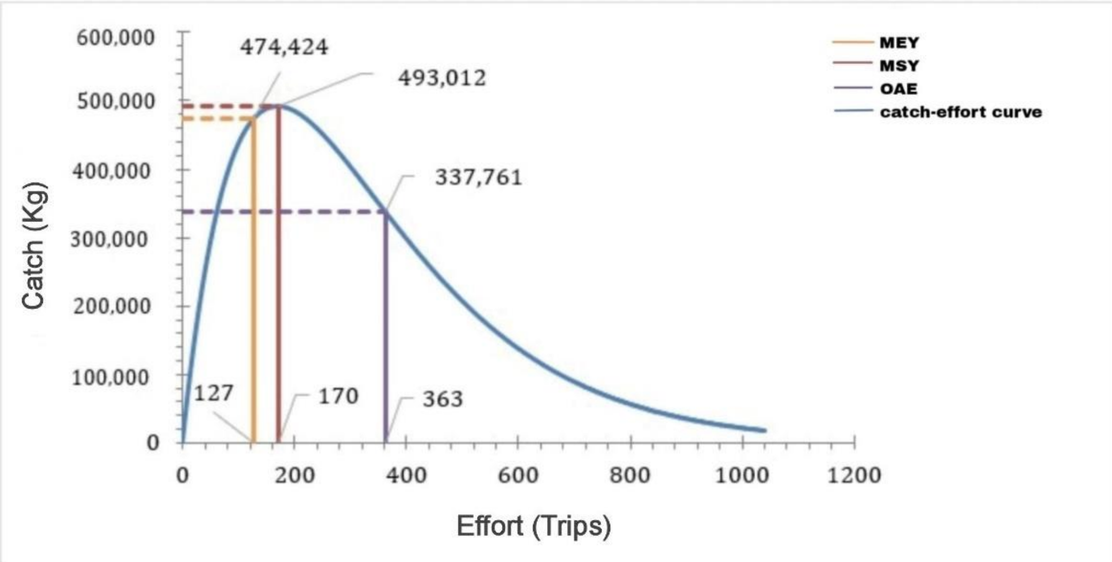

Figure 3 Fox model catch-effort graph

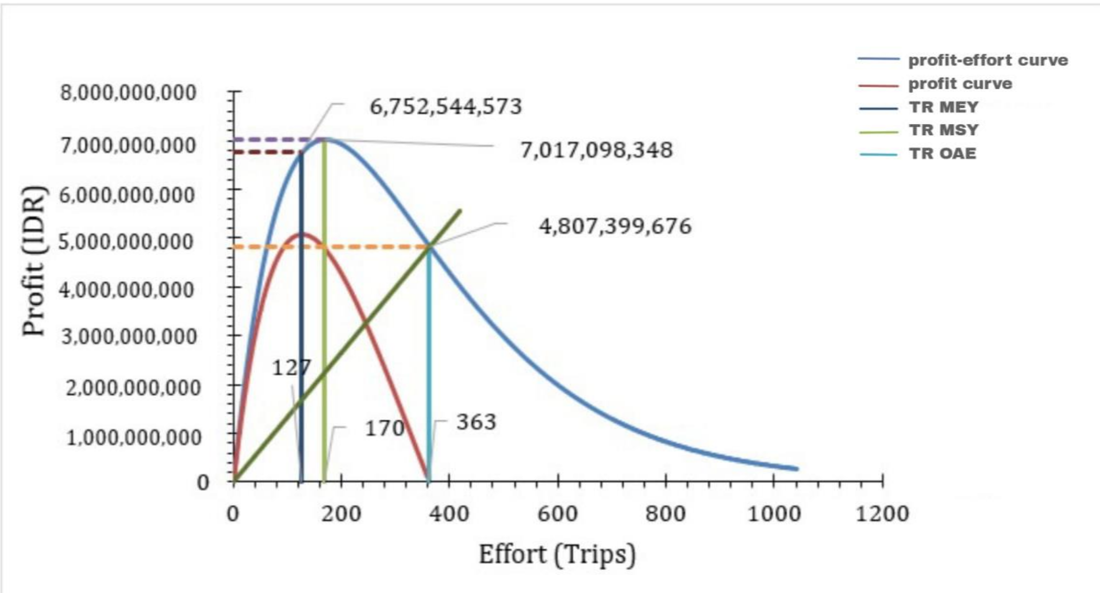

Figure 4 Fox model balance graph

MSY conditions (EMSY), the effort required is greater than under MEY conditions, which leads to a lower total cost (TCMEY) under MSY conditions, specifically IDR 1,681,299. The fishing condition at the MEY point is the optimal point when the MEY production (C_{MEY}) obtained is a lot but the fishing effort made (E_{MEY}) is less than during MSY conditions so that it can generate greater income and profits. Under MEY conditions, IDR 5,071,245.038 can be obtained, while under MSY conditions, it can be obtained with IDR 4,768,675.442. The profit of skipjack tuna fishing is at its maximum point during MEY conditions, as evidenced by this.

In bioeconomic studies using the Fox model, a decreasing rate of fishing effort is taken into account, while the Gordon-Schaefer model does not use the assumption of a decreasing rate but uses the assumption of a constant rate (Chen & Liu 2023). The Fox and Gordon-Schaefer models' TR, TC, profit, and E curves also differ. However, the profit obtained is much different in the OAE condition between the Fox and Gordon-Schaefer models. The decreasing rate of fishing efforts influences this. If the decreasing rate of fishing effort is close to zero (or close to constant), then the curves obtained from the Fox model and the Gordon-Schaefer model are almost the same or coincide (Hutagalung *et al*. 2015). During 2015-2021 the average level of effort in the skipjack fishery based on the Fox model is presented in Table 10.

In the condition of large catch that can be taken from species' stock over an indefinite period the averages of the level of effort was the same i.e. 70% which could be referred to as fully-exploited (Pham *et al*. 2023). Whether 70% is considered fully exploited depends on the specific circumstances of the fishery in question. It's a nuanced determination that requires careful analysis and management to ensure sustainability.

Table 10 shows that the average level of effort in skipjack tuna fisheries is 70%, the highest was in 2017 at 97%. While the lowest was in 2020 at 42%. This indicates that the existing effort rate in Sadeng CFP has not exceeded E_{MSY}, so it is still possible to increase fishing efforts. It should be done with a comprehensive understanding of the fishery's dynamics and under careful management to ensure long-term sustainability and economic viability. It's also important to note that E_{MSY} is not a fixed point but can change over time due to environmental changes, market conditions, and improvements in fishing technology.

CONCLUSION

Skipjack tuna research with 30 GT to 80 GT of vessels in the Southern Waters of Yogyakarta using the Fox model, the sustainable effort rate was 70% or 119 trips of the E_{MSY} value, which was to be increased to 80% (136 trips) as a precautionary measure. Although these calculation results are almost

Table 10 Level of effort based on Fox model analysis

Years	Actual Catch (Kg)	Actual Effort (Trips)	E_{MSY} (Trips)	Level of effort
2015	510,014	162	170	95%
2016	187,368	140	170	82%
2017	887,524	164	170	97%
2018	482,115	111	170	65%
2019	403,978	87	170	51%
2020	373,823	72	170	42%
2021	557,385	91	170	54%
Average		118		70%

Table 11 Level of effort based on Gordon-Schaefer model analysis

Years	Actual Catch (Kg)	Actual Effort (Trips)	E_{MSY} (Trips)	Level of effort
2015	510,014	162	168	96%
2016	187,368	140	168	83%
2017	887,524	164	168	98%
2018	482,115	111	168	66%
2019	403,978	87	168	52%
2020	373,823	72	168	43%
2021	557,385	91	168	54%
Average		118		70%

the same, the Fox was better than the Gordon Schaefer model because of its dynamic and prevents species extinction on account of how living creatures can recover as shown on the graph.

SUGGESTION

I want to suggest that the skipjack tuna fishery is not underfished yet, we have to take a precautionary approach with increased effort and careful analysis and management to ensure sustainability. Further research on small vessels under 30 GT is needed to uncover this research.

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