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STOCK RECOVERY EFFORTS OF SHORTFIN MAKO SHARK (*Isurus oxyrinchus* Rafinesque, 1810) LANDED AT CILACAP OCEAN FISHING PORT (PPS Cilacap)

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ABSTRACT

The high exploitation rates of several shark groups in Indonesia have the potential to threaten the sustainability of their populations. The shortfin mako shark *(Isurus oxyrinchus*) represents one of the most significant catches of shark species in the Indian Ocean, with a considerable portion of these catches landing at the Cilacap Ocean Fishing Port. Studies on the recovery of shark stocks must be conducted to provide effective management plans that will prevent overexploitation. The objective of this study is to ascertain the exploitation status of *I. oxyrinchus* and to develop a simulation model for its stock recovery. The data on the total catch of shortfin mako shark (*I. oxyrinchus*) in the period between 2009 and 2022 in the statistical report of Cilacap Ocean Fishing Port, were subjected to analysis using the CMSY (Catch-based Maximum Sustainable Yield) method. The analysis demonstrated that the total sustainable catch (MSY) was 9.6 tons, with an exploitation rate of 2.61. The utilization rate falls within the red zone, indicating that overfishing has occurred. The simulation results from several stock recovery scenarios indicated that a reduction in fishing mortality to 5% of FMSY (fishing mortality) would be required to achieve stock recovery in approximately 10 years. The implementation of stock recovery for *I. oxyrinchus* by reducing fishing pressure can be achieved by setting a maximum catch limit. Therefore, the establishment of a maximum catch limit represents a crucial conservation effort for this species, as well as a form of implementation of the CITES policy in Indonesia.

Keywords: CITES; CMSY; *Isurus oxyrinchus*; Recovery stock

INTRODUCTION

Indonesia is the world's largest producer of shark fisheries, with significant catches and a diverse range of species traded in both domestic and international markets (White et al., 2006; FAO, 2019). Although sharks are frequently caught as bycatch, the high economic value of their products, particularly fins, meat, and oil, is driving increased demand and exploitation (Fahmi et al., 2013; Wujdi et al., 2021). As top predators in marine ecosystems, sharks exhibit relatively slow growth and reproduction rates, rendering their populations susceptible to intensive fishing pressure (Dulvy et al., 2014). The high exploitation rates of certain shark groups pose a significant threat to the sustainability of their populations (Chodrijah & Faizah, 2021; Fahmi et al., 2013; Stevens et al., 2000). A decline in shark populations not only jeopardizes the stability of marine ecosystems but also compromises the resilience of future fisheries resources (Heupel et al., 2014; Roff et al., 2016). Therefore, enhanced management strategies are imperative to prevent the threat of overfishing and conserve sharks in Indonesian waters.

The shortfin mako shark (*Isurus oxyrinchus* Rafinesque, 1810) is a large oceanic and pelagic predatory shark with a fairly wide distribution in tropical and subtropical waters with warm temperatures (Compagno, 2002; White et al., 2006; Marin and Fariaz, 2009). In Indonesian waters, the shortfin mako shark *(I. oxyrinchus*) is a type of mako shark found in the Indian Ocean, ranging from western Sumatra to southern Nusa Tenggara (Fahmi et al., 2013; Ichsan et al., 2019). The shortfin mako shark (*I. oxyrinchus* Rafinesque, 1810) is included in the Convention on International Trade in Endangered Species (CITES) Appendix II list (Fahmi, 2018) and the International Union for Conservation of Nature (IUCN) Red List, categorized as endangered (Rigby et al., 2019). This necessitates regulatory measures to ensure its utilization aligns with the provisions of the CITES convention, particularly concerning the sustainable and traceable management of this species. The objective of shark management is to guarantee that utilization is conducted in a legal, sustainable, and traceable framework (Oktaviyani et al., 2019; Raharjo et al., 2024).

The recovery of shark stocks is an essential component of any shark utilization management policy, and thus the present research is of great importance. Fish resource stocks must be managed with due consideration to ensure the maintenance of biodiversity and the optimal utilization of their potential (Bardey, 2019; Hasan et al., 2017; Nurdin et al., 2023). A stock status baseline study is required to determine the current status of shark stocks and to recommend the optimal management strategy for shark fisheries in Cilacap Ocean Fishing Port, Central Java Province. In general, population estimates for several shark species in their natural habitats remain unavailable. The limited data and information on biological aspects, capture, and exploitation rates have resulted in the development of stock assessment methods that require fewer data requirements than classic stock assessment methods, such as the use of catch data (Froese et al., 2017; Zhou et al., 2018). The objective of this study is to analyze the exploitation status of *I. oxyrinchus* and to simulate its stock recovery using the CMSY (Catch-based Maximum Sustainable Yield) method.

RESEARCH METHODS

Data and Sources

The study was conducted by assessing the total sustainable catch using secondary data. The secondary data used is the total catch data of shortfin mako sharks (*I. oxyrinchus*) from the Cilacap Ocean Fishing Port (PPS Cilacap) fisheries statistics in 2009 - 2022. Cilacap Ocean Fishing Port (PPS Cilacap) is a shark landing center with a fishing area covering the Fisheries Management Area (WPP) 573, namely the Indian Ocean waters south of Java, Bali, and Nusa Tenggara.

Data Analysis

The total sustainable catch was analyzed using the CMSY method developed by Froese *et al*., (2017). Based on the Schaefer production model :

$$B_{t+1} = B_t + rB_t\left(1 - \frac{Bt}{k}\right) - C_t \quad (1)$$

biomass in year t + 1 (Bt + 1), intrinsic population growth rate (r), carrying capacity (k), biomass in year t (Bt), and catch in year t (Ct). This production model simulates annual catch data as a series of catches from available biomass with a certain level of productivity. If two of the three variables, namely catch, biomass, and productivity are known, then the third variable can be estimated. The CMSY method uses catch (C) and productivity (r and k values) to estimate biomass (B), exploitation rate, and MSY. The stages of CMSY analysis are as follows:

Determination of The Range of r – k Values

The r value can be determined based on the resilience level of the species, which can be seen on the Fishbase site. The resilience value of the *I. oxyrinchus* species is “low” so the r value ranges from 0.05 – 0.5 (Table 1).

Table 1 . Range of r Values

Range of r values	Resilient
0.6 – 1.5	tall
0.2 – 0.8	medium
0.05 – 0.5	low
0.015 – 0.1	very low

The value of k can be found using the equation below.(Froese *et al*., 2017)

$$k_{low} = \frac{\max(C)}{r_{high}},\ k_{high} = \frac{4\max(C)}{r_{low}} \quad (2)$$

$$k_{low} = \frac{2\max(C)}{r_{high}},\ k_{high} = \frac{12\max(C)}{r_{low}} \quad (3)$$

Equation (2) is used if the trend in catch data in the last year is decreasing, while equation (3) is used if the catch in the last year has increased.

Estimation of The Determination of The Feasible Value of r and k Pairs

The pair of r and k values are used to predict biomass values based on equation [1]. The Monte Carlo approach is used to detect a pair of 'reasonable' r k values, namely producing an estimated biomass value of not less than 1% of the k value and not exceeding the k value (Carvalho *et al*., 2014), and is within the range of biomass values based on the conditions of fish resource utilization. (Table 2).

Table 2. Range of Biomass Values Based on Fish Resource Utilization Conditions(Froese *et al*., 2020)

Conditions of Use	Biomass Value Range
Very high	0.01 – 0.2
Tall	0.01 – 0.4
Currently	0.2 – 0.6
Low	0.4 – 0.8

The r and k values that are feasible to be used to determine the reference value of fisheries status are MSY = rk/4, fishing mortality that produces MSY (F_{MSY}) = 0.5r, and biomass that produces MSY (B_{MSY}) = 0.5k (Ricker, 1975). This CMSY analysis was carried out using R software version 4.2.2 with the CMSY analysis code downloaded from http://oceanrep.geomar.de/33076/ (accessed on February 3, 2022). The total sustainable catch of *I. oxyrinchus* sharks calculated using the CMSY method will provide information on the highest fish stock that can be caught from an existing potential without affecting the sustainability of the fish stock. This MSY value also shows the potential for sustainable catch of a type of fish, which can be used as a reference in determining its utilization status.

Stock Recovery Status and Scenarios

CMSY provides a reference point that can be used to evaluate the stock status. The results of the CMSY analysis can also be used to assess the future stock status in several exploitation scenarios implemented in the modified Schaefer model, as follows:

$$\frac{B_{t+1}}{B_{MSY}} = \frac{B_t}{B_{MSY}} + 2F_{MSY}\frac{B_t}{B_{MSY}}\left(1 - \frac{B_t}{2B_{MSY}}\right) - \frac{B_t}{B_{MSY}}F_t \ \ ketika\ \frac{B_t}{B_{MSY}} \geq 0{,}5 \quad \text{....(4)}$$

$$\frac{B_{t+1}}{B_{MSY}} = \frac{B_t}{B_{MSY}} + 4F_{MSY}\left(\frac{B_t}{B_{MSY}}\right)^2\left(1 - \frac{B_t}{2B_{MSY}}\right) - \frac{B_t}{B_{MSY}}F_t \ \ ketika\ \frac{B_t}{B_{MSY}} < 0{,}5. \quad (5)$$

$$F_{red} = 2F_t\,\frac{B_t}{B_{MSY}} \quad (6)$$

The four simulated exploitation scenarios are as follows:

1) 0.05 F_{MSY}, implies no fishing activity when biomass falls below 0.5 B_{MSY} (B < 0.5); otherwise, maintains the fishing mortality rate (F) at 0.05 F_{MSY} (F = 0.05 F_{MSY}).
2) 0.2 F_{MSY}, with F set at 0.2 F_{MSY} when B ≥ 0.5 B_{MSY}; however, F decreases linearly to zero when biomass decreases below 0.5 B_{MSY}. The reduction in fishing mortality (F_{red}) was calculated using Equation [6].
3) Exploitation scenario 0.35 F_{MSY}, with F set at 0.35 F_{MSY} when B ≥ 0.5 B_{MSY}; otherwise, F also decreases linearly.
4) Exploitation scenario 0.5 F_{MSY}, with F fixed at 0.5 F_{MSY}.

Changes in stock biomass and catch were predicted and compared under four exploitation scenarios. The catch in 2023 was the starting point for the simulation, and the fishing pressure in 2022 determined the biomass and catch estimates for the period 2023–2024. Resource recovery was estimated under the four exploitation scenarios. All analyses were conducted in R software version 4.2.2 using the CMSY forecasting methodology, modified for single-species fisheries. The code was downloaded from https://github.com/SISTA16/cmsy_multispecies_forecast/ (accessed 30 October 2023).

RESULT AND DISCUSSION

Shortfin mako sharks (*I. oxyrinchus*) display several distinctive morphological characteristics, including the presence of a hard keel on the lateral aspect of the tail base (1), short pectoral fins that are shorter than the length of the head (2), relatively small eyes (3), and a sharp snout (4) with smooth front teeth that have curved tips (5) (White et al., 2006). The shortfin mako shark (*I. oxyrinchus*) is a member of the Lamnidae family of sharks that frequently interacts with tuna fisheries. As an apex predator, this shark species is widely distributed in coastal to offshore waters and is classified as one of the fastest marine fish in the world, with a swimming ability of up to 70 km/h (Compagno, 2001). Like other sharks in the Lamnidae family, this species has a low regeneration rate due to oophagy, which involves embryos cannibalizing embryos that fail to develop during pregnancy in the uterus (Ebert et al., 2013). Therefore, the number of pups produced by female broodstock is relatively low, with a range of 2 to 18 (Ebert et al., 2013; Mollet & Cailliet, 2002). The low regeneration rate, slow growth characteristics, and long lifespan of over 30 years render this shark species highly vulnerable to overfishing pressure (Campana et al., 2005).

Figure 1. Morphological Characteristics of *I. oxyrinchus* (White *et al.*, 2006)

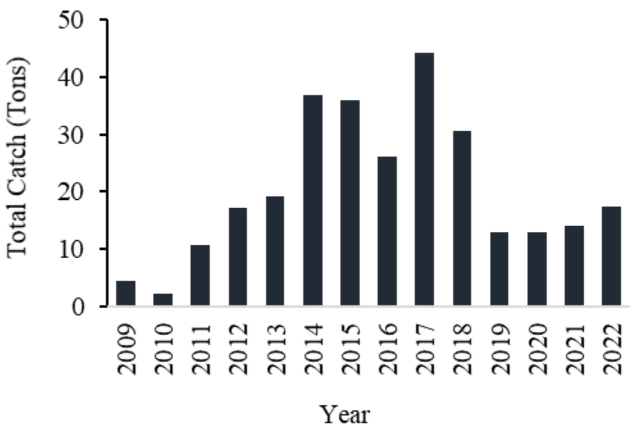

Figure 2. Total catch *of I. oxyrinchus* (PPS Cilacap Fisheries Statistics Report, 2009-2022)

The tabulation of the total catch of shortfin mako shark (*I. oxyrinchus*) based on the fisheries statistics of Cilacap PPS was presented in Figure 2. The data indicate that the number of mako sharks landed at Cilacap Ocean Fishing Port increased from 2009 to 2017, and reached a peak of 44 tons in 2017. The elevated value may be attributed to the heightened activity of tuna fishing in the Indian Ocean waters, thereby increasing the likelihood of shortfin mako sharks being caught in both artisanal (Dharmadi et al., 2013; Sembiring et al., 2015; Ehite et al., 2006) and industrial-scale fisheries (Setyadji & Nugraha, 2012). The total catch of shortfin mako sharks from 2009 to 2022, analyzed using the CMSY method was presented in Table 3.

Table 3. CMSY Analysis Results

Parameter	Mark	95%Cl
F_{MSY} (year $^{-1}$)	0.031	0.019-0.049
MSY (10^3 tons)	0.009	0.006-0.017
B_{MSY} (10^3 tons)	0.312	0.151-0.643
Biomass in 2022	0.215	0.098-0.248
B/B_{MSY} in 2022	0.689	0.313-0.797
F in 20222	0.081	0.071-0.179
Exploitation rate (F/F_{MSY})	2,615	2,263-5,763

The fishing mortality rate of *I. oxyrinchus* in 2022 (Table 3) was 0.081 year-1, which exceeded the maximum Fishing mortality rate (FMSY = 0.031 year-1). The exploitation value (F/FMSY) of *I. oxyrinchus* in 2022 (2.61) exceeded 100% of the maximum sustainable limit. This level of utilization indicates that the species has been subjected to an overfishing status, wherein the catch has exceeded the total sustainable catch (MSY) value of 9.67 tons from 2011 to 2022. Figure 3 illustrates the output of the *I. oxyrinchus* CMSY analysis. As illustrated in the catch graph, the catch of shortfin mako sharks has exceeded the MSY value limit since 2012, reaching a peak in 2017. Although there was a decline in the catch trend from 2018 to 2019, it has increased again over the past three years. This is also evident in the biomass graph, which shows a decrease in biomass below the sustainable threshold (B/BMSY = 1) occurring in 2017

Based on the "Kobe" plot (Figure 4), there has been a gradual depletion of *I. oxyrinchus* stocks since 2011. In 2017-2022, the stock has started to enter the red zone. The red zone describes the depleted stock biomass that is no longer able to produce MSY due to continuous exploitation (Alam et al., 2021). On the other hand, the green area indicates a safe area for fishing, where MSY is achieved through sustainable fishing and a healthy biomass. The orange zone indicates an emerging risk of overfishing due to increased fishing pressure on fish stock biomass, and the yellow zone indicates a recovery phase characterized by decreased fishing pressure. Looking at the exploitation trend of the *I. oxyrinchus* stock, it appears that the mako shark stock has entered the red zone in 2017-2022, indicating a level of overexploitation (overfishing) that requires efforts to recover the stock in the natural environment. The conservation status of shortfin mako sharks globally is known to be endangered according to the IUCN Red List, and in some waters, it has even been classified as critically endangered (Rigby et al., 2019). The catch of shortfin mako sharks in the Hinfia Ocean in 2019 was 1,087 tons, with an average catch of 1,789 tons over the last 5 years (IOTC, 2020). Although the current stock status in the Indian Ocean is unknown, fishing pressure on tuna and other pelagic fish may affect shortfin mako sharks as they are often bycatch in these fisheries. This is an issue that threatens the sustainability of shortfin mako shark populations.

Shortfin mako shark meat is also recognized as a significant economic commodity in numerous European and American countries (Dent & Clarke, 2015), which resulted in its inclusion in Appendix II of CITES in 2019. Furthermore, the management of international trade activities is essential to ensure the sustainability of this resource. As a CITES member country, Indonesia is obliged to conduct a Non-Detrimental Finding (NDF) study to ascertain whether the pressure exerted by shortfin mako shark fisheries in Indonesia can still ensure the sustainability of the species in its natural habitat (Oktaviyani et al., 2019)

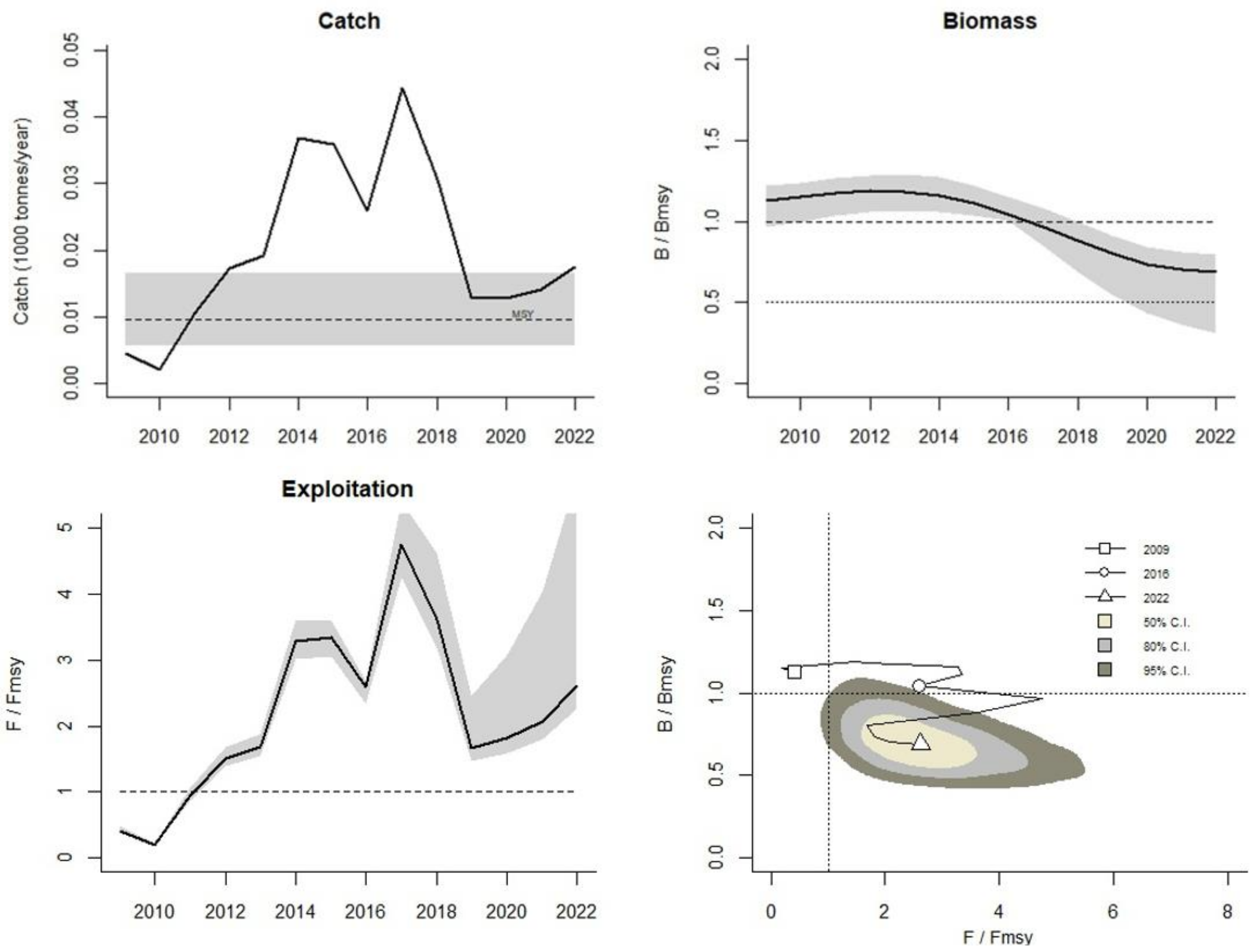

Figure 3. CMSY Analysis *Output for I. oxyrinchus*

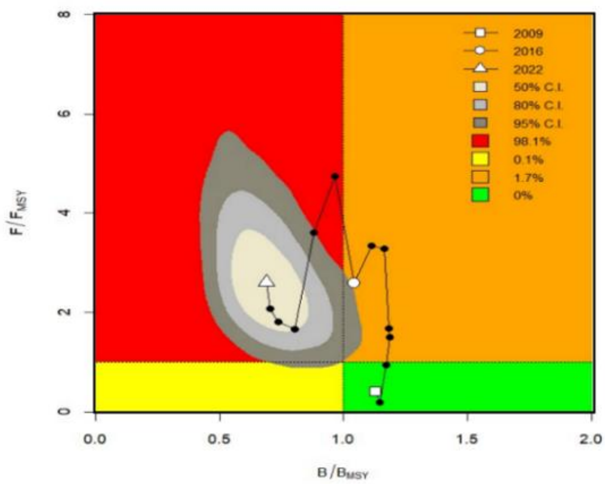

Figure 4. “Kobe” Plot Of Exploitation Level and Biomass

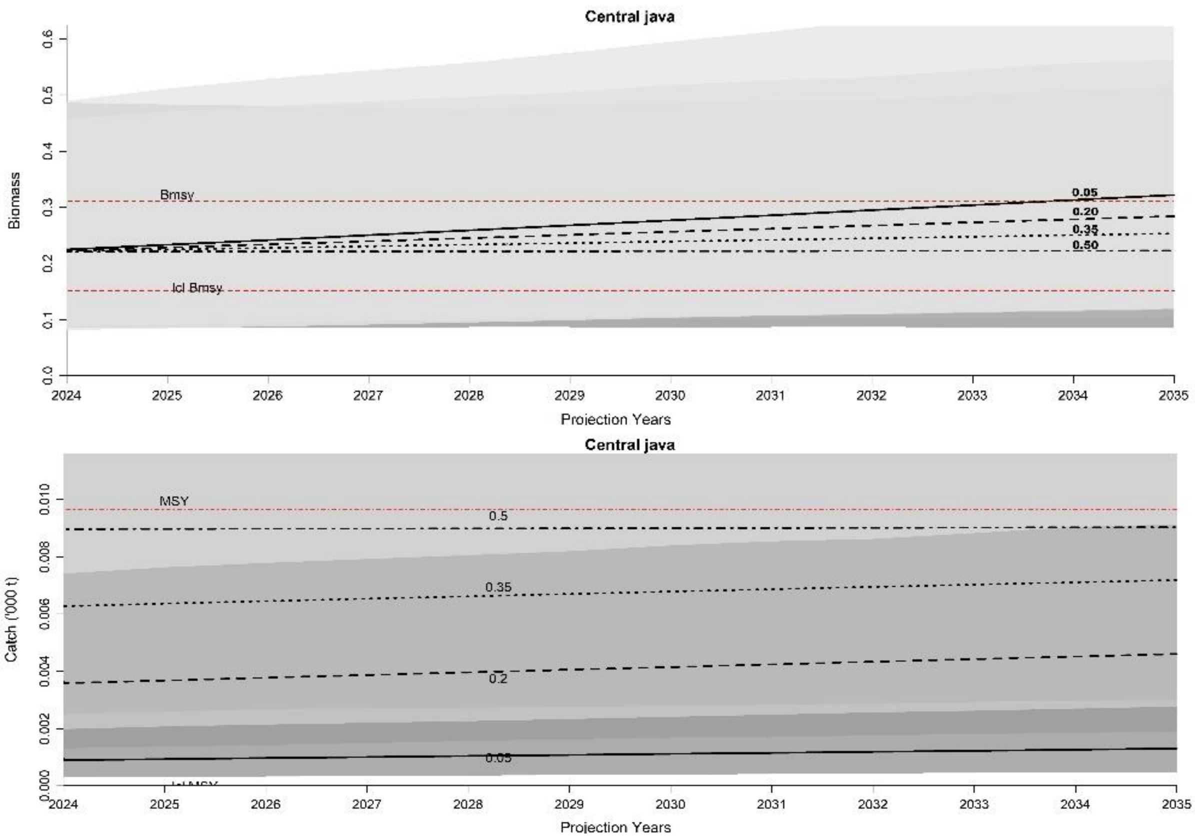

Figure 5. Simulation Results of Biomass and Catch Values Using 4 Exploitation Scenarios

Four exploitation scenarios were considered in the simulations of biomass and catch values. The four exploitation scenarios were 0.05 FMSY, 0.2 FMSY, 0.35 FMSY, and 0.5 FMSY. The simulation results indicate that the recovery of shortfin mako shark *(I. oxyrinchus*) biomass to a sustainable level (BMSY) is feasible by 2034, with an exploitation scenario of 0.05 FMSY (Figure 5). The other exploitation scenarios (0.2 FMSY, 0.35 FMSY, and 0.5 FMSY) resulted in the inability of the biomass to recover to a sustainable level until the conclusion of the simulation. The simulations indicate that a reduction in fishing effort by 95% of FMSY could facilitate the recovery of the shortfin mako shark (*I. oxyrinchus*) stock to sustainable levels, although this would require a significant time frame. This reduction in fishing effort could be achieved through the implementation of maximum catch restrictions (fishing quotas).

Based on the results of a simulation model that estimates the biomass and catches of shortfin mako sharks *(I. oxyrinchus*), the allowable quota for a sustainable yield is approximately 1 ton per year. Assuming that mako sharks reach reproductive maturity at 275 kg (Natanson et al., 2020), this quota is equivalent to approximately five fish per year, which would be challenging to support in the context of sustainable stock recovery. A moratorium on mako shark fishing in Cilacap PPS is imperative to provide an opportunity for this stock to recover to more sustainable levels. A moratorium accompanied by regular monitoring and evaluation will ensure more accurate data on stock status and the effectiveness of recovery measures. This step is expected to support the sustainability of the shortfin mako shark *(I. oxyrinchus)* population while maintaining the balance of the marine ecosystem and assisting the implementation of species protection policies following CITES regulations in Indonesia.

CONCLUSION

The total sustainable catch (MSY) of shortfin mako shark (*I. oxyrinchus*) was 9.67 tons, with an exploitation rate of 2.61. Since 2012, the utilization rate has been over the threshold for overfishing. The 0.05 FMSY scenario illustrates a potential trajectory of stock recovery, ultimately leading to the attainment of sustainable biomass (BMSY). These findings may be utilized in the formulation of a utilization policy for the shortfin mako shark (*I. oxyrinchus*) in Fisheries Management Area (WPP) 573, which encompasses the Indian Ocean waters south of Java, Bali, and Nusa Tenggara. The establishment of a maximum allowable catch through the implementation of catch limits is an essential measure for the conservation and restoration of shortfin mako populations in the wild. Additionally, this strategy aligns with Indonesia's obligations under the CITES policy.

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