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Stock Status of Skipjack Tuna (*Katsuwonus pelamis* Linnaeus, 1758) using Length-Based Assessment in Cenderawasih Bay, Indonesia

(Status Stok Tuna Skipjack (*Katsuwonus pelamis* Linnaeus, 1758) menggunakan Penilaian Berasaskan Panjang di Teluk Cenderawasih, Indonesia)

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ABSTRACT

The West Pacific and the waters of Cenderawasih Bay are potential fishing grounds and part of the fishery management area (FMA) 717 of the Republic of Indonesia. Increased production demand may result in overfishing, which has led to the depletion of fish stocks. To ensure the long-term viability of these fisheries, effective management practices are essential. This study aims to examine size distribution, growth, and population parameters that can be used as fish resource management inputs for skipjack fisheries in Cenderawasih Bay. Length-based approach was used to estimate biological parameters and the dynamics of populations as well as the stock status within data-limited fisheries. Length frequency data was used to assess the *Katsuwonus pelamis* fisheries condition. From January to November 2021, in all of 2,211 fish were taken samples from numerous commercial small-scale vessel units that were operating around anchor fish aggregating devices (FADs). The results showed that the exploitation rate (E) was 0.69 year^{1}, L_{∞} = 96.8 cm fork length (cmFL), k= 0.38 year^{-1}, and t_0= -0.31 year. Natural mortality (M) was 0.66 year^{-1}, fishing mortality (F) was 1.46 year^{-1}, and total mortality (Z) was 2.12 year^{-1}. Overfishing condition has occurred according to the current fishing mortality rate (F_{cur}=1.46 year^{-1}), which has exceeded the reference point of maximum fishing mortality (F_{max} =0.76 year^{-1}) and $F_{40\%}$ (0.9 year^{-1}). The growth overfishing condition was indicated based on the current selectivity of handline (Lc_{cur}=42 cm), which is smaller than the optimal selectivity of L_{max} (55 cm). Some management tools, such as the regulation on minimum size of hooks and the total allowable catch (TAC) system, can be utilized to consider skipjack tuna fisheries sustainability in Cendrawasih Bay.

Keywords: Exploitation rate; fisheries; growth; handline

ABSTRAK

Pasifik Barat dan perairan Teluk Cenderawasih merupakan kawasan perikanan berpotensi dan sebahagian daripada Kawasan Pengurusan Ikan (Wilayah Pengelolaan Perikanan 717) Republik Indonesia. Peningkatan permintaan pengeluaran boleh menyebabkan penangkapan ikan berlebihan yang telah membawa kepada penurunan stok ikan. Untuk memastikan kelangsungan hidup jangka panjang ikan ini, amalan pengurusan yang berkesan adalah penting. Penyelidikan ini bertujuan untuk mengkaji taburan saiz, pertumbuhan dan parameter populasi yang boleh digunakan sebagai input pengurusan sumber ikan untuk memancing skipjack di Teluk Cenderawasih. Pendekatan berasaskan panjang digunakan untuk menganggar parameter biologi dan dinamik populasi serta status stok dengan data yang terhad. Data frekuensi panjang digunakan untuk menganalisis keadaan perikanan *Katsuwonus pelamis*. Dari Januari hingga November 2021, semua 2,211 ikan diambil sampel daripada pelbagai unit kapal komersial berskala kecil yang beroperasi di sekitar peranti agregasi ikan (FADs). Keputusan menunjukkan bahawa kadar eksploitasi (E) adalah 0.69 tahun^{-1}, L∞ = 96.8 cm, panjang cabang (cmFL), k = 0.38 tahun^{-1} dan t_0 = -0.31 tahun. Kematian semula jadi (M) ialah 0.66 tahun^{-1}, kematian akibat perikanan (F) ialah 1.46 tahun^{-1} dan kematian keseluruhan (Z) ialah 2.12 tahun^{-1}. Keadaan penangkapan ikan berlebihan telah berlaku mengikut kadar kematian semasa (F_{cur}=1.46 tahun^{-1}) yang telah melebihi titik rujukan F_{max} (0.76 tahun^{-1}) dan $F_{40\%}$ (0.9 tahun^{-1}). Keadaan pertumbuhan penangkapan ikan berlebihan dinyatakan berdasarkan pemilihan pancing semasa (Lc_{cur}=42 cm), lebih kecil daripada pemilihan optimum L_{max} (55 cm). Sesetengah alatan pengurusan seperti peraturan mengenai saiz minimum mata kail dan jumlah system tangkapan yang dibenarkan (TAC) boleh digunakan untuk mempertimbangkan kestabilan perikanan tuna skipjack di Teluk Cendrawasih.

Kata kunci: Kadar eksploitasi; pancing; perikanan; pertumbuhan

INTRODUCTION

Fisheries are shared resources that all parties are allowed to utilize together. Utilization of resources from fisheries, including skipjack tuna fisheries, is currently indicated to be increasing because of strong market demand of the target species. The continuous increase in demand puts pressure on skipjack fishing. The long-term effects will have an influence on fish stock sustainability. Therefore, a management concept for controlling a sustainable yield is needed. The high demand for fish as a source of protein has led to more intensive fishing efforts and increased catch production. If this continues, it can lead to a decrease in the size of the fish caught and a reduction in the number of adult fish that could spawn. Furthermore, fish will have limited opportunities to spawn if the size is reduced, which would impact the growth population and recruitment. The depletion of fish stocks could potentially lead to overfishing (Guiry et al. 2021; Nurdin et al. 2016).

The Republic of Indonesia's Fisheries Management Area (FMA) 717 includes the waters of Cenderawasih Bay and the West Pacific region, which are potential fishing areas, particularly for tuna and tuna-like species. This bay has a national park and relates to the Pacific Ocean in the north, as stated by Hisyam et al. (2020). Based on the summary report of the Fifteenth Regular Session of the Scientific Committee 2019 of Western and Central Pacific Fisheries Commissions (WCPFC, 2019), and the Ministry of Marine Affair and Fisheries (MMAF 2021), stock status of skipjack tuna in Western and Central Pacific including Cenderawasih Bay waters is in good condition.

As stated by Li et al. (2020) and Sin et al. (2024), global fishing fleets are significantly overcapacity, and most marine fish stocks are overfished. The number of captured fisheries in the world has decreased significantly in recent years, with some fisheries collapsing because of poor management, overfishing, and overexploitation. Evaluating the behavior of fishing fleets and management strategies in specific fisheries is a crucial aspect of sustainable fisheries management. According to Monteiro (2017) and Sin et al. (2024) management agencies will need to develop legally binding, and thoroughly examined harvest plans in the future, together with appropriate rights-based incentives for the fishing community.

Skipjack tuna (*Katsuwonus pelamis*) dominate the large pelagic fish catches of fishers from FMA 717. Skipjack tuna occurs in the Pacific, Indian, and Atlantic oceans. In the Pacific Ocean, they are distributed across a larger area of tropical and subtropical waters in the Western Pacific, but in the Eastern Pacific, they only occur in tropical waters (Kiyofuji & Ochi 2016). Skipjack tuna accounts for about 70% of the total tuna landings in the Pacific Ocean (IATTC 2016; Williams & Terawasi 2016). A large proportion (~76% in 2018) of Indonesia's skipjack tuna caught in the western and central Pacific Ocean comes from Indonesian Archipelagic Waters (IAW), including the Indonesian Fisheries Management Areas (FMAs) 713, 714, and 715 (Satria et al. 2021); and also by far the most commonly caught tuna in the world, both in terms of the total number and weight (Galland, Rogers & Nickson 2016; International Seafood Sustainability Foundation (ISSF) 2023).

This species, along with yellowfin tuna (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*) has a high commercial value in the world, as stated by Arrate et al. (2021), with Indonesia as one of the tropical countries with high skipjack tuna production (Putri & Zainuddin 2019). One of the most significant fisheries in Nabire, the Province of Central Papua is skipjack tuna fishery, where skipjack tuna is the second highest fishery production after tuna in Nabire (Table 1), where fishing areas are in Cenderawasih Bay (Figure 1). In Nabire, the fishers mostly use handlines as their primary fishing gear to harvest large pelagic fish resources and operate around an anchored fish aggregation device (FAD).

Management of fisheries resources should be done based on the precautionary approach principle to protect fish resources. A length-based approach has been used to estimate biological parameters and the dynamics of populations within data-limited stocks. A holistic stock assessment is challenging for *K. pelamis* stock in Cendrawasih Bay due to unreported data and a lack of data for the annual catch and catch per unit effort (CPUE) data sets. The objective of this research was to examine the size distribution, growth, and population parameters of skipjack tuna that could be used as baseline information in reviewing and managing the fish resource in Cenderawasih Bay. Therefore, this study used a length-based approach as an indicator to determine the stock status in a relatively short period. Moreover, the length-based approach can also be used as an indicator in determining optimal selectivity, which cannot be determined in some other analyses.

MATERIALS AND METHODS

DATA COLLECTION

Data collection was conducted in Nabire from February to November 2021 at three fishing village as the observation location, which are Waharia, Smoker, and Kalibobo (Figure 1). The fishing gear used by fishers to catch skipjack tuna was a handline, consisting of monofilament line numbers 400 to 800 and hook sizes numbers 8 to 12. Measurements of 2,211 fish samples were carried out by two enumerators using a measuring board with an accuracy of 1 mm. The measured fish samples were taken when the fishers landed the catch at the landing site from 56 vessel of 156 trips. Identification of fish species was based on Market Fishes of Indonesia, authored by White et al. (2013).

Operational fishing days at sea range from 1 to 7 days in Cenderawasih Bay with a crew of 1 to 3 person. Vessels are made of basic materials such as wood or fiberglass with lengths ranging from 8 to 15 m, widths of 1 to 1.2 m,

TABLE 1. Top 10 fishery production in Nabire District

No	Species	Production (Tons)					
		Years					
		2018	2019	2020	2021	2022	Average
1	Tunas	1,300	1,310	1,328	1,302	2,500	2,301
2	Skipjack	1,042	1,096	1,100	1,128	2,329	1,339
3	Snapper	429	429	425	498	757	1,051
4	Mackerel	910	989	905	813	1,320	987
5	Trevally	650	730	735	740	1,025	776
6	Anchovies	336	348	350	371	732	427
7	Wahoo	300	315	320	321	502	352
8	Frigate tuna	298	302	300	322	508	346
9	Sardinella	307	327	330	332	339	327
10	Scad	200	210	211	218	418	251

Source: Nabire district fisheries office

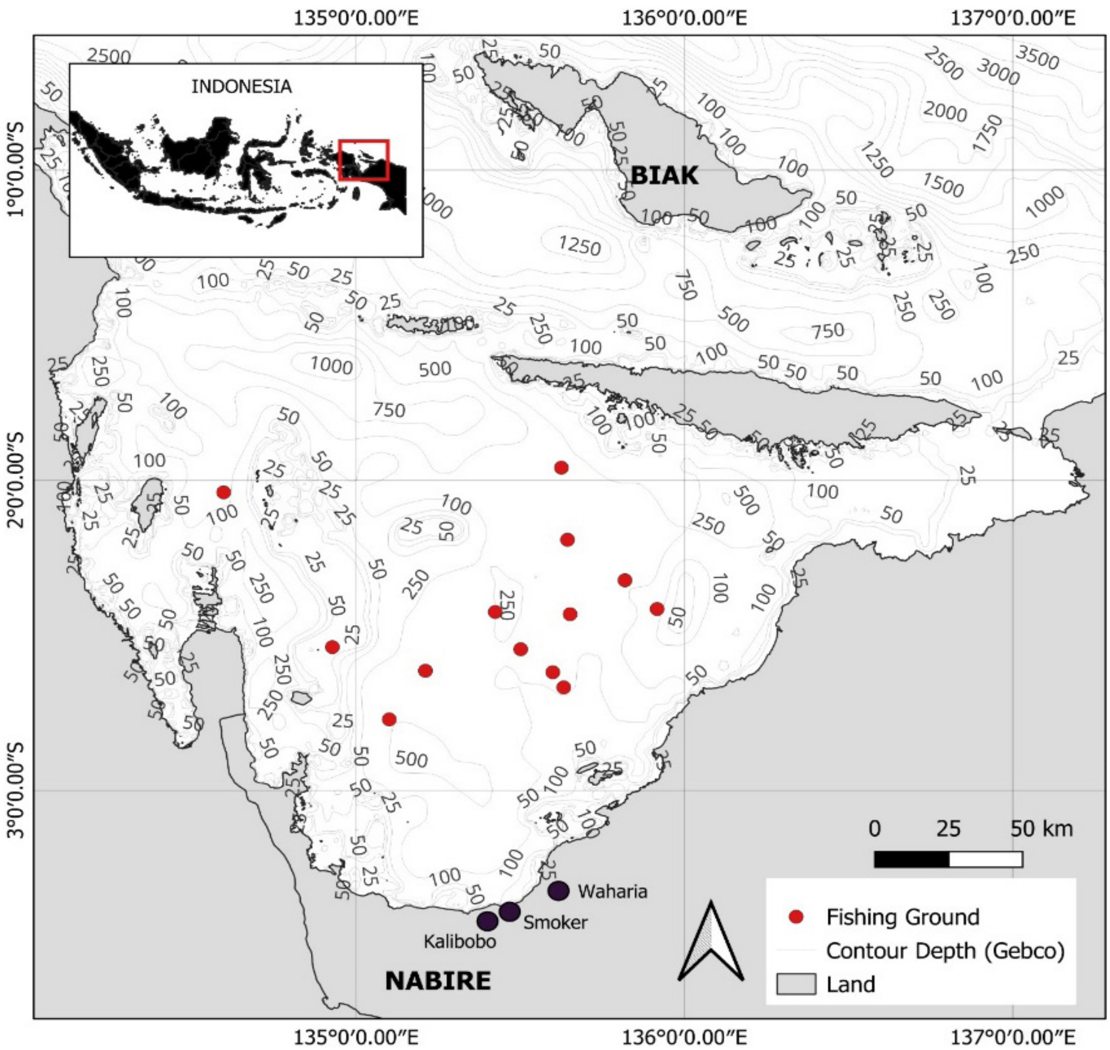

FIGURE 1. Skipjack tuna fishing ground at Cenderawasih Bay, landing site at Nabire district

and depths of 0.7 to 1 m and a main engine power of 15 horsepower (HP). The fishing ground of handline operation at Cenderawasih Bay were obtained from fishers GPS recordings (Figure 1).

DATA ANALYSIS

The length of skipjack tuna in this study stated in the centimeter of fork length (cm FL). The frequency of skipjack tuna composition in each length class was measured to determine the length at first capture. Logistic models were utilized to estimate the length at first capture. The equation used to compute the logistic curve (Pramulati et al. 2023; Sparre & Venema 1998; Tirtadanu et al. 2024) was:

$$SLest = \frac{1}{(1+e^{(S1-S2L-r(L-Lc))}} \; and \quad ln\left[\frac{1-P}{SLP}\right] - 1 = S1 - S2L; L_{50\%} = \frac{S1}{S2}.rLc - rL \tag{1}$$

where SL is a logistic curve; S1 is the intercept (a); and S2 is the slope (b).

Asymptotic length was used as an input parameter to compute the length at first maturity (Froese & Binohlan 2000; Nurdin, Kembaren & Tirtadanu (2023); Tirtadanu et al. (2023) and calculated as:

$$log_{10}L_m = 0.8979 \times log_{10}L_\infty - 0.0782 \tag{2}$$

where L_m is the length at first maturity; and L_∞ is the asymptotic length.

The FiSAT-II software's ELEFAN I module was utilized to estimate the growth parameters (K) and length infinity (L∞) (Gayanilo Jr., Sparre & Pauly 2005; Nurdin, Kembaren & Tirtadanu 2023).

Estimation of the theoretical age parameter (t_0) was determined by an empirical equation proposed by Pauly (1983), which also used by Nurdin, Kembaren and Tirtadanu (2023) and Widiyastuti and Tirtadanu (2024):(3)

$$Log\,(-t_0) = -0{,}3922 - 0{,}2752\; Log\, L_\infty - 1{,}038\; Log\, K \tag{3}$$

The age data was analyzed using the von Bertalanffy growth function of:

$$L_t = L_\infty\,(1 - e^{-K(t-t_0)}) \tag{4}$$

where t_0 is the theoretical age at zero length; K is the coefficient of growth; L_t is the length at age t; and L_∞ is the asymptotic length.

The age at length at first captured and length at first maturity were estimated using von Bertalanffy function (Sparre & Venema 1998), which also used by Nurdin, Kembaren and Tirtadanu (2023) and Tirtadanu et al. (2024):

$$t(L) = t_0 - \tfrac{1}{k} * \ln(1 - L/L_\infty) \tag{5}$$

where t_0 is the theoretical age at zero length; K is the coefficient of growth; L_∞ is the asymptotic length; and t(L) is age at length L.

Pauly's empirical equation (1983) was used to calculate natural mortality (M), while the length converted catch curve on FiSAT II software (Gayanilo Jr., Sparre & Pauly 2005; Nurdin, Kembaren & Tirtadanu 2023) provided the value of total mortality (Z):

$$Log\,(M) = -0{,}0066 - 0{,}279\; Log\, L_\infty + 0{,}6543\; Log\, K + 0{,}4634\; Log\, T \tag{6}$$

where the mean annual temperature is T (29 °C). Where the mean annual temperature of Cenderawasih Bay was >28 °C based on Darmawan et al. (2021) and Yoke et al. (2021).

Sparre and Venema (1998) formula (Nurdin, Kembaren & Tirtadanu 2023; Prihatiningsih et al. 2024) was also used to compute the exploitation rate (E) and fishing mortality (F):

$$F = Z - M \; and \; E = F/Z \tag{7}$$

The biological reference F_{max} and Lc_{max} was estimated using yield per recruit analysis. The maximum yield per recruit is given by F_{max} and Lc_{max} which are the fishing mortality and length at the first capture level. By calculating yield per recruit as a function of fishing mortality and length at first capture, both biological limits were determined. The yield per recruit analysis was followed by the equation (Beverton & Holt 1957; Nurdin, Kembaren & Tirtadanu 2023; Tirtadanu et al. 2022):

$$\frac{Y}{R} = F(\alpha L_\infty{}^{\beta})\left[\frac{L_\infty - L_c}{L_\infty}\right]^{\frac{M}{K}}\left[\frac{L_\infty - L_r}{L_\infty}\right]^{\frac{M}{K}}\sum_{n-0}^{3}\frac{Un[\frac{L_\infty - L_c}{L_\infty}]^n}{F+M+nK} \tag{8}$$

where Y/R is the yield per recruit; Lc is the length at first capture; a and b are the constant of Length-Weight function; L_∞, M and K are asymptotic length, natural mortality and the growth rate, respectively.

The use of yield per recruit in this study has been modified from the age-based Beverton and Holt (1957) by changing the age-based method to length-based yield per recruit in the formula (Zhang 2020) and used in Tirtadanu et al. (2022):

$$exp[-nK((t_c - t_{0)}] = \left[\frac{L_\infty - L_c}{L_\infty}\right]^n \tag{9}$$

The remaining proportion of spawning stock biomass per recruit in nature is known as the spawning potential ratio (SPR) indicating the reproductive ability to recover the stock as stated by Goodyear (1993). SPR analysis estimates the biological reference $F_{40\%}$ and $Lc_{40\%}$. $F_{40\%}$ and $Lc_{40\%}$ are the fishing mortality and length at first capture, giving an optimal 40% spawning potential ratio. The length-based spawning potential ratio (LB-SPR) analysis was followed by the equation of Hordyk et al. (2015) and Nurdin, Kembaren & Tirtadanu (2023):

$$SPR = \frac{SSBR_{fished}}{SSBR_{unfished}} \quad (10)$$

where $SSBR_{fished}$ and $SSBR_{unfished}$ are the spawning stock biomass per recruit in the present and the absence of fisheries. The SPR was estimated by using the length-based approach, with the inputs including the length-frequency data, with length at 50% and 95% maturity, asymptotic length, and M/K. Spawning stock biomass per recruit was obtained through the equation:

$$SSBR = \sum_{t=0}^{t=\infty} N_t M_t W_t \quad (11)$$

where Nt is the abundance at age t; MatL is the proportion of maturity at length L; Mt is the proportion of maturity at age t; and Wt is the weight of the individual at age t.

RESULTS AND DISCUSSION

The total catch of fish landed in Nabire was 54.73 tons based on observations of 559 fishing trips for handline fleets where the proportion of yellowfin tuna accounted for 70.1% of the total catch, skipjack tuna for 19.4%, sharks 3.95%, sailfish 3.14%, squids 1.91%, frigate tuna 0.77%, dolphinfish 0.28%, billfish 0.27%, and bigeye tuna 0.18%.

The length of 2,211 skipjack tuna sampled by enumerators in Nabire from February to November 2021 was in the range of 18 - 94 cm FL, with an average of 40.93 cm FL and a mode in the length class of 40 cm FL (Figure 2). The findings indicated that 41.6 cm FL was the length at first capture (Figure 3), while the length at first maturity was 50.7 cm FL.

Based on the von Bertalanffy model the growth equation could be written as $L_t = 96.8\,(1 - e^{-0.38(t-(00.31))})$ $L_t = 96.8\,(1 - e^{-0.38(t-(00.31))})$ (Table 2). We found that the asymptotic length (L_∞) skipjack tuna was 96.8 cm, the growth coefficient (K) was 0.38 $year^{-1}$ and t_0 was -0.31 year (Figure 4). Based on the estimated growth curve (Figure 4), the length at first catch (Lc) was 41.6 cmFL aged about 1.16 years, and the length at first maturity (Lm) was 50.7 cmFL aged about 1.64 years.

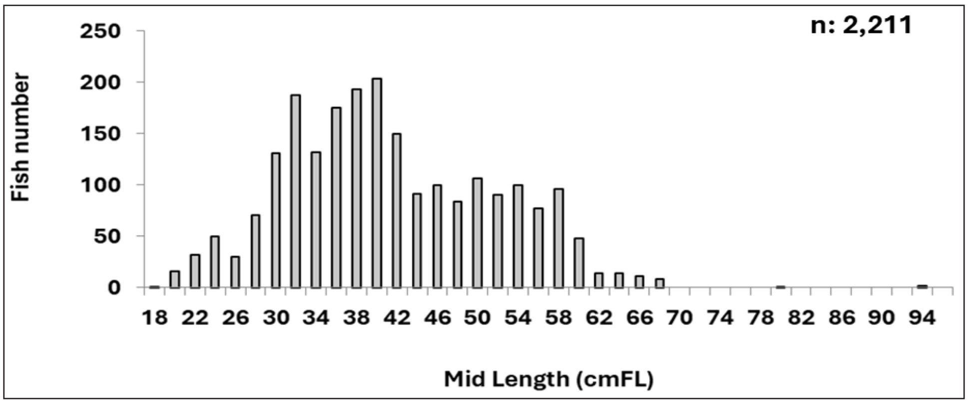

FIGURE 2. Size distribution of skipjack tuna caught by handline

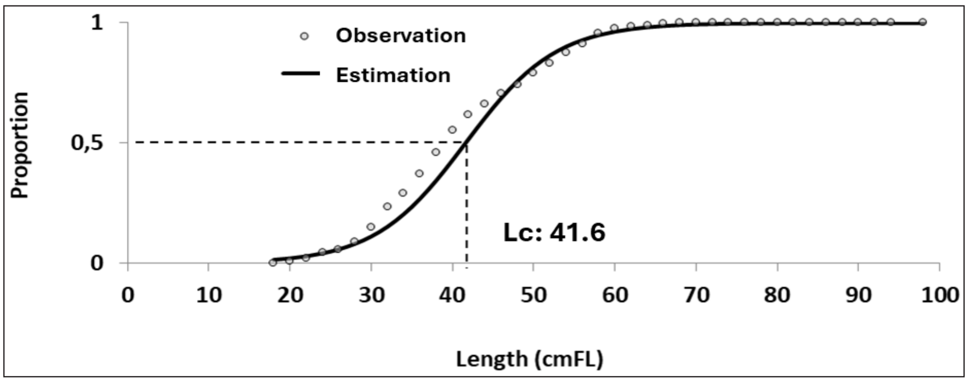

FIGURE 3. Length at first capture of Skipjack tuna

TABLE 2. Growth parameters of skipjack tuna in Cenderawasih Bay

Species	L_∞ (cmFL)	K (year $^{-1}$)	t_0 (year)	Growth parameter equation
K. pelamis	96.8	0.38	-0.31	$L_t = 96.8\ (1\text{- } e^{\ 0.38(t-(-0.31))})$

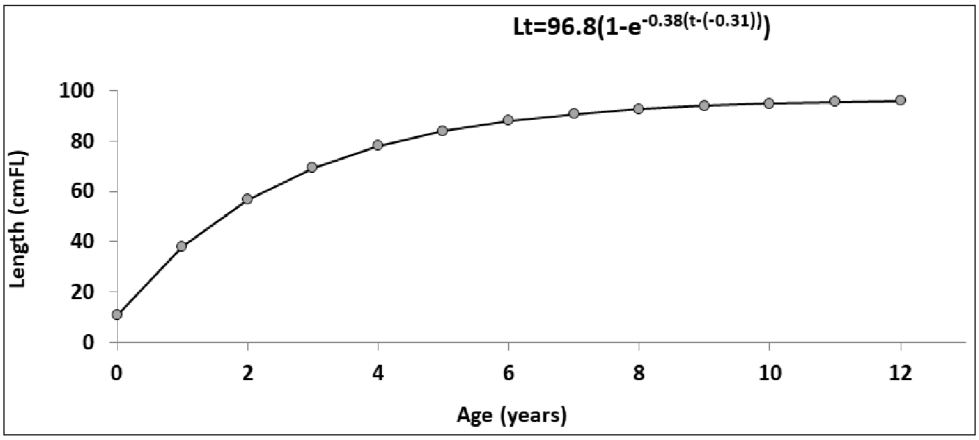

FIGURE 4. Estimated growth curve of *K. pelamis* in Cenderawasih Bay

By using the calculated growth parameters (K and L_∞) as inputs to construct the catch curve, the result showed that the total mortality (Z) was 2.13 per year (Figure 5) and the natural mortality (M) was 0.66 per year, while fishing mortality (F) was 1.47 per year (Table 3). The exploitation rate (E) for *K. pelamis* in Cenderawasih Bay was 0.69 per year. The observed rate of exploitation exceeds the expected optimal level (E = 0.50).

The current fishing mortality is 1.46 year^{-1}, which resulted in a spawning potential ratio of 30%. The optimal 40% spawning potential ratio will be reached by decreasing 73% of the current fishing mortality into $F_{40\%}$=0.90 year^{-1}. By making the handline more selective, the spawning potential ratio will increase (Figure 6).

The current fishing mortality resulted in yield per recruit (YPR) of 92,205 g recruit^{-1}. At the current selectivity of the handline gear, the yield per recruit will be at a maximum point at the fishing mortality (F_{max}) of 0.76 year^{-1}, which resulted in the increasing yield recruit from the current condition (YPR_{cur}=92,205 g recruit^{-1}; YPR_{max}=106,366 g recruit^{-1}) (Figure 7). The current fishing mortality is higher than the reference point F_{max} and $F_{40\%}$, meaning the overfishing condition of *K. pelamis* fisheries in Cendrawasih Bay.

The spawning potential ratio (SPR) value will be higher if we increase the handline selectivity (Figure 7). The current length at first captured of *K. pelamis* in Cendrawasih Bay is 41.6 cm, which resulted in the yield per recruit of 92,205 g recruit^{-1}. By increasing the length at first capture to 55 cm (L_{cmax}), the yield per recruit increased by 89% from the current yield per recruit, or the yield per recruit will be at 170,592 g recruit^{-1}.

The current length at first capture was less than the reference points $L_{c40\%}$ and L_{cmax}, meaning that the fish was captured in a non-optimal condition. The current length at first captured is 41.6 cm, which resulted in a 30% spawning potential ratio. The optimal 40% spawning potential ratio can be reached by increasing the length at first capture from L_{ccur}=41.6 cm to $L_{c40\%}$=50 cm.

Fishing should be regulated as it can lead to stock depletion. Overexploitation of fish resources can compromise their sustainability, reducing the quantity and quality of fish resources in the area, even though they are a recoverable resource. Sustainable fisheries management can be achieved by optimizing catch output utilizing efficient and ecologically friendly fishing gear that delivers high-quality catches.

It is suggested to limit the size of hooks used to capture fish that are eligible to be caught at the minimum legal size, as well as the total authorised catch (TAC) system, which determines the maximum number of a fish species that fishers may take. To allow fish to reproduce and protect vulnerable fish populations during the spawning period, there may be temporary closures of fishing areas or designated periods of fishing prohibition. It may also be necessary to avoid over fishing condition by reducing the number of fishing trips or the number of fishing fleets for the sustainability of skipjack tuna fisheries in Cenderawasih Bay.

Based on the catch composition, it is highly likely that hand-line fishers in Cendrawasih Bay who caught in FADs brought various fishing gears. Williams and Ruaia (2021) stated the same thing in Western and Central Pacific Ocean, that the small-scale troll and hook-and-line fishery

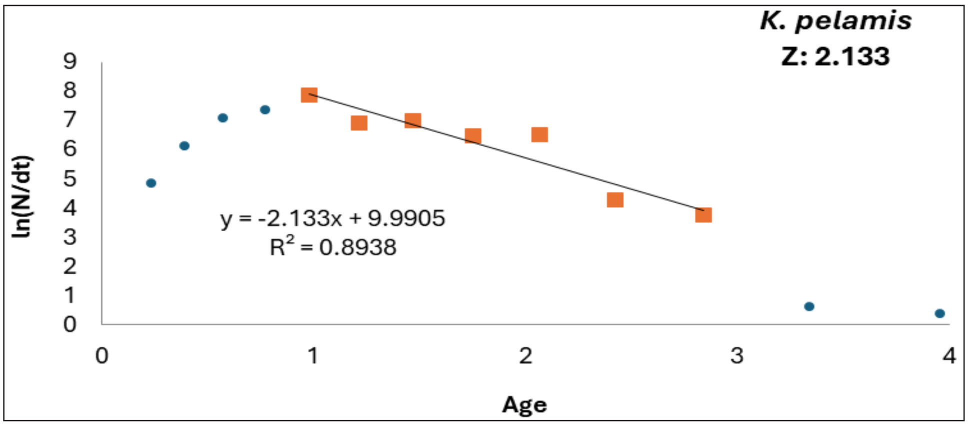

FIGURE 5. Skipjack tuna length converted catch curve, the value of z as slope of curve

TABLE 3. Mortality and exploitation rate of skipjack tuna in Cenderawasih Bay

Species	Total mortality (Z)	Natural mortality (M)	Fishing mortality (F)	Exploitation rate (E)
K. pelamis	2.13	0.66	1.47	0.69

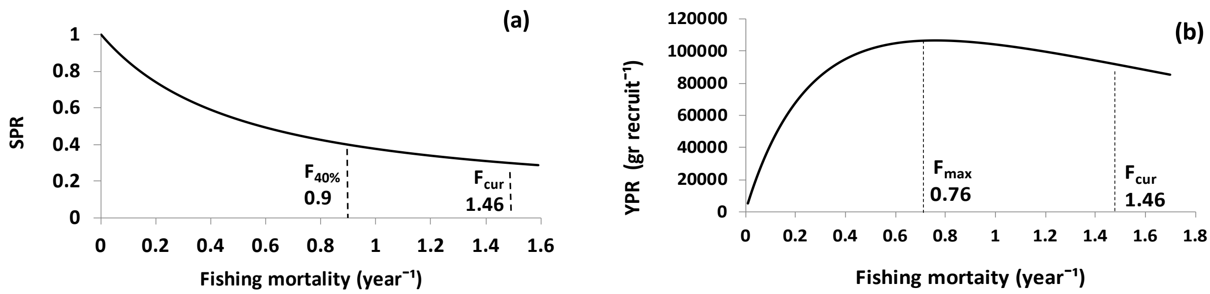

FIGURE 6. The fishing mortality (F) as a function of spawning potential ratio (a) and a yield per recruit (b) of *K. pelamis* in Cendrawasih Bay

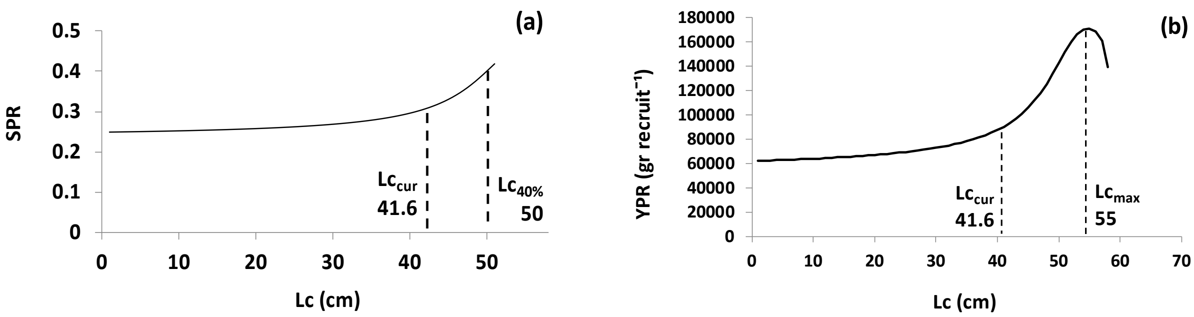

FIGURE 7. The length at first captured (Lc_{50}) as a function of spawning potential ratio (a) and a yield per recruit (b) of *K. pelamis* in Cendrawasih Bay

uses a variety of fishing gear, including troll line and surface handline, with skipjack tuna and yellowfin as the primary targets. The primary target of hand-line fishing is tuna, but bycatch includes marlin, shark, and sailfish. The skipjack tuna and dolphinfish caught were not from handlines that caught tuna, but from the surface handline, which was specifically different from the tuna handline. The difference lies in the hook size number used to catch large tuna and skipjack tuna, as well as the fishing depth area set.

Skipjack tuna is the second highest catch for handline after yellowfin tuna. This was also stated by Williams and Ruaia (2021) that in Western Central Pacific waters, the composition of the small-scale troll and hook and-line tends to fluctuate with several years having a high proportion of small yellowfin tuna (in recent years, the catch of small yellowfin tuna is estimated to be at least 50% of the total tuna catch for this fishery). While in the waters of the Banda Sea, Hidayat, Noegroho and Wagiyo (2017) reported that the composition of the troll line catch consisted of skipjack tuna (*Katsuwonus pelamis*) 67%, yellowfin tuna (*Thunnus albacares*) 27%, bigeye tuna (*Thunnus obesus*) by 5%, and dolphinfish (*Coryphaena hippurus*) by 1%. According to Widodo et al. (2016), the survey results in Sodohoa (Kendari) included at least 18 fish species caught by handline and troll line fleets, including yellowfin tuna, which was the most dominant (47.6%), followed by skipjack tuna (*Katsuwonus pelamis*) with 41.0%, big eye tuna (5.4%) and billfishes (marlin, sailfish, spearfish) with a percentage of at least.

The size distribution and maximum length in this study are almost identical to those reported by Hidayat, Noegroho and Wagiyo (2017) with a length range of 15-94 cm and mode value of 40-45 cm. Jatmiko, Hartaty and Bahtiar (2015) reported fishing in the East Indian Ocean by handline, troll line, and according to Koya et al. (2012) in Indian waters with gillnet, pole and line fishing gear obtained bigger size mode values of 50 cm and 52-56 cm, respectively. Size distribution with smaller mode from this study was reported by Tadjuddah et al. (2017) in Banda Sea, and Setiyawan et al. (2021) in Maumere Sikka with 34-37 cm and 25-39 cm. This disparity in size distribution is due to the selectivity of fishing gear used to catch skipjack tuna, in addition to differences in fishing grounds, water fertility conditions, and fishing time.

Comparing the length at first gonadal maturity (Laringm) and length at first capture (Lc) in fish populations is crucial for understanding the impact of fishing on fish stock sustainability (Lappalainen et al. 2016; Suyasa et al. 2023). Because fishing has an impact on fish populations, this data can be used to inform fisheries strategies for management. Ideally, the Lc value should be greater than the Lm, indicating that the average fish caught has a larger size than the mature size, ensuring the long-term viability of skipjack tuna populations.

The results of this study, on the other hand, demonstrate that the value of Lc is lower than Lm, indicating that the resource is in an unsafe condition. However, when skipjack tuna Lm values from other sites are compared, Cendrawasih Bay waters had the greatest value (50.7 cm). According to Ashida, Tanabe and Suzuki (2009) and Ohashi et al. (2019), whose research area is likewise in Pacific waters, they discovered Lm values was 40 cm and 40.9 cm in western-central-Pacific Ocean, which is part of Pacific waters. Grande et al. (2014) reported a skipjack tuna Lm value of 39.9 cm in the Western Indian Ocean, whereas Jatmiko, Hartaty and Bahtiar (2015) reported a Lm value of 42.9 cm in the Eastern Indian Ocean the following year (2015). Other research on the study of Lm skipjack tuna in Indonesia have been reported, including a Lm value of 48.9 cm in Ternate waters in 2014 by Susanto and Lumingas (2014) and a Lm value of 40.1 cm in Yogyakarta waters following that year by Anggraeni, Solichin and Saputra (2015). According to Chodrijah, Hidayat and Wagiyo (2020), the Lm value of skipjack tuna in the Toli-Toli waters of Central Sulawesi is 41 cm. In Kagoshima, Japan, Ashida and Horie (2015) recorded a Lm value of 40.5 cm.

The infinity length of skipjack tuna from this study is 96.8 cm, which is less than that discovered in Papua Western Pacific with 101.8 cm stated by Hidayat, Noegroho and Wagiyo (2017); Makassar Strait with 108.2 cm (Mallawa, Mallawa & Amir 2016); and Papua New Guinea waters with 150 cm as reported by Kumasi et al. (2010). Another region was slightly smaller, with 91 cm in Nusa Tenggara (Herawaty et al. 2021) and India with 92 cm (Said Koya et al. 2012); while other region was smaller, with 74.8 in the Central Pacific (Wankowski 1981), 70.1 cm in the Banda Sea (Tadjuddah et al. 2017), and 70.3 cm in Maumere-Sikka (Setiyawan et al. 2021).

The result from growth analysis shows that the skipjack tuna growth rate (K) in this study is 0.38, which is higher than in the Banda Sea with 0.26 (Tadjuddah et al. 2017) and 0.30 in the Papua New Guinea Sea (Kumasi et al. 2010). Other regions with higher K from the study are 0.41 in Papua, western Pacific stated by Hidayat, Noegroho and Wagiyo (2017); 0.45 in Makassar Strait (Mallawa, Mallawa & Amir 2016); 0.50 in India waters (Said Koya et al. 2012); 0.51 in East Nusa Tenggara (Herawaty et al. 2021); and Central Pacific (Wankowski 1981). Maumere-Sikka is the largest with 0.55 (Setiyawan et al. 2021). Overall, the various values of length infinity and growth in the region show a range of growth dynamics, which are thought to be influenced by surrounding environmental conditions.

The Von Bertalanffy formula graph shows that L_∞ can be reached at age > 12 years. Ages 1, 2, 3, 4, and 5 will be reached at lengths of 38, 56.6, 69.3, 78, and 83.9 cm, respectively. Hidayat, Noegroho and Wagiyo (2017) reported that in northern Papua of Pacific waters skipjack tuna at ages of 1, 2, 3, 4, and 5 reach lengths of 41.7, 61.9, 75.3, 84.2, and 90.2 cm. Collette and Nauen (1983) stated that the maximum age of skipjack tuna is 12 years old with a maximum weight of 34,5 kg with a maximum length of 110 cm.

Most of the skipjack tuna captured by handline in Cendrawasih Bay are in a small size or non-optimal condition. Based on the current length at first capture of handline (Lc_{cur}=41.6 cm), which was lower than reference points $Lc_{40\%}$ (50 cm) and Lc_{max} (55 cm), the fishers will get more benefit in their catch and economics if they increase the selectivity to 50-55 cm. To catch the optimal sizes, the selectivity value can be attained by enlarging the hook size. According to Mehanna et al. (2021) and Yulianto et al. (2023), the hook size and the bait types significantly affect the catch size. Therefore, the hook size can be an effective management tool to increase the selectivity of the handline to help the fishers get an optimal catch and maintain the stock sustainability of *K. pelamis* in Cendrawasih Bay.

The recruitment overfishing condition for *K. pelamis* in Cendrawasih Bay has occurred according to the current fishing mortality rate, which has exceeded the reference point of $F_{40\%}$, with the current SPR at 30%. The continuous fishing mortality at the current level will threaten the stock sustainability of *K. pelamis* in Cendrawasih Bay. According to Pramurdya, Watiniasih and Ginantra (2022), Sala et al. (2023) and Yonvitner, Boer and Kurnia (2021), low spawning stock biomass of *K. pelamis* is also found in some areas in Indonesia, including *K. pelamis* in Cilacap waters (SPR=4%), Manokwari Waters (SPR=16%), and in South Bali (SPR=19%). Some management measures that focus on effort reduction are highly needed to increase the spawning stock biomass. Total allowable catch (TAC) is one of the effective management measures for Tuna fisheries as stated by Squires, Allen and Restrepo (2013). As a commercial fishery with a recruitment overfishing condition, the TAC system is highly needed for *K. pelamis* in some areas of Indonesia. Furthermore, the current fishing mortality is not optimal according to the present fishing mortality, which exceeds the F_{max} reference point. The TAC system will help the fishers know their optimal quota, where the increasing effort will affect the higher operational cost. With local involvement, the MCS (Monitoring Controlling and Surveillance) system should be strengthened. The awareness of fishers should be raised by understanding that management measures are a valuable investment for resources and economic sustainability.

CONCLUSION

This study indicated that the status of skipjack tuna in Cenderawasih Bay is in the light overfishing condition, according to the present fishing mortality, which exceeded the optimal reference point of F_{max} and $F_{40\%}$. Furthermore, the skipjack tuna was also captured (L_{c50}=42 cm) before they reach the optimal condition (L_{cmax}=55 cm) to give the higher yields, which indicated a growth overfishing and non-optimal fishing condition. Therefore, some management options, such as the regulation on minimum size hooks and the TAC system, adjusting fishing effort as well, and determining the lowest allowable size could be considered for the sustainability of skipjack tuna fisheries in Cendrawasih Bay.

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