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INDONESIAN FISHERIES RESEARCH JOURNAL
Volume 27 Nomor 1 June 2021
p-ISSN: 0853-8980
e-ISSN: 2502-6569
Accreditation Number RISTEK-BRIN: 85/M/KPT/2020

ESTIMATES OF LENGTH-BASED POPULATION PARAMETERS OF SKIPJACK TUNA (*KATSUWONUS PELAMIS,* LINNAEUS 1798) FROM A POLE & LINE FISHERY IN MAUMERE-SIKKA, INDONESIA

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Received; January 26-2021 Received in revised from April 05-2021; Accepted April 20-2021

ABSTRACT

Several population parameters of skipjack tuna (*Katsuwonus pelamis*) taken by pole and line gear from Maumere Waters from March 2017 to February 2018 were analyzed. A total of 2,194 skipjack tuna was sampled randomly. Fishing activities were carried out around FADs (*Fish Aggregating Devices*) and free fish shoal. Observers and enumerators collected data from several landing sites and by direct on-board observations. This study aims to provide length-frequency distribution by season, estimate growth mortality parameters, and estimate stock exploitation rate using FISAT software. The results showed that the total catch was dominated by skipjack tuna; up to 80% with the CPUE of 30.8 kg/person/trip, and the skipjack tuna's length distribution ranged from 26 to 69 cm FL. Length at first capture (L_c) was 34.71 cm FL, and immature fish dominated the total catch with 53%, indicating growth overfishing. The calculated von Bertalanffy growth (VBG) parameters were L_∞ = 70.35 cm, K = 0.55 yr^{-1}, and t_0 = -0.39 yr. Natural mortality (*M*) was estimated to be 0.92 and fishing mortality (*F*) was 0.91. The mean longevity of skipjack tuna is estimated to be 3.2 years, with an exploitation rate (*E*) of 0.50. Sustainable exploitation of skipjack tuna determined from this analysis could be developed with an E_{max} of 0.73. There is a focus on reducing the catch of immature fish through various methods that include changing the fishing target area from FADs to fishing on natural fish schools and using gear modifications such as larger-sized (lower number) hooks.

Keywords: Pole and line fishery; skipjack tuna; population dynamics; Maumere-Sikka; Indonesia

INTRODUCTION

Skipjack tuna, *Katsuwonus pelamis,* is a relatively short-lived, tropical, epipelagic, and highly migratory species distributed primarily in seas with temperatures above 15°C (Collette & Nauen, 1983). FAO reported that the skipjack tuna is the largest tuna fishery worldwide, with 58% of the total catch compared to the other tuna species (FAO, 2016). In Indonesia, tuna and other fisheries are managed regionally in Fisheries Management Areas (FMAs) described by Pomeroy *et al*. (2019).

In the Banda Sea, fishing gear used in skipjack tuna harvest includes purse seines, gillnets, troll lines, and pole and lines (Tampubolon, 1990), with a majority of the catches coming from purse seines. In 2018, skipjack tuna's total production in the Banda Sea (FMA 714) was 172,835 tonnes (MMAF statistics 2019).

Pole and line fishing is presumed to be a highly selective gear type compared to the other harvest methods. The technique frequently captures predominantly mature skipjack (L_m = 49.3cm FL), produces a high-quality product, and is relatively safe for participating fishers (Nugraha & Rahmat, 2008; Nanholy, 2013). Currently, the status of tuna stocks in Indonesian waters is officially considered "*moderate*" (ranging from no overfishing to overfished, MMAF Decree`#50 (2017). However, pole and line fishing is one of the two methods explored to promote more sustainable tuna fisheries in Indonesian waters (Setiyawan *et al*., 2016). Various factors limit the viability of pole and line fishing in any given geographic area and the availability of live bait is a crucial one. Artificial lures are also useful to attract tunas. However, they are not as effective as the live bait that is preferred by most pole and line fishers (Susanto *et al*., 2012). The other method promoted as a sustainable means

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DOI: http://dx.doi.org/10.15578/ifrj.27.1.2021.37-49

of tuna harvesting is purse seining with control of mesh size in the net bunt. Purse seining does not require live-bait, but it is arguably less sustainable due to presumed lack of selectivity. There are trade-offs in choosing between the two recommended methods to catch tuna in a sustainable way (Resma *et al*., 2006).

Understanding the relationship between fish population structure and stock status is essential for policymakers and stock managers to inform fisheries management recommendations and subsequent policymaking. Population dynamic parameters, including temporal distribution of length frequencies, age, growth, and mortality, are necessary for any reliable stock assessment and ensure sustainable fisheries (Chen & Paloheimo, 1994). There is a considerable paucity of data about the skipjack tuna populations on FAD structures and growth performance in the Flores (Indonesia FMA 713) and Banda Sea region (Indonesia FMA 714). Currently, international treaty organizations, the Western and Central Pacific Tuna Commission (WCPFC) and the Indian Ocean Tuna Commission (IOTC), are responsible for coordinating all tuna species' international management. Hence, as a member of both organizations, Indonesia cooperatively provides tuna data collection for the Southeast Asian regional pelagic fish management efforts.

In this research, an investigation was made on important population dynamic features of skipjack tuna using length-frequency data from pole and line vessels in Maumere-Sikka within the Flores and Banda Seas. The main objective of this study is to provide the length-frequency distribution by season, growth parameters, estimates of mortality, and the exploitation rate using the Electronic Length-Frequency Analysis (ELEFAN) I technique. The results are expected to provide data about skipjack tuna resources in the Maumere-Sikka and make recommendations for sustainable tuna fishery management policies for the region.

Table 1. Data Summary of the Maumere on-board fishery observer program in 2017

Data Summary							
No	**Month**	**Fishing Ground**	**Live bait**	**Total Bait (kg)**	**Total Fishing**	**Total Catch (kg)**	**Fishing Area**
1	March	Flores Sea	Anchovy	64	6	5920	Shoaling
2	April	Banda Sea	Anchovy & Lure	48	13	8700	FADs & Shoaling
3	May	Banda Sea	Anchovy	24	5	2200	FADs & Shoaling
4	June	Flores Sea	Anchovy	42	1	700	Shoaling
5	July	-	-	-	-	-	-
6	August	Flores Sea	Anchovy & Lure	14	3	1010	FADs & Shoaling
7	September	-	-	-	-	-	-
8	October	-	-	-	-	-	-
9	November	Flores Sea	Anchovy & Lure	4	1	200	Shoaling
10	December	Banda Sea	Anchovy	26	2	1500	FADs

Note: " - "; No data available

MATERIALS AND METHODS

The pole and line skipjack tuna fishery in Maumere-Sikka (about 8ºS, 122ºE) was monitored during 2017 by on-board observers who recorded catch numbers and fork lengths (cm FL) of individual fish (Table 1). The sample was obtained at each landing site every month from the commercial and private vessels, which landed in several ports in the Sikka Regency, including Wuring fishing port, the Karya Cipta Buana Sentosa (KCBS) Company, and other local fishing ports by enumerators. The data on FL, the number of trips, total catch, and the amount of live bait they used were recorded.

A total of 2,194 skipjack tuna were sampled randomly from the catches. Nominal catch per unit effort (CPUE) was calculated by the number of total catches per trip along with the number of on-board fishers and reported as kg catch/person/trip.

The von Bertalanffy growth parameters, L_∞, and *K* were calculated from monthly data using ELEFAN-I programmed in FISAT software (Sparre & Venema, 1991), and the t_0 value is predicted by the empirical formula (Pauly, 1983). A total of 1,710 skipjack tuna measured were in the length range of 25 – 69 cm FL and used for the t_0 estimation. The length-frequency distribution was plotted with the open-source statistical package "R" (R Core Team 2019). The estimate of length at first capture was obtained from the length-frequency distribution.

The maximum length of fish (L_{max}) was predicted using the Maximum Length Estimation routine from the support menu of the ELEFAN-I software program. The best value of growth parameter (*K*) for the given value of L_{max} was identified by Shepherd's method when we used a scan of the *K*-values option from the assess menu. The von Bertalanffy growth function (VBGF) (von Bertalanffy, 1938; Sparre & Venema, 1998) was fit to the data using the von Bertalanffy formula:

$$L_t = L\infty\left(1 - e^{-K\left(t - t_0\right)}\right) \quad ....………………….(1)$$

In this equation, t_0 represents the theoretical age at length zero, L_∞ is the asymptotic length, and L_t is the fish length at age *t*. The parameter *L* below was taken from the Powell-Wetherall plot, which used length frequencies data with equation given thus:

$$L = \frac{-a}{b} \; L = \frac{-a}{b} \quad ....………………………………(2)$$

When *b* is the slope, and *a* is the intercept of the regression. The estimation of length at age was calculated by the equation:

$$\text{Log}(-t_0) = -0.3922 - 0.2752\log L_\infty - 1.038\log K \; ……..(3)$$

When :

- L_t = fish length at age, *t* in years;
- L_∞ = length-at-infinity in cm;
- *K* = von Bertalanffy growth coefficient in yr^{-1};
- *t* = time in years;
- t_0 = theoretical age at which the fish length equals zero.

The FISAT – ELEFAN I (Pauly and David 1981; Yang *et al*., 2013) and Pauly's empirical formula was used to estimate natural mortality (*M*) (Pauly, 1980). The FISAT software uses the length frequency of skipjack to estimate the asymptotic length (L_∞), growth rate (*K*), natural mortality (*M*), total mortality (*Z*), fishing mortality (*F*) and exploitation ratio (*E*).

Total mortality (*Z*) was analyzed by catch curve and it was converted by length (Length Converted Catch Curve Analysis) in the FISAT – ELEFAN I (Pauly and David 1981; Brey & Pauly, 1986; Yang *et al*., 2013). The analysis was taken by the data input of growth parameters (length infinity and *K*) as Beverton & Holt (1956) equation:

$$Z = K\,(L_\infty - L")/(L" - L') \; ....……………………….....(4)$$

When:

- *Z* = total mortality rate ($year^{-1}$)
- *K* = growth coefficient ($year^{-1}$)
- L_∞ = asymptotic length of fish (cm)
- *L*" = average length of fish catch (cm)
- *L*' = lower limit of the highest catch class length interval (cm)

The natural mortality coefficient (*M*) was calculated by the empirical equation as follows:

$$Ln\,M = -0.0152 - 0.279\ \ln L_\infty + 0.6543\ \ln K + 0.4634\ \ln T \; ....(5)$$

When:

- L_∞ = asymptotic body length (cm),
- *K* = the von Bertalanffy growth coefficient (yr^{-1}),
- *T* = the annual average water temperature of 26°C

It is well known that sea surface temperature will affect the growth of skipjack tuna (Barkeley *et al*., 1978). Since growth parameters are used in the estimates of mortality rates in this method, then it follows that mortality rates will also be temperature dependent. The fishing mortality has been calculated from *M* and *Z* as $F = Z\text{-}M$.

RESULTS AND DISCUSSION

Results

Fisheries

The pole and line fishery for tuna was introduced in North Sulawesi in the 1950s (Naamin *et al.,* 1995). Since that time, the number of vessels has increased considerably, raising questions about the sustainability of the fishery. Data from the Ministry of Marine and Fisheries Affairs (KKP, 2016) showed that the total catch of tuna increased every year since 2000, with skipjack tuna as the predominant species caught. Pole and line fishing rely on live bait, consisting primarily of anchovies and sardines, but lures are sometimes used (Figure 1).

Figure 1. Banda Sea pole and line fishery (left: Pole and line vessel, right: examples of hooks of size #7 and a lure of comparable size).

The typical pole and line fishing vessel is made of wood and fiberglass (Figure 1), and a water sprayer is attached to attract tuna during the fishing process. The sprayer is often used to induce "false schooling" in the ocean, thereby increasing catch. Hook size chosen for fishing consists of the five, six, and seven-size types depending upon the preference of the fisher. Moreover, lures can be utilized as a "fake-bait" attached to the hooks as well (Figure 1).

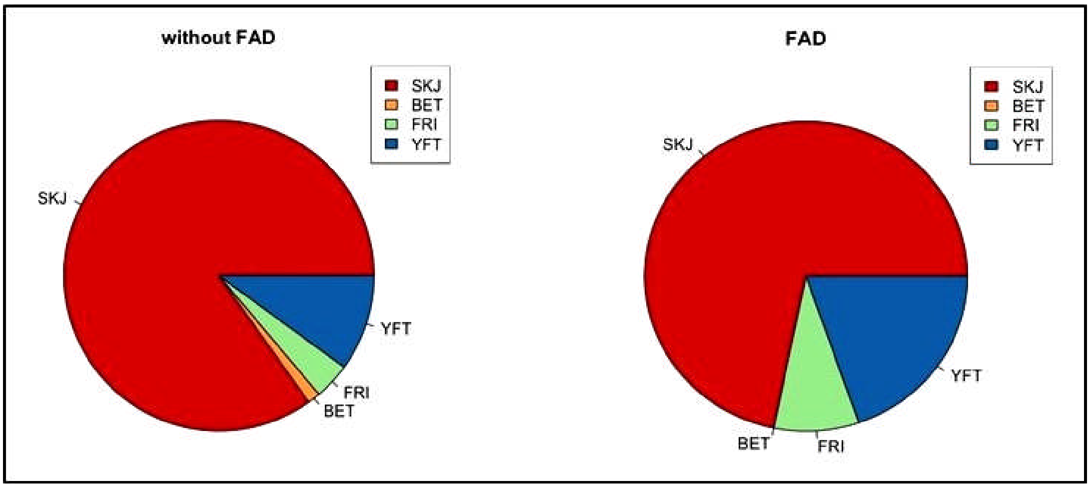

Figure 2. The composition of catches from all sites with free schooling (n=815) and with FADs (n=1379); SKJ = Skipjack tuna; YFT = Yellowfin tuna; BET = Bigeye tuna; FRI = Frigate tuna).

Figure 2 presents the composition of catches from sites with FADs and free shoaling (free schooling). In areas with FADs and free shoaling, dominant catches in the pole and line fishery are of skipjack tuna: fish shoaling (85%) and FADs (72%). The relative percentages of yellowfin and frigate tuna catches are increased by the presence of the FADs, while bigeye tuna appear to avoid them.

Fishing Ground

The fishing ground area in this research was focused around 8°S and 122°E (Figure 3) and is in the Indonesia Fisheries Management Areas (FMAs) 714 and 713, with FMA 714 to the east, including the Banda Sea and Tolo Strait, with Maumere Waters belonging to the more westerly Indonesia FMA 713 in the Flores Sea. The westerly flowing equatorial current system dominates the currents pattern in the fishing grounds.

Catch Per Unit Effort (CPUE)

The monthly total trip frequency of pole and& line vessels werefluctuated, depending on the availability of live-bait. The magnitude of the nominal *catch per unit effort* (CPUE) is 30 per kg per fishers for a single trip. Currently, there is no known standard for calculating CPUE for pole and line fisheries. In this research, CPUE is calculated based on the total catch per trip, divided by the number of fishers who were fishing (called nominal CPUE). The number of anglers was determined from the number of fishers who were actual fishing per trip by the logbook. The trip is defined as the summation of gear sets in a day to catch fish; usually, there are two or three gear sets per day.

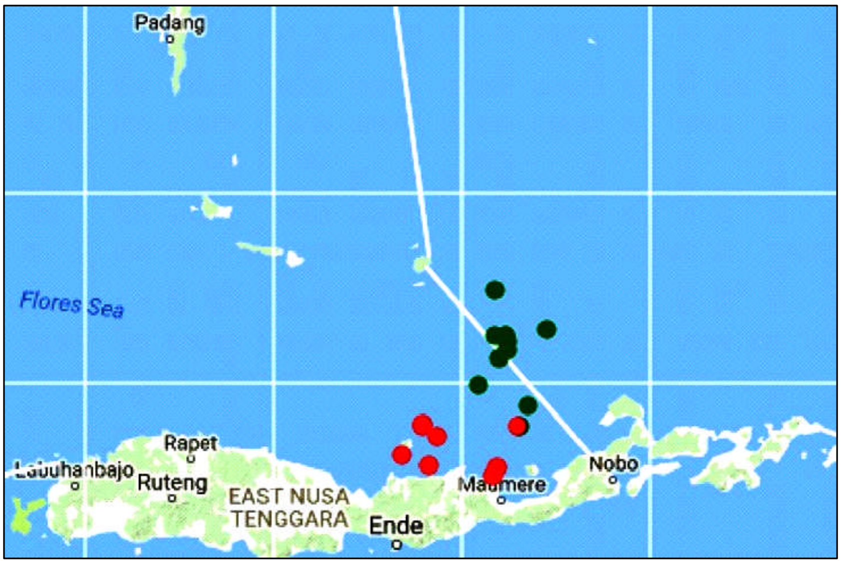

Figure 3. The Pole and Line Fishing Ground in the Flores and Banda Seas. The boundary line (white line) between FMA 713 in the Flores Sea toward the west and FMA 714 toward the east in the Banda Sea is shown. The longitude & latitude grid represents 1° of arc, or 60 nautical miles (111.1 km). (Red dot: Fish Schooling, Green dot: FADs).

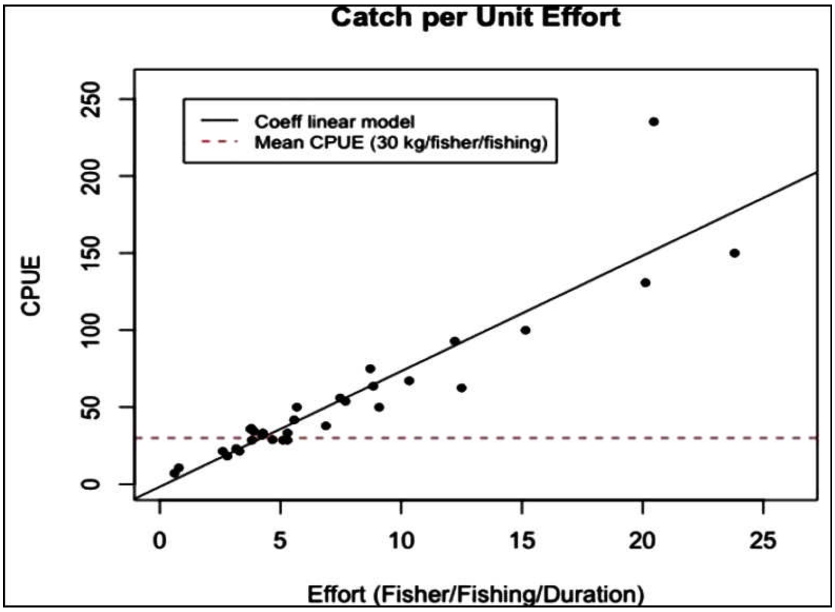

Figure 4. Catch per Unit Effort (CPUE) as a function of effort in the pole and line fishery in Maumere-Sikka. (dashed line is the mean CPUE; solid line: Coefficient linear model).

Length Distribution

The exploited size range of caught skipjack tuna is 26 to 69 cm FL. The length distribution for skipjack tuna displayed in Figure 5A is dominated by sizes ranging from 25 – 39 cm FL. However, the number of samples calculated in this research is limited and analyzed carefully.

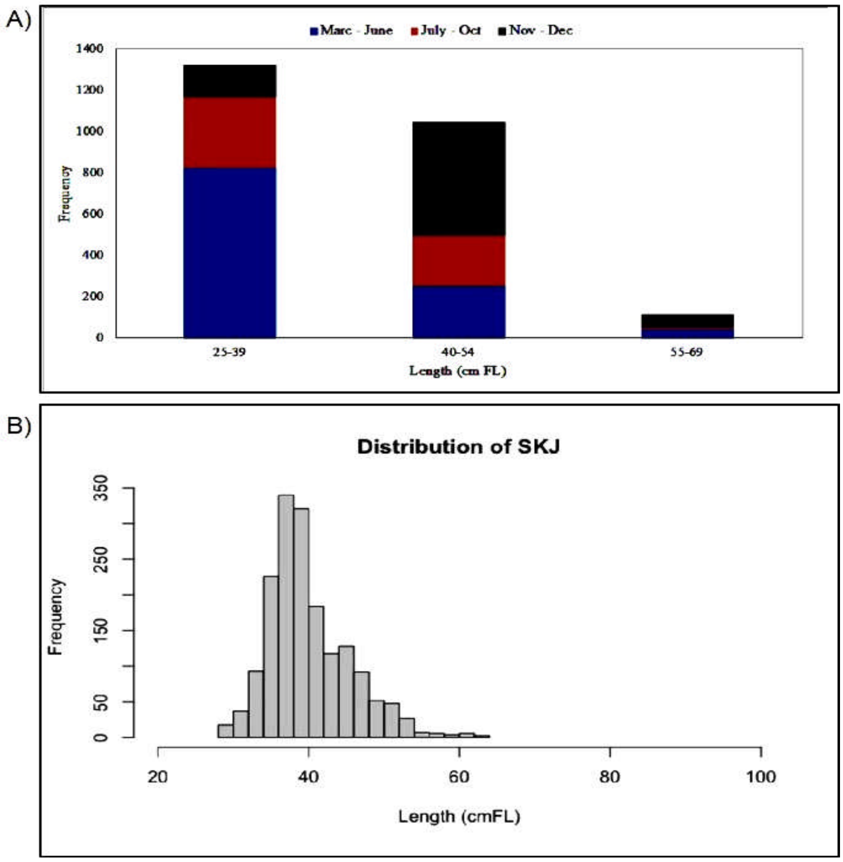

Figure 5. (A) The rough length-frequency distribution (L in cm) of skipjack tuna by season, (B) The normal distribution (L in cm) of skipjack tuna in Sikka-Maumere.

The size category in Figure 4 illustrates the fork length distribution of skipjack tuna in the catch. The length-frequency ranging from 25 to 39 cm FL are maximum in March to June, but in later months (July and October), the major size range is 40 to 54 cm FL.

Length at First Capture (L_c)

The probability of capture analyses provides an estimate of mean size-at-first capture (L_c) for skipjack tuna to be 34.71 cm FL, using the logistic transformation and running average methods, respectively (Figure 6).

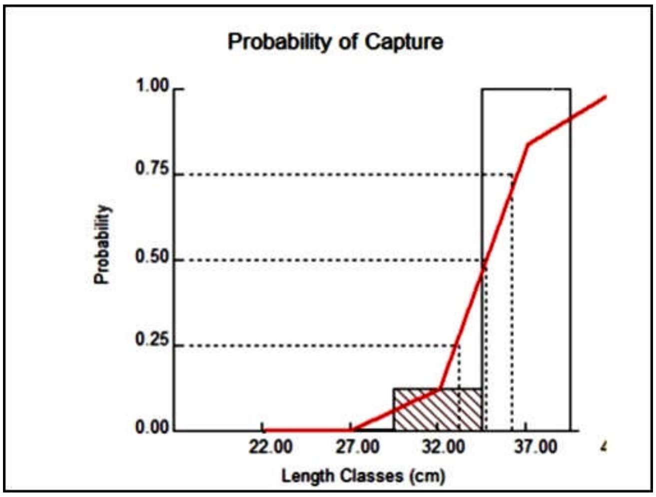

Figure 6. Probability of capture by length class of skipjack tuna from the ascending arm of the catch curve (Y = -25.08 + 0.72X, r = 0.99). The length at first capture (dotted lines) were L_{50} = 34.71 cm FL, L_{25} = 33.19 cm FL, L_{75} = 36.32 cm FL, by logistic transformation (a) and running average routines (b), respectively.

Skipjack tuna caught by pole and line gear type indicates that the composition of mature fish is 47%, and immature fish is 53% based on n = 2,194. The length of the range, L_{max}, is 63.43 – 72.53 cm FL on a 95% confidence level and is predicted to be 67 cm FL (Figure 7). Accordingly, the K value was 0.55 year^{-1} (Figure 8). Length infinity (L_∞) and Z/K were 70.35 and 3.3, respectively, by Powell-Wetherall plot (Figure 7).

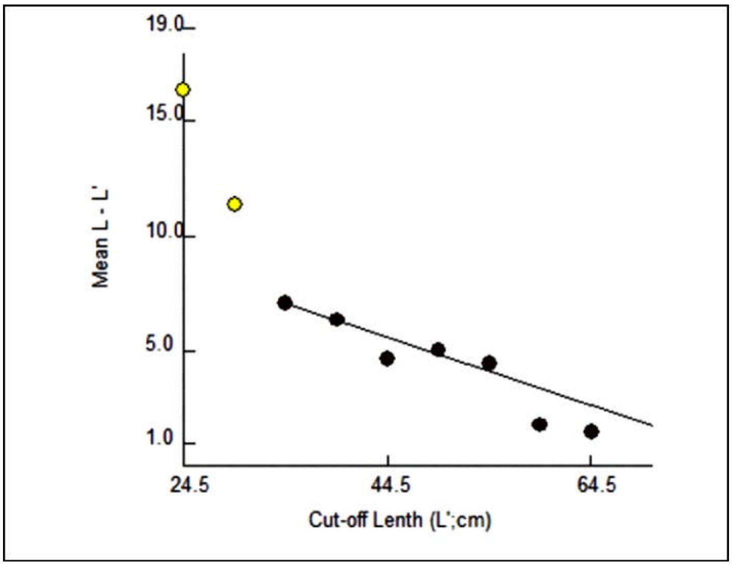

Figure 7. Powell-Wetherall plot for skipjack tuna in Maumere-Sikka identifies length at first exploitation. The regression line: Y =14.25 + (-0.18) * X identifies the first length at full exploitation (L') of 64.5 cm FL, coinciding with the largest size grouping in the length-frequency data (rightmost in Figure 5A, ranging 55-69 cm FL).

The theoretical age at length zero (t_0) of the von Bertalanffy model (von Bertalanffy, 1938) was estimated at -0.39 year. The longevity, t_{max}, of skipjack tuna was 3.2 years or 38 months, with a growth performance index (Pauly, 1991) of 3.32. The von Bertalanffy growth equation is written as:

$L_t = 70.35\ (1\text{-}e^{-0.55(t+0.39)})$ ....……………..(6)

By adopting t_0 = -0.39, the skipjack tuna's length was calculated at 69.73 cm FL and 70.34 cm FL or approximately 1 to 3 years, respectively. The skipjack tuna grows rapidly and reaches catchable size within one year.

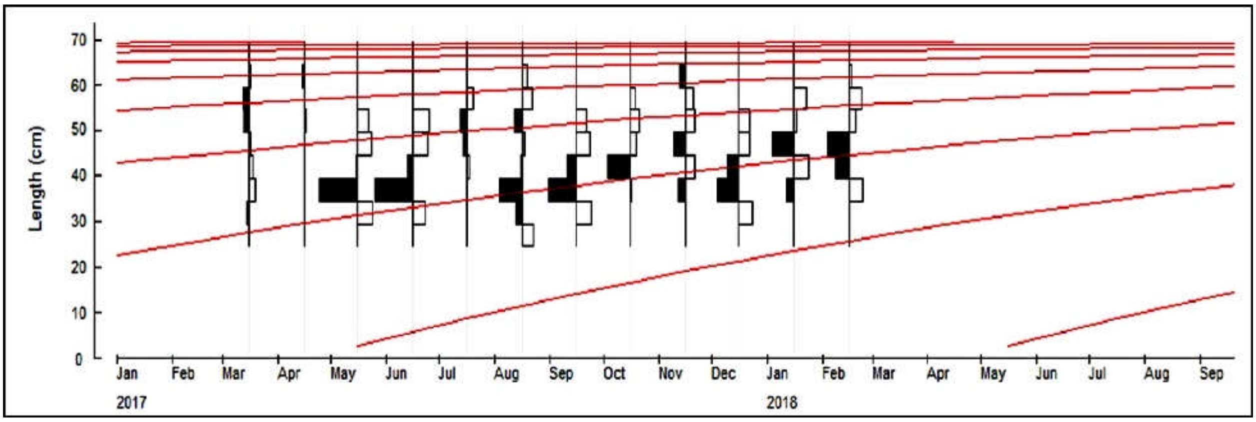

Figure 8. The ELEFAN I analysis for determining von Bertalanffy's growth parameters of skipjack tuna stocks in Maumere-Sikka from March 2017 to February 2018.

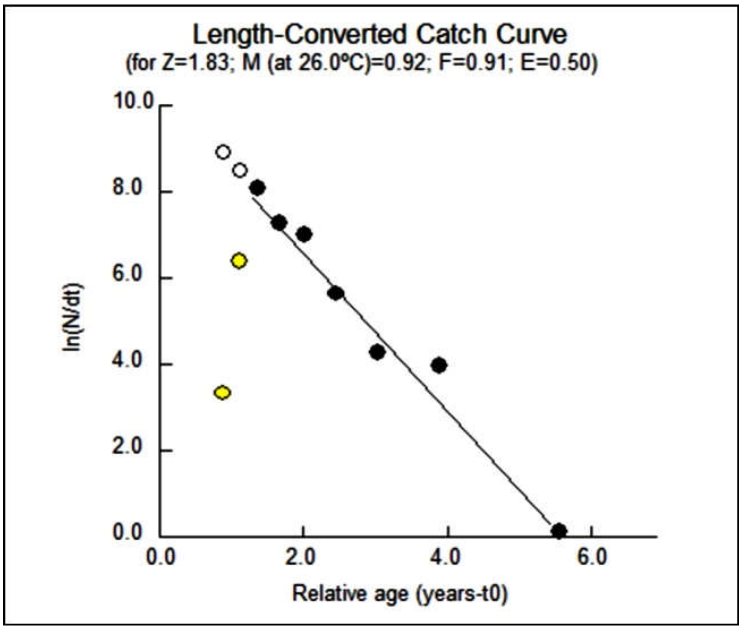

Figure 9. The length-converted catch curve showing the relative age (years) to the fishing mortality (F), natural mortality (M), and the exploitation rate (E).

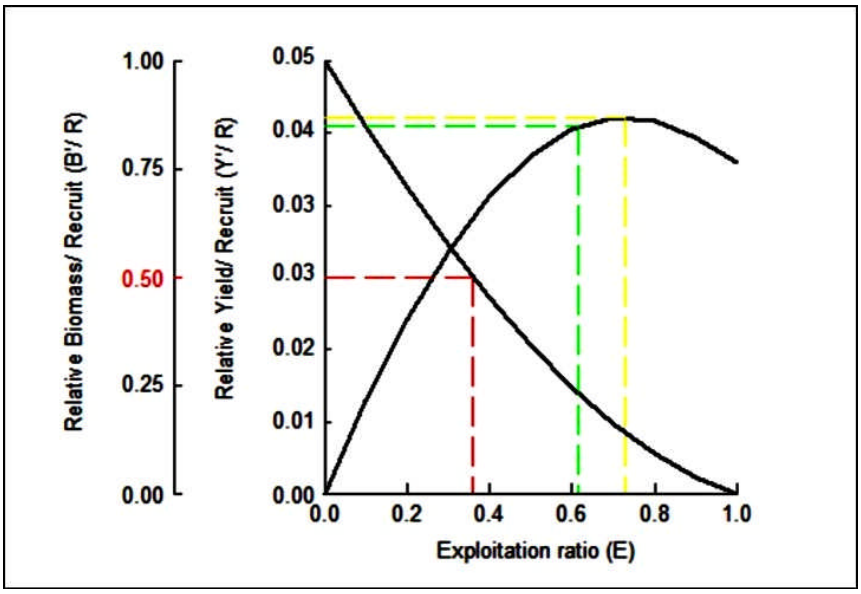

Figure 10. An exploitation rate graph showing that E_{50} as 0.36, E_{max} as 0.73, and E_{-10} as 0.62.

Natural mortality (*M*) was calculated to be 0.92 year^{-1}, while fishing mortality (*F*) was 0.91 year^{-1}. Taking Z = 1.83 into account, and exploitation level (*E*) of 0.50 year^{-1} obtained for skipjack tuna in the Maumere-Sikka is less than the optimum level of exploitation (E_{max} = 0.73) as shown in Figure 10.

Table 2. Comparison of the length size for skipjack tuna among pole and line (PL) and purse seine (PS) based on the hook numbers and mesh size; not reported (n.r.).

No	Gear	Mesh & Hook	Length Range	Mean Length	Location	Source
1	PL	Hook: 5,6 and 7	26-69 cm FL	40.5 cm FL	Flores Sea & Banda Sea	Present study
2	PL	Hook: 4 and 5	46-50 cm FL	42 cm FL	Sulawesi Waters	Setiyawan *et al*. (2018)
3	PL	n.r.	18-73 cm FL	n.r.	Flores Sea	Susaniati *et al*. (2014)
4	PS	Mesh: 3.5 inch	18–78 cm FL	n.r	Celebes & Bismarck Seas	Resma *et al*. (2006)
5	PS	n.r	30-70 cm FL	n.r	Central Pacific Ocean	Boyra *et al.* (2018)

Discussion

The present study shows the observed size range of skipjack tuna exploited by pole and line gear type in the Maumere-Sikka as 26 to 69 cm FL. The length range is in contrast to skipjack tuna's size harvested in the Flores Sea, ranging from 18 to 73 cm FL (Susaniati *et al*., 2014). But more similar to Tadjuddah *et al*. (2017), where they reported that the fork length of skipjack tuna taken from purse seine, trolling line, and pole and line gear type in the Banda Sea ranging from 9 to 71 cm FL, which are quite similar (Figure 5).

There have been many similar studies of skipjack tuna in Indonesia and elsewhere. In a 2006 study of skipjack tuna catches using purse seine gear in the Celebes Sea and in the Bismarck Sea north of Papua, the greatest CPUE among skipjack tuna was in the 1.8 to 3.4 kg size range (Resma *et al*., 2006). The modal length of skipjack of 40 cm in the pole and line caught in this study corresponds to an individual weight of about 1.19 kg. In comparison, the mean catch length of 56.6 cm corresponds to a weight of 3.93 kg using allometric parameters (*a*) = 3.581×10^{-6} and (*b*) = 3.446, from data in Resma *et al*. (2006) (Table 2). The highest CPUE for skipjack tuna in both the purse seine and pole and line fisheries are in roughly the same size ranges.

The length at first capture (L_c) of skipjack tuna was calculated as 34.71 cm FL (Figure 5). In contrast, Setiyawan (2018) found that L_c of skipjack tuna is 43.36 cm FL in the Pacific Ocean. If compared to the length at maturity (L_m) of 40 cm FL (Tandog-Edralin *et al*., 1990; Froese & Pauly, 2019), the skipjack tuna is experiencing growth overfishing and immature fish caught during the fishing still represents 53% of the total catch (Figure 7).

Our data suggest that the fishing method alone is not solving the problem of overfishing since such a high percentage of immature fish are being caught. To improve upon the sustainability of the fishery, the size of the hook to be used in the pole and line should be carefully considered since evidence suggests that larger-sized hooks (with a smaller number) tend to catch larger fish. Setiyawan (2016) found that in the Sulawesi and Maluku Waters, the pole and line fishers use hook sizes #4 and #5 that are larger-sized hooks than in the present study. The mean fish length of fish caught in Sulawesi and Maluku waters is larger. Given the high number of juveniles caught in the Maumere pole and line fishery, reducing the numbers of the juveniles being caught is necessary to boost the reputation of this gear type as being a more "environmentally friendly" way of catching skipjack tuna in comparison with purse seining or any other fishing gear types.

Interestingly, Satrioajie *et al*. (2018) suggested that the Banda Sea should be considered a conservation area for the tuna population since tuna spawning grounds have been found in this area. Tuna tagging programs were conducted in 2009 by the Pacific tuna tagging project (Nicol *et al*., 2010). They have shown that smaller tuna found in the Banda Sea will afterward be as larger adults migrate to the North, toward the Celebes Sea, and northwesterly into the open Pacific Ocean. This pattern is also borne out in Resma *et al*. (2006), who showed that considerably larger skipjack tunas are found in the Bismarck Sea area north of Papua Waters and the Celebes Sea northwest of North Sulawesi. Our data showing the longevity of 3.2 years with length infinity 70.35 cm FL is comparable with Tajduddah et al. (2017) in the Banda Sea at 3.7 years. They assumed that skipjack tuna devotes energy to reproduction and growth before reaching length infinity. If our data is compared with average length at maturity globally of 40 cm FL, the skipjack tuna has a chance to reproduce almost two times before reach the length infinity with most of its energy is devoted to growth and reproduction, so it would make sense that skipjack tuna population in Banda have high fecundity because they are capable of producing large numbers of offspring.

As we found, the pole and line fisheries are not as "environmentally friendly" as assumed initially because of the high percentage of immature skipjack in the catch. A similar research result by Resma *et al*. (2006) showed that purse seines also resulted in considerable landing of immature skipjack. Still, they recommended that a gradual increase in the mesh size of the bunt on purse seines from the 3.5 inches (8.9 cm) spacing from their study up to as much as 8 inches (20.3 cm) as a strategy to exclude smaller immature skipjack from the catch in the multispecies tuna fisheries, thus improving the sustainability of that method. Pole and line gear are generally more selective than purse seines, but they can be more selective for mature skipjack depending upon hook size. Pole and line fisheries may have the advantage of allowing for regulations requiring a release of smaller skipjack tuna immediately upon landing and unhooking. A good fisheries management strategy for skipjack tuna in the Eastern Flores and the Banda Sea region may change the fishing gear from purse seine to pole and line, particularly in waters likely to be within identified spawning areas. In these waters, skipjack tuna is often a by-catch in a purse seine fishery that is mainly targeting carangids and other small pelagic fishes.

The growth pattern of skipjack tuna seems to be different depending on different fishing grounds within FMA 714. Yearly growth rate consultations are made in the WCPFC Working Group or Scientific Committee Meeting for compliance with the international treaty obligations. Studies in different Pacific Ocean areas, including the Banda Sea, have indicated that the L_∞ varies from 61.3 to 144 cm FL, while the range of *K* was 0.1 to 1.3 yr^{-1}.

Our results (L_∞ = 70.35 cm FL and *K* = 0.55 yr^{-1}) are consistent within these ranges (Table 4) and the rapid growth rate of skipjack tuna, mirroring similar findings by other authors.

Table 3. Growth parameters calculated for skipjack tuna in different areas

Location/Area	L_∞ (cm)	*K* ($year^{-1}$)	t_0	Methods	Source
Maumere Waters	70.35	0.55	-0.39	Length frequency	Present, (2019)
South Atlantic	90.1	0.24	-0.54	Length frequency	Soares *et al.* (2019)
Andaman Waters	74.6	0.59	-0.21	Length frequency	Divakar *et al*. (2017)
Banda Sea	70.1	0.26	0.49	Length frequency	Tadjuddah *et al*. (2017)
Banda Sea	97.6	0.41	0.29	Length frequency	Wailenury *et al*. (2014)
Banda Sea	75.9	0.19	0.36	Length frequency	Jamal *et al*. (2011)
Western Pacific	93.6	0.43	-0.49	Otolith	Tanabe *et al*. (2003)
Worldwide mean (n=61)	82.6	0.54	-0.19	Various	Froese & Pauly (2019)

The growth parameter of t_0 is comparable with the findings of Tanabe (2003), even though the methodology they used was different. They found that t_0 is a negative number by otolith-based estimation. Still, Tadjuddah *et al.* (2017), Wailenury *et al.* (2014), and Jamal *et al.* (2011) reported t_0 as a positive number by length-frequency-based estimations. Our data shows the numerical value of t_0 as negative, indicating that younger fish grow faster than strict von Bertalanffy predictions (Table 3).

The natural mortality estimation of skipjack tuna seems constant, ranging from 0.7 $year^{-1}$ to 0.8 $year^{-1}$ (Koya *et al.*, 2012) compared to different fishing grounds in the Indian Ocean. In a WCPFC working paper, Rice *et al*. (2014) showed that the fishing mortality has generally been increasing recently, with $F_{current}$ estimated to be 0.61 times higher than the fishing mortality that will support *Maximum Sustainable Yield* (MSY). In the estimation in the present study, fishing mortality (*F*) was 0.91 $year^{-1}$, indicating that the fishing pressure is occurring with more than 50% of the catch being immature fish. Overall, the pole & line fishery is recommended as the preferred gear type to catch skipjack tuna in Maumere-Sikka, given its proximity to presumed spawning grounds, especially in the Banda Sea area (Satrioajie *et al*., 2018). However, an analysis of live-bait availability must be undertaken if an economically viable pole and line fishery were to be further developed. Reducing the immature and juvenile fish caught is also critical for a sustained pole and line fishery.

The majority of skipjack tuna caught is reported as 51,994 tons of total catch in 2004 by purse seine, troll line, gillnet, and pole and line gear type landed in the Sulawesi Sea (Wudianto *et al.*, 2006). One practical management strategy is to enforce bans on gear types that have been demonstrated to be environmentally unfriendly to optimally harvest skipjack tuna and prevent the probability of stock collapse. Promotion fishing gears with skipjack free shoaling and offering disincentives for the use of FADs to reduce more significant percentages of juvenile fishes are being caught (Setiyawan *et al*., 2018). There are also considerable numbers of immature skipjack tuna being caught from fish shoals, suggesting that fishing effort controls may ultimately be necessary to protect the stocks, regardless of gear type. Institution of a fishing season for FADs may be one strategy for consideration, particularly during the early months of the year when juvenile fish are dominant (Figure 5A). Further studies are needed to directly compare the effects of fishing methods used to determine growth parameters and exploitation rate are required to improve the utility of the data for deriving fisheries management recommendations.

CONCLUSIONS

The length distribution of skipjack tuna in the pole and line fishery was dominated by the size of 26-69 cm FL. The total catch composition was dominated by skipjack tuna up to 80% with a CPUE of 30.8 kg per person per trip. Length at first capture (L_c) is 34.71 cm FL. The pole and line fishing method has less by-catch during fishing compared to purse seine and other methods, but there is still a need to reduce the number of immature or juvenile fishes caught. The von Bertalanffy growth function (VBGF) for skipjack tuna at Maumere were L_{∞} = 70.35 cm, K = 0.55 yr^{-1}, and t_0 = -0.39 yr. The longevity of skipjack tuna was calculated as 3.2 years or 38 months. Finally, the estimate of total mortality (Z) was 1.83 yr^{-1}, natural mortality (M) was 0.92 $yr^{-1,\text{ and}}$ fishing mortality (F) was 0.91 yr^{-1} The exploitation ratio (E) was as low as 0.50. The recommendation for sustainable fisheries is to maintain the skipjack tuna catch below E_{max} of 0.73 and reduce the number of juvenile fishes caught by managing fishing grounds with FADs. We are encouraging targeting of wild fish schools and increasing awareness on the use of larger hooks size.

ACKNOWLEDGMENTS

The authors are thankful to the Center for Fisheries Research, Ministry of Marine and Fisheries Affairs who provide the data, and grateful to observers and enumerators who collected the data under WCPFC-WPEA Project Maumere-Sikka, and also thankful to KCBS company that has provided additional data. The authors are also thankful to Dr. Kathleen M. Castro of the URI-FAVS Department for critiquing earlier versions of this manuscript. Thanks are given to Dr. Jason McNamee, Deputy Director of the Rhode Island Department of Environmental Management, to read the paper and offer valuable suggestions carefully.

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