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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ABSTRACT

This study tests the hypothesis that pole & line fishing method can be considered "environmentally friendly" because it produces less by-catch during fishing. Several population parameters of skipjack tuna (*Katsuwonus pelamis*) taken by pole & line gear from Maumere Waters from March 2017 to February 2018 were analyzed. A total of 2,194 skipjack tuna was sampled randomly. The fishing grounds were around FADs (*Fish Aggregating Devices*) and free fish shoal. Observers and enumerators collected data from several landing sites and by direct onboard observation. The objective of this study is to provide length-frequency distribution by season, estimate growth mortality parameters, and estimate rate of stock exploitation using FISAT software. The results showed that the total tuna catch is dominated by skipjack tuna; up to 80% with the CPUE of 30.8 kg/person/trip, and length distribution of the skipjack tuna 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 formula (VBGF) parameters were $L\infty$ = 70.35 cm, K = 0.55 yr^{-1}, and t_0 = -0.39 yr. Natural mortality (M) was estimated to be 0.92, with fishing mortality (F) estimated as 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 as determined from this analysis could be developed with an E_{max} of 0.73, when there is a focus on reducing catch of immature fish through various methods that include changing the fishing target area from FADs to fishing on natural fish schools, and by using gear modifications such as use of larger-sized (lower number) hooks.

Keywords: Pole & 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 that is distributed primarily in seas with temperatures above 15^{o}C (Collette and Nauen, 1983). FAO reported that the skipjack tuna is the largest tuna fishery worldwide with 58% of the total catch in comparison with the other tuna species (FAO 2016). In indonesia, tuna and other fisheries are managed regionally in Fisheries Management Areas (FMAs) as described by Pomeroy et al, (2019).

In the Banda Sea, fishing gear used in skipjack tuna harvest include purse seines, gillnets, troll lines, and pole & lines(Tampubolon, 1990) with a majority of the catches coming from purse seines. The 2018, thetotal production of skipjack tuna was 172,835 tonnes in the Banda Sea (Indonesia Fisheries Management Area or FMA 714) according to MMAF statistics (2019).

Pole & line fishing is presumed to be a highly selective gear type when compared to the other methods of harvest. 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 & line fishing is one of two methods stakeholders are exploring to promote more sustainable tuna fisheries in Indonesian waters (Setiyawan *et al*., 2016). Various factors limit the viability of the pole & 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 & line fishers (Susanto *et al*., 2012). The other method promoted as a sustainable means of tuna harvesting is by 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, so 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 an essential factor for policy makers and stock managers to inform fisheries management recommendations, and subsequent policy making. Population dynamic parameters including temporal distribution of length frequencies, age, growth, and mortality are necessary for any reliable stock assessment, and to ensure sustainable exploitation of the fisheries (Chen and Paloheimo, 1994). There is a considerable paucity of data about the skipjack tuna populations on FAD structures, and on 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 international management of all tuna species, so 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 & 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.

Summary data							
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 and Lure	48	13	8700	FADs and Shoaling
3	May	Banda Sea	Anchovy	24	5	2200	FADs and Shoaling
4	June	Flores Sea	Anchovy	42	1	700	Shoaling
5	July	-	-	-	-	-	-
6	August	Flores Sea	Anchovy and Lure	14	3	1010	FADs and Shoaling
7	September	-	-	-	-	-	-
8	October	-	-	-	-	-	-
9	November	Flores Sea	Anchovy and Lure	4	1	200	Shoaling
10	December	Banda Sea	Anchovy	26	2	1500	FADs

Note: " - "; No data available

Materials and methods

The pole & line skipjack tuna fishery in Maumere-Sikka (about 8^oS, 122^oE) was monitored during 2017 by observers on-board 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 of 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 and Venema, 1991) and t_0 value is predicted by the empirical formula (Pauly, 1983). A total of 1,710 of 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 estimation 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 Bertalanffy growth function (VBGF) (von Bertalanffy 1938; Sparre and Venema, 1998) was fit to the data using the von Bertalanffy formula:

$$L_t = L_\infty\left(1 - e^{-K(t-t_0)}\right)$$

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 Powell-Wetherall plot which used length frequencies data with equation given thus:

$$L = \frac{-a}{b}$$

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

$$\text{Log}(-t_0) = -0.3922 - 0.2752\log L\infty - 1.038\log K$$

When:

L_t = fish length at age, t in years;
$L\infty$ = 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) 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 and Pauly 1986; Yang *et al*., 2013). The analysis was taken by the data input of growth parameters (length infinity and K) as Beverton & Holt (1986) equation:

$$Z = K(L_\infty\text{-}L")/(L"\text{-}L')$$

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 empirical equation as follows:

$$Ln\ M = -\ 0.0152 - 0.279\ \ln L\infty + 0.6543\ \ln K + 0.4634\ \ln T,$$

When,
L is asymptotic body length (cm),
K is the von Bertalanffy growth coefficient (yr^{-1}),
and T is the annual average water temperature of 26^{o}C

It is well known that sea surface temperature will affect growth of skipjack tuna (Barkeley et al., 1978), and 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

Fisheries

The pole & 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 & line fishing rely on live bait, consisting primarily of anchovies, and sardines, but lures are sometimes used (Figure 1).

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

The typical pole & 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 as a way to induce “false schooling” in the ocean, thereby increasing catch. Hook size chosen for fishing consists of the five, six, and seven-size type depending upon the preference of the fisher. Moreover, lures can be utilized as a “fake-bait” attached on the hooks as well (Figure 1).

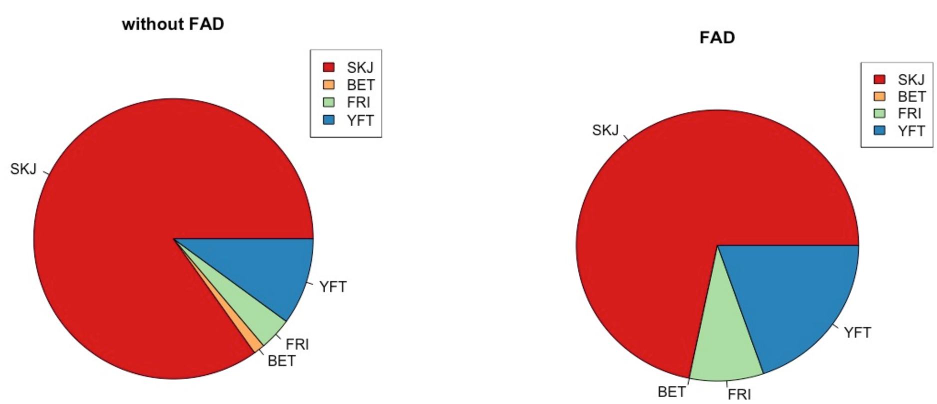


Figure 2. The composition of catches from all sites with free schooling (n=815) and with FADs (n=1379); SKJ = Skipjack tuna; YFT = Yellowfin tuna; BET = Bigeye tuna; FRI = Frigate tuna).

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 & line fishery are of skipjack tuna: fish shoaling (85%), and with 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 were focused around 8°S and 122°E (Figure 3) and is in the Indonesia Fishing Marine 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 currents in the fishing grounds are dominated by the westerly flowing equatorial current system.

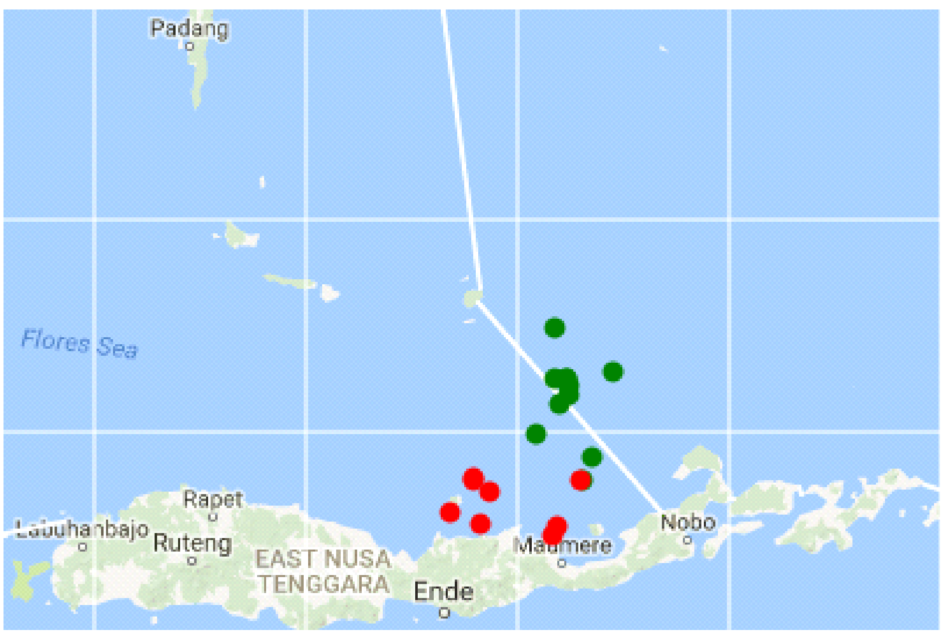


Figure 3. The Pole & Line Fishing Ground in the Flores and Banda Seas. The boundary line (white line) between FMA 713 in the Flores Sea toward the west, and FMA 714 toward the east in the Banda Sea is shown. The longitude & latitude grid represents 1° of arc, or 60 nautical miles (111.1 km). (Red dot: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

Catch per unit effort (CPUE)

The total trip frequency of pole & line vessels every month fluctuated depending on the availability of live-bait. The magnitude of the nominal *catch per unit effort* (CPUE) is 30/kg per fishers for a single trip. Currently, there is no known standard for calculating CPUE in respect to pole & line fisheries. In this research, CPUE is calculated based on total catch per trip, divided by the number of fishers who were fishing (called nominal CPUE). The number of fishers was determined from the number of fishers who were actually fishing per trip by logbook. 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.

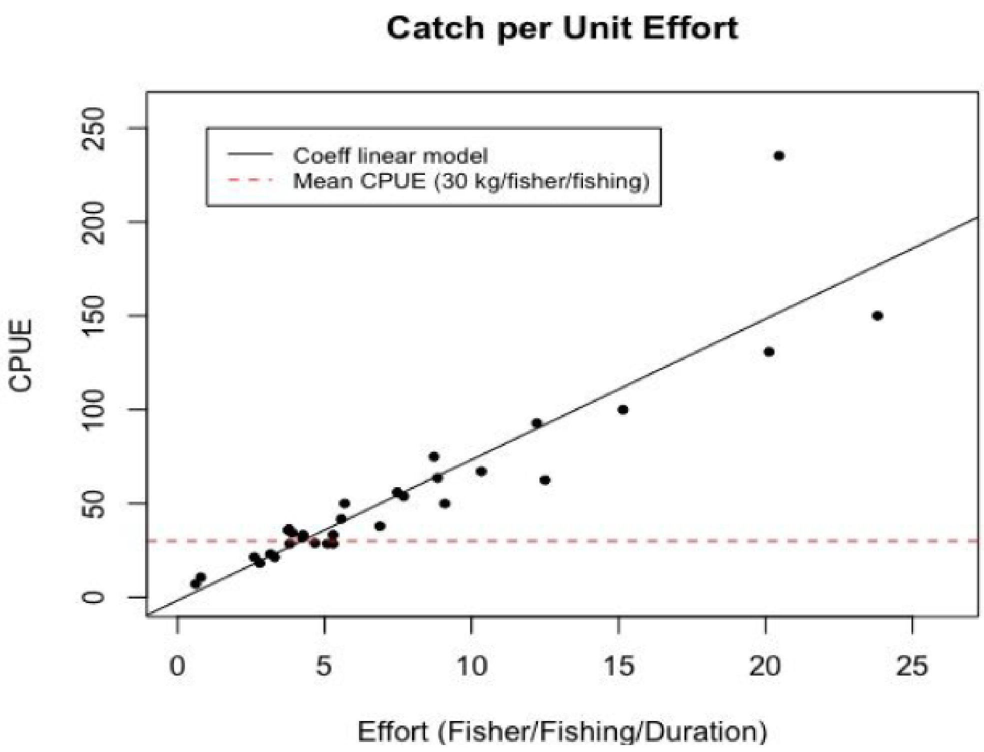
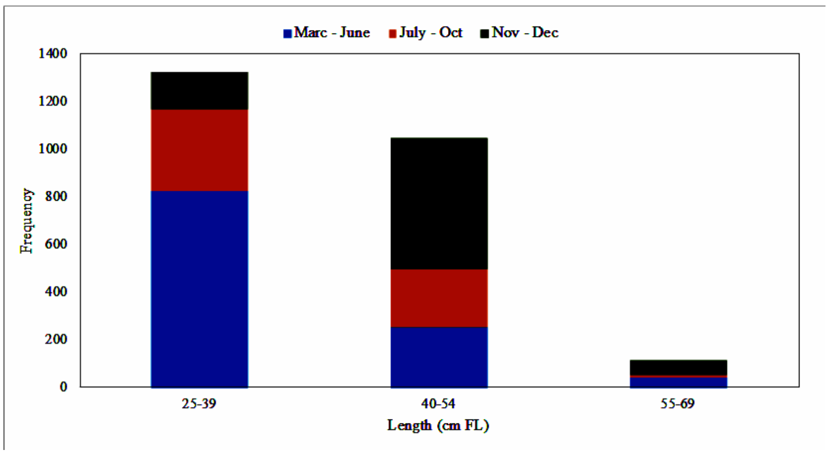


Figure 4. *Catch per Unit Effort* (CPUE) as a function of effort in the pole & line fishery in Maumere-Sikka. (dashed line is the mean CPUE; solid line : Coefficient linear model)

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 sampled calculated in this research is limited and analyzed carefully.

A)



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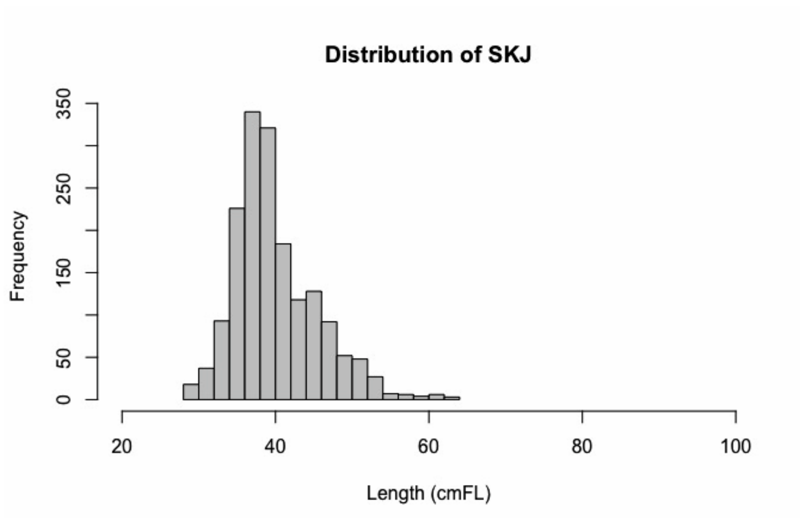

Figure 5. (A) The rough length-frequency distribution (L in cm) of skipjack tuna by season, (B) The normal distribution (L in cm) of skipjack tuna in Sikka-Maumere.

The fork length distribution of skipjack tuna in the catch is illustrated by size category in Figure 4. The size of length-frequency 25 to 39 cm FL is 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).

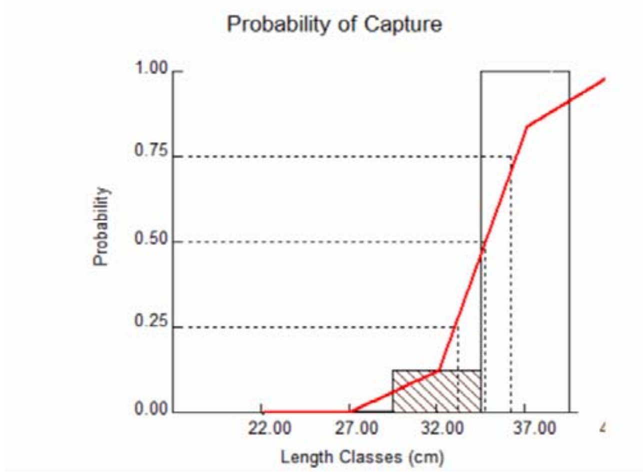

Figure 6. Probability of capture by length class of skipjack tuna from the ascending arm of the catch curve (Y = -25.08 + 0.72X, r = 0.99). The length at first capture (dotted lines) were L_{50} = 34.71 cm FL, L_{25} = 33.19 cm FL, L_{75} = 36.32 cm FL by logistic transformation (a) and running average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

Skipjack tuna caught by pole & 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 at 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).

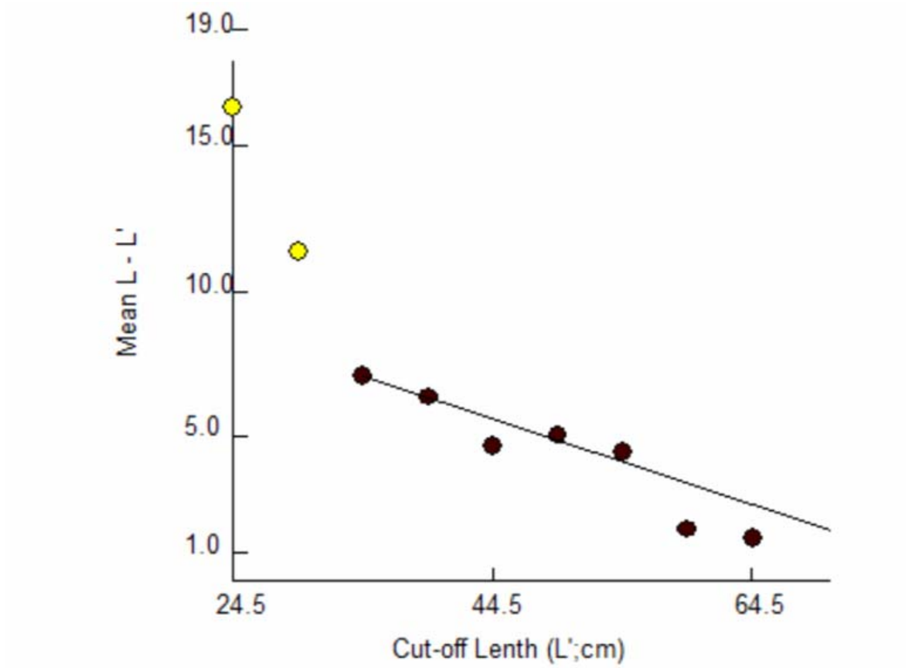

Figure 7. Powell-Wetherall plot for skipjack tuna in Maumere-Sikka identifies length at first exploitation. The regression line: Y =14.25 + (-0.18) * X identifies the first length at full exploitation (L') of 64.5 cm FL, coinciding with the largest size grouping in the length-frequency data (rightmost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

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

Taking t_0 = -0.39 the length of the skipjack tuna was calculated as 69.73 cm FL and 70.34 cm FL at 1 to 3 years respectively. The skipjack tuna grows rapidly and reaches catchable size within one year.

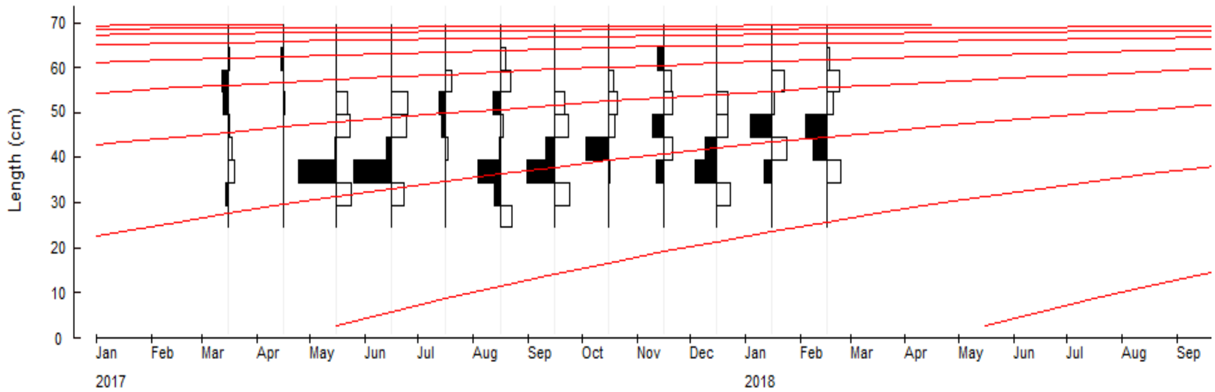

Figure 8. The ELEFAN I analysis for determination of von Bertalanffy growth parameters of skipjack tuna stocks in Maumere-Sikka from March 2017 to February 2018.

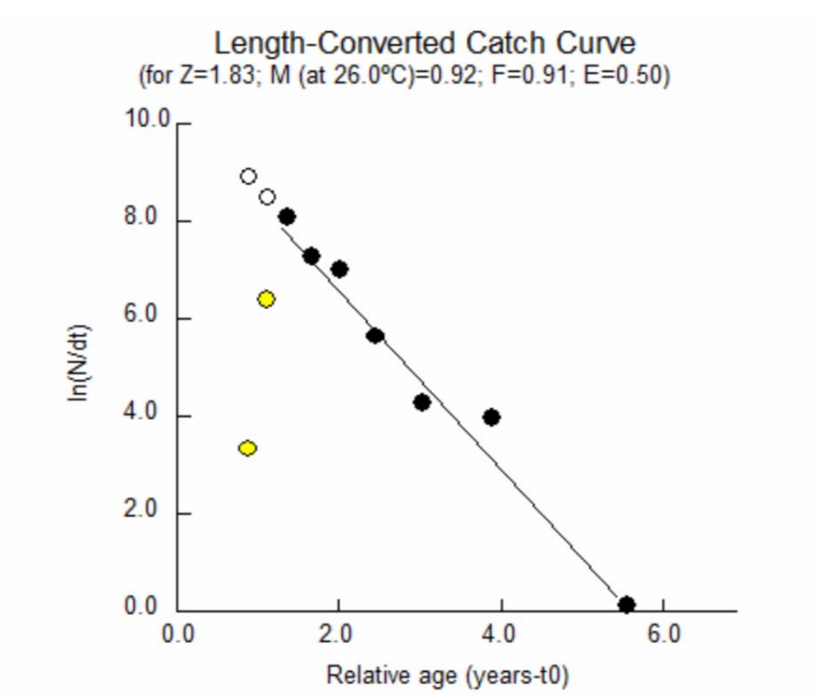

Figure 9. The length-converted catch curve showing the relative age (years) to the fishing mortality (F), natural mortality (M) and the exploitation rate (E)

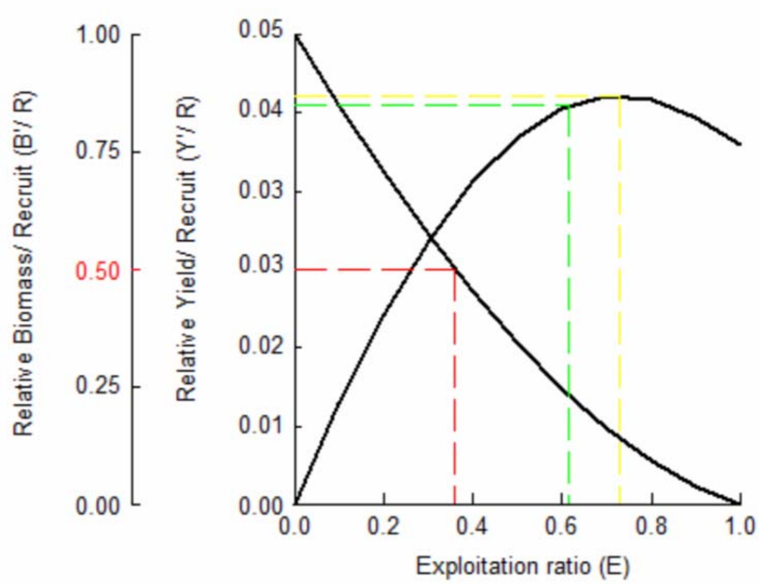

Figure 10. An exploitation rate graph showing that E_{50} as 0.36, E_{max} as 0.73 and E_{-10} as 0.62

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} that was obtained for skipjack tuna in the Maumere-Sikka is less than optimum level of exploitation (E_{max} = 0.73) as shown in Figure 10.

Discussion

The present study shows the observed size range of skipjack tuna exploited by exploited by pole & line gear type in the Maumere-Sikka as 26 to 69 cm FL. This is in contrast to the size of skipjack tuna exploited 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 & line gear type in the Banda Sea ranging from 9 to 71 cm FL, which is quite similar (Figure 5).

Table 3. Comparison 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)

There have been a number of 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, 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 & line catch in this study corresponds to an individual weight of about 1.19 kg, while the mean catch length of 56.6 cm corresponds to a weight of 3.93 kg using allometric parameters (a) = 3.581 x 10^{-6} and (b) = 3.446, from data in Resma *et al*. (2006). Greatest CPUE for skipjack tuna in both the purse seine and pole & 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 and 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 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 hook to be used in the pole & line should be carefully considered since evidence suggests that larger sized hooks (with smaller number) tend to catch larger fish. Setiyawan (2016) found that in the Sulawesi and Maluku Waters, the pole & line fishers use mostly hook sized #4 and #5 that are larger size hooks than in the present study. Mean fish length of fish caught in Sulawesi and Maluku waters is larger. Given the high number of juveniles that are being caught in the Maumere pole & line fishery, reducing the numbers of the juveniles being caught is necessary boost rhe 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 as conservation area for tuna population, since tuna spawning grounds have been found in this area. Tuna tagging programs was conducted in 2009 by Pacific tuna tagging project (Nicol *et al*., 2010), have shown that smaller tuna found in the Banda Sea, will afterwards 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 the data of Resma *et al*., (2006) who showed that considerably more larger skipjack tunas are found in the Bismarck Sea area north of Papua Waters and in the Celebes Sea northwest of North Sulawesi. Our data showing longevity of 3.2 years with length infinity 70.35 cm FL is comparable with Tajduddah et al. (2017) in 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 making 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 & line fisheries are not as "environmentally friendly" as originally assumed 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, but they recommended that a gradual increase in the mesh size of the bunt on purse seines from the 3.5 inch (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 sustainability of that method. Pole & line gear are generally more selective than purse seines, but they can be more selective for mature skipjack depending upon hook size. Pole & line fisheries may have the advantage of allowing for regulations requiring release of smaller skipjack tuna immediately upon landing and unhooking. A good fisheries management strategy for skipjack tuna in the Eastern Flores and Banda Sea region may be in changing the fishing gear from purse seine to pole & 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, consultations are made on the growth rate in the WCPFC Working Group or Scientific Committee Meeting for compliance with the international treaty obligations. Studies in different areas of the Pacific Ocean, including the Banda Sea have indicated that the $L\infty$ 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 rapid growth rate of skipjack tuna, mirroring similar findings by other authors.

Table 4. 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, but 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. But our data showing the numerical value of t_0 as being negative, indicating that younger fish grow faster than strict von Bertalanffy predictions. Figure 12 compares the growth curve of skipjack tuna between the present study and others from the WCPFC convention fisheries management area. For the first three years, skipjack tuna grew at the faster rate in WCPFC convention area that includes the Banda Sea.

The natural mortality estimation of skipjack tuna seems constant, ranging from 0.7 $year^{-1}$ to 0.8 $year^{-1}$ (Koya *et al.*, 2012) from comparisons with 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 & line fishery were to be further developed. But, reducing the immature and juvenile fish caught is also critical for a sustained pole & 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 & line gear type landed in Sulawesi Sea (Wudianto *et al.*, 2006). To optimally harvest the available stock of skipjack tuna and to prevent the probability of stock collapse, one practical management strategy that could be is to enforce bans on gear types that have been demonstrated to be environmentally unfriendly, promotion of the fishing grounds with skipjack tuna shoaling, and offering disincentives for use of FADs, because of proportionally greater percentages juvenile fishes are being caught in them (Setiyawan *et al*., 2018). There are also considerable numbers of immature and juvenile skipjack tuna being caught from fish shoals as well, suggesting that controls of fishing effort 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 methodologies used to determine growth parameters and exploitation rate areneeded to improve the utility of the data for deriving fisheries management recommendations.

Conclusion

The length distribution of skipjack tuna in the pole & line fishery was dominated by the size of 26-69 cm FL. The composition of total catch is dominated by skipjack tuna up to 80% with a CPUE of 30.8 kg/person/trip. Length at first capture (*Lc*) is 34.71 FL-cm. The pole & line fishing method has less by-catch during fishing in comparison 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 factors (VBGF) for skipjack tuna at Maumere were L_∞ = 70.35 cm, K = 0.55yr^{-1}, and t_0 = -0.39 yr. The longevity of skipjack tuna was calculated as 3.2 years or 38 months. Finally, estimate of total mortality (Z) was 1.83 yr^{-1}, natural mortality (M) 0.92 yr^{-1} fishing mortality (F) 0.91 yr^{-1} The exploitation ratio (E) was low as 0.50. The recommendation for sustainable fisheries is to maintain the skipjack tuna catch optimally below than E_{max} of 0.73 and reducing the number of juvenile fishes caught by changed my managing fishing grounds with FADs, encouraging targeting of natural fish school and encouraging the use of larger (lower-number) hooks when fishing for skipjack tuna in Maumere Waters.

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