Population dynamics of longtail tuna (*Thunnus tonggol*) in the Java Sea and adjacent waters

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Abstract. Growth, mortality, and exploitation rate parameters of longtail tuna (*Thunnus tonggol*) were estimated from the Java Sea, Pekalongan based fisheries, Indonesia. A total of 17152 specimens were collected by drift gillnet and small purse seine from April 2018 to March 2019. The fork length data was analyzed by using FiSAT II to estimate population parameters. The fork length ranged between 9 and 81 cm, with the mode between 47 and 49 cm. Based on the von Bertalanffy growth function, it was estimated that the growth constant (K) was 0.41 year^{-1}, asymptotic length (L_∞) and the value of 78.8 cm, age at zero length (t_0) was -0.0483, and growth performance index (φ) was 3.406. The natural mortality (M), fishing mortality (F), and total mortality rate (Z) were 0.77 year^{-1}, 0.92 year^{-1}, and 1.69 year^{-1}, respectively. The recruitment pattern occurred twice a year in March-April (peak recruitment) and August-September (lean recruitment), and the rate of exploitation (E) was estimated to be 0.54 year^{-1}, indicating that longtail tuna in the Java Sea was fully exploited.
Key Words: exploitation rate, growth, Java Sea, mortality, *Thunnus tonggol*.

Introduction. Longtail tuna (*Thunnus tonggol*) is an economically important pelagic fish. They inhabit almost exclusively the neritic waters close to the shores, avoiding estuaries, turbid wasters and open ocean. Its geographical distribution encompasses tropical and subtropical waters within the Indo-Pacific region between 47°N and 33°S (fishbase.org), from the south of Japan, Philippines, Papua New Guinea, the Indonesian archipelago, Australia, from the Java Sea to Malacca Strait, Indian waters, the Arabian Peninsula, Persian Gulf, Red Sea and the Somali Coast (Collette & Nauen 1983).

In Indonesian fisheries, this species is often caught along with other neritic scombrids such as kawakawa (*Euthynnus affinis*) and frigate tuna (*Auxis thazard*), being exploited by semi industrial and artisanal fisheries. Its annual landings have increased from 95325 tons in 2006 and reached its peak with 117783 tons in 2011. It then declined to 84022 tons in 2012, and recorded its lowest production in 2016, with 65651 tons (DGCF 2017). The contribution of longtail tuna from Java Sea was 37% to the national landing catch. In the Java Sea, longtail tuna is mainly caught by drift gillnet and small purse seine. As an important target species, a decrease in annual landings might be a sign of declining stock conditions. Because of this, a better management should be conducted. This is in order to avoid what Hilborn & Walters (1992) stated, that a steady increase of catch can results in a declining rate of fishing success as the stock is reduced, the fisheries entering overexploitation, followed by collapse (Hilborn & Walters 1992).

The growth and exploitation rate are key information in fishery management. Based on landing, length data is used to estimate population dynamics parameters partially including length-frequency distribution, growth, mortality, and exploitation rate, which is reliable information in stock assessments (Chen & Paloheimo 1994). In terms of longtail tuna, the pertinent aspects have been reported from several geographical areas, such as India (Abdussamad et al 2012; Kumar et al 2017), Oman and Persian Gulf (Prabhakar & Dudley 1989; Kaymaram et al 2013; Yasemi et al 2017; Darvishi et al

2018), and Australia (Griffiths et al 2010). The studies were limited to certain areas and sub-populations of longtail tuna. The present research aimed to estimate the growth and exploitation rate of longtail tuna in the Java Sea.

Material and Method. Longtail tuna was collected from the Fisheries Management Area 712 of the Java Sea. Fishing was conducted using drift gillnet and small purse seine with an average mesh size of 4 and 1 inch, respectively. The catch was landed at the Fish Landing Site of Pekalongan, Central Java, from April 2018 to March 2019, monthly (Figure 1). Each individual longtail tuna was randomly selected and fork-length was measured with a precision of 0.1 cm.

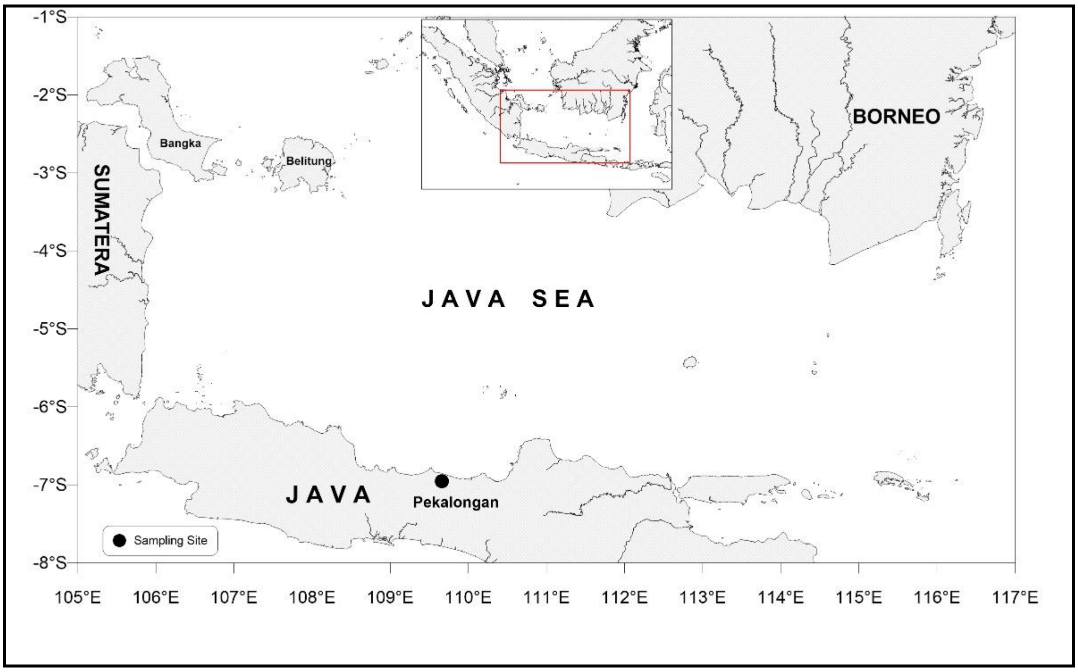

Figure 1. Fish Landing Site of Pekalongan, Central Java.

Data analysis. The data analyses in the present work were based on the length data of each individual fish that was grouped into monthly periods. The data was analyzed with ELEFAN I (Electronic Length Frequency Analysis) model made by FiSAT II (FAO-ICLARM Stock Assessment Tools) (Gayanilo et al 2005). Length data was grouped by 3 cm intervals, then pooled into monthly length frequencies, being the best fit for the model to reduce sampling errors. Growth coefficient (K) and asymptotic length (L_∞) were determined. In order to estimate growth, the theoretical age at length zero (t_0) is firstly calculated using the equation from Pauly (1983):

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

L_∞, K, and t_0 are parameters used to build von Bertalanffy's growth function (VBGF) determined by Sparre & Venema (1998), as follows:

$$L_t = L_\infty [1 - e^{-k(t-t_0)}]$$

Where: L_t is the length at age t (cm), L_∞ is the asymptotic length (cm), K is the growth coefficient (year^{-1}) and t_0 is the theoretical age at length zero (years).

The growth performance index (Ø) is calculated by the following equation from Pauly & Munro (1984):

$$\phi = \text{Log } K + 2*\text{Log } L\infty$$

Based on the von Bertalanffy growth and the growth parameters available in the program package FiSAT II, the seasonal recruitment of longtail tuna is estimated (Gayanilo et al 2005).

The annual total mortality rate (Z) was calculated by firstly estimating its natural mortality rate (M) by using Pauly's empirical equation (1983):

$$\ln M = -0.0152 - 0.279*\ln(L_\infty) + 0.6543*\ln(K) + 0.4634*\ln(T)$$

Where: T is the mean annual sea surface temperature (in ^{0}C). In the present study, T was 30^{0}C, in accordance with Ma'mun et al (2019).

The estimation of fishing mortality (F) is in accordance with Pauly (1983):

$$F = Z - M$$

Having the values of F and Z, the exploitation rate (E) was calculated using the following formula (Gulland 1985):

$$E = F/Z$$

Results and Discussion

Length frequency distribution. The annual length frequency of longtail tuna is presented in Figure 2, constructed from 17152 individuals. The fork length ranged from 9 to 81 cm, with a mode of 47–49 cm. The average fork length was 42 cm.

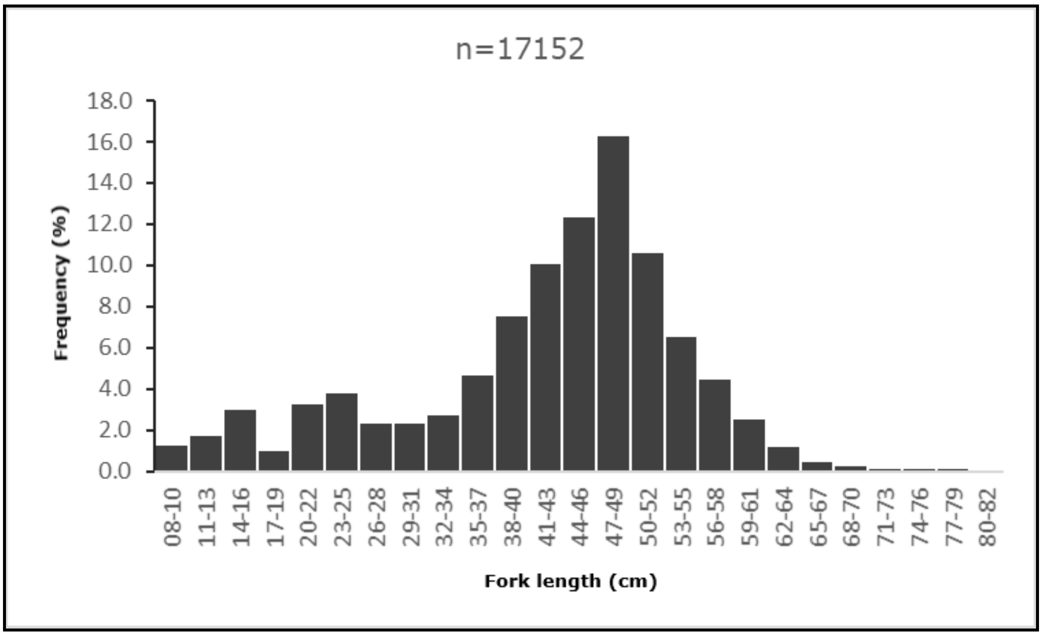

Figure 2. Length frequency distribution of longtail tuna (*Thunnus tonggol*) in the Java Sea; n - number of fish.

The fork length value of longtail tuna differed from those of other studies, in different seas. Hidayat & Nugroho (2018) obtained values between 35 and 83 cm. The fork length value was between 23-111 cm in Indian waters (Abdussamad et al 2012), 27-107 cm the Persian Gulf (Yasemi et al 2017), 26-125 cm in Omani waters (Kaymaram et al 2013), and 30-150 in Australian waters (Griffiths et al 2010). The discrepancies in maximum fork length of longtail tuna caught in the Java Sea compared to other regions might occur due to the variability of aquatic habitat conditions and fishing gear characteristics, especially the mesh size, different mesh size resulting in different size structures (Reddin 1986; Chindah & Tawari 2001; Shoup et al 2003; Sbrana et al 2007; Ago et al 2014).

Yesaki (1989) states that the differences in size structure are dependent on the different subpopulations throughout the distribution range. Size frequency distribution can provide information on population dynamics such as growth, mortality and recruitment, and population migration (Azpeitia et al 2013).

Growth parameters. The growth parameters show the L_∞, K, age at t_0, Rn and φ values of 78.8 cm, 0.41 $years^{-1}$, -0.0483, 0.252, and 3.41, respectively (Figure 3). The annual growth of longtail tuna corresponds to 27.53, 44.77, 56.22, 63.81, and 68.85 cm length, from the first year onward. The highest K was found between the age of 0+ to 1+, with an average of 2.16 cm per month (Figure 4).

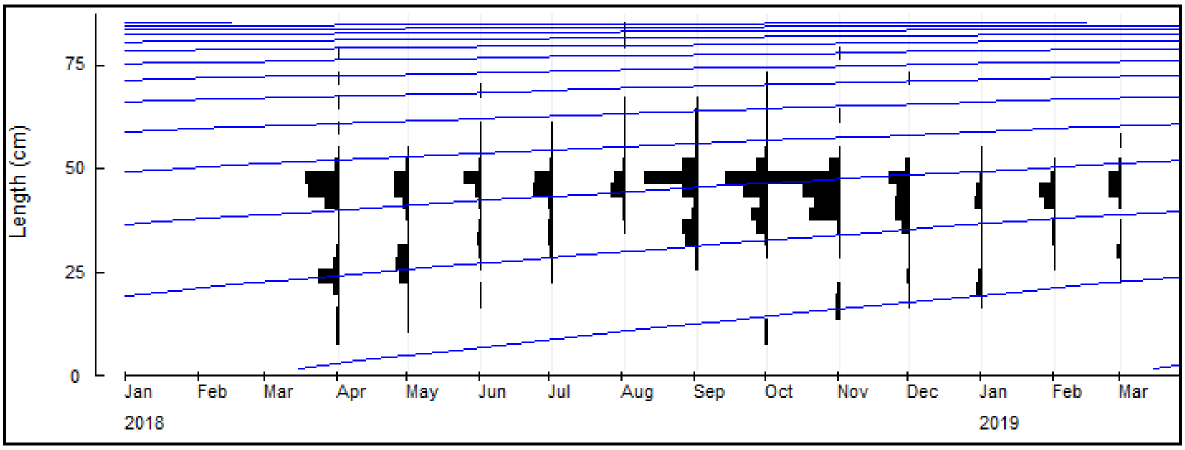

Figure 3. Monthly length frequency distribution output from FiSAT II with overlying growth curve for *Thunnus tonggol* in the Java Sea.

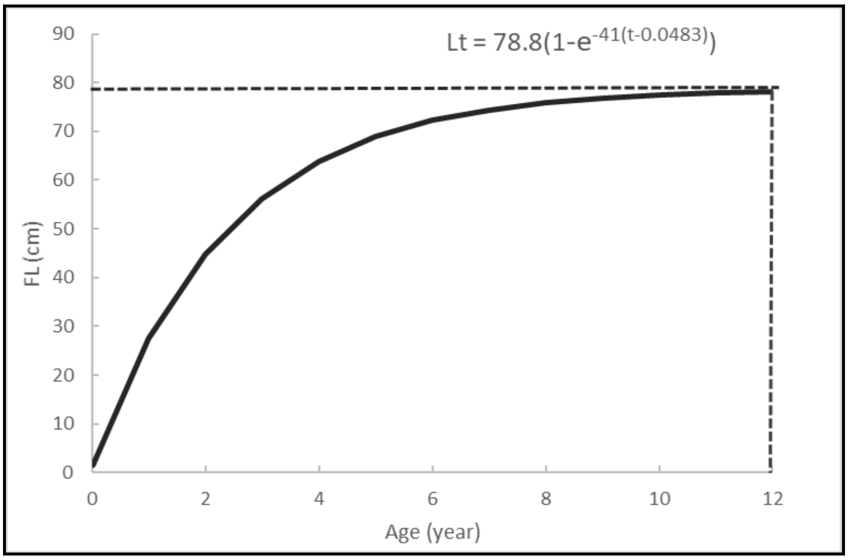

Figure 4. Length at age t of *Thunnus tonggol* from the Java Sea based on the Von Bertalanffy growth curve. Lt - length at age t; FL - fork length.

Table 1 shows the values of growth and mortality parameters in longtail tuna estimated from different areas. The geographical discrepancies in growth parameters might occur because of the variability of the analytical methods and different fishing gears, including drift gillnets, hooks and lines, troll and trawls (Pillai et al 2002; Mehanna et al 2012). In terms of L_∞ and K, Taghavi Motlagh et al (2010) state that the variability in these two parameters might be associated with sampling errors, variations in fishing intensity or environmental conditions.

Among the methods used to estimate growth, like tag and recapture data, analysis of the hard parts of the fish (otoliths, vertebrae), and length-frequency distribution (Gaertner et al 2004), the latter method is considered more applicable for tropical species. In tropical waters, the hard part changes are less pronounced, therefore, it is difficult to use a seasonal ring to estimate growth and age (Sparre & Venema 1998). The characteristics of ecological factors in different areas, such as population density, temperature and prey density may cause variations in the values of growth parameters (Ju et al 2016; Wootton 1999; Magnussen 2007).

Table 1

Growth parameters of longtail tuna (*Thunnus tonggol*) from several geographical areas

Area	*L∞ (cm)*	*K (year^{-1})*	*t_0 (year^{-1})*	*Method*	*Source*
Papua New Guinea	122.9	0.41	-0.032	Length frequency	Wilson 1981a
Papua New Guinea	131.8	0.395	-0.035	Otoliths	Wilson 1981b
India	93	0.49	-0.24	Length frequency	Silas et al 1985
Thailand	58.2	1.44	-0.027	Length frequency	Supongpan & Saikliang 1987
Oman	133.6	0.228	-	Length frequency	Prabhakar & Dudley 1989
Thailand	108	0.55	-	Length frequency	Yesaki 1989
Japan	55	1.7	-0.089	Otoliths	Itoh et al 1999
Australia	135.4	0.233	-0.02	Otoliths	Griffiths et al 2010
India	123.5	0.51	0.032	Length frequency	Abdussamad et al 2012
Iran	133.8	0.35	-	Length frequency	Kaymaram et al 2013
Pakistan	55.7	1.049	-	Length frequency	Ahmed et al 2016
Iran	129.6	0.39	-0.28	Length frequency	Darvishi et al 2018
Iran	111.23	0.3	-0.38	Length frequency	Yasemi et al 2017
Java Sea	78.8	0.41	-0.048	Length frequency	Present study

Note: L∞ - asymptotic length; K - growth constant; t_0 - age at zero length.

Mortality and exploitation rate. The length-converted catch curve depicted in Figure 5 has estimated the M value of 0.77 year^{-1} at an annual average temperature of 30°C. F value was 0.92 year^{-1}, hence the Z value was estimated to be 1.69 year^{-1}, and the E value was 0.54 year^{-1}.

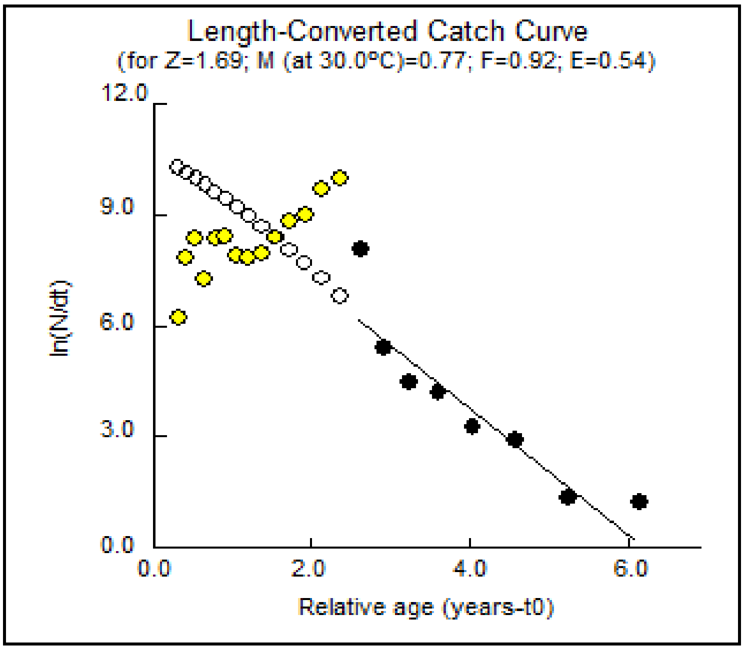

Figure 5. Length-converted catch curve for longtail tuna (*Thunnus tonggol*) in the Java Sea. Z - total mortality rate; M - natural mortality rate; F - fishing mortality rate; E - exploitation rate.

The Z value in this study was slightly higher than the results of Yasemi et al (2017) in the Persian Gulf, with 1.15 year^{-1}. A higher value was recorded by Abdussamad et al (2012), with 3.85 year^{-1} in Indian waters. The M value in this study was 0.77 year^{-1}, higher than in the Persian Gulf, Omani waters, and Iranian coasts, with 0.43, 0.429, and 0.44, respectively (Yasemi et al 2017; Prabhakar & Dudley 1989; Kaymaram et al 2013). The present results coincide with the values present in Indian waters, 0.77 year^{-1} (Abdussamad et al 2012). Natural mortality is dependent on fishing pressure, seawater temperature during sampling periods, diseases, the presence of predators, stress, and old age (Sparre & Venema 1998; Darvisi et al 2018). The difficulties in estimating the M value are also linked to the selection of the estimation method and the differences in the study area (Su et al 2003).

The fishing mortality and exploitation rate of longtail tuna in the Java Sea were 0.92 year^{-1} and 0.54 year^{-1}, respectively. According to Gulland (1985), the optimally exploited stock occurs when the fishing mortality is equal to the natural mortality (M), or the highest value of exploitation rate is 0.5. Kumar et al (2017) states that the exploitation rate of this species in Indian water was 0.42. The differences in the exploitation rate in some areas compared to others occur due to differences in the level of fishing effort. The exploitation level of longtail tuna in the present study was 0.54, indicating that longtail tuna in the Java Sea is fully exploited. The management effort that can be applied is in the direction of maintaining the exploitation at the current level, preventing additional efforts.

The annual recruitment pattern of longtail tuna in the Java Sea has two peaks, in March-April (peak recruitment) and August-September (lean recruitment) (Figure 6).

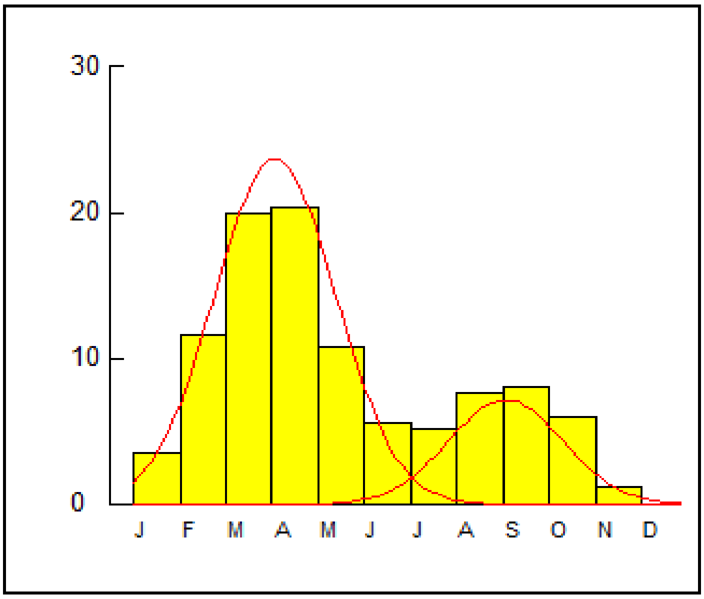

Figure 6. Recruitment pattern of longtail tuna (*Thunnus tonggol*) in the Java Sea.

Recruitment is bimodal with the size of the species at recruitment of 9-10 cm fork length. The species growth rate indicates that the recruitment from the east monsoon season spawning leads off in March-April and the recruitment from the west monsoon season spawning is in August-September. This is similar to those reported in the Indian Water (Abdussamad et al 2012). The bimodal recruitment assumed may be related to the two monsoon season in this area (Pauly & Navaluna 1983; Ingles & Pauly 1984)

Conclusions. Longtail tuna in the Java sea has the growth constant K of 0.41 year^{-1}, and can grow to the asymptotic length of 78.8 cm. Natural mortality, fishing mortality, and total mortality rates were 0.77 year^{-1}, 0.92 year^{-1}, and 1.69 year^{-1}, respectively. The recruitment occurs twice a year in March-April (peak recruitment) and August-September (lean recruitment).The exploitation rate was 0.54 year^{-1}. The *T. tonggol* fishery in the

Java Sea is fully exploited, therefore current exploitation level needs to be maintained, and additional efforts prevented.

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