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SOUTHERN BLUEFIN TUNA (*Thunnus maccoyii*) CAUGHT BY INDONESIA'S TUNA LONGLINERS IN THE SPAWNING AREA

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ABSTRACT

Southern Bluefin Tuna in spawning area of the Eastern Indian Ocean where the Indonesian's longliners operated has a specific character in term of size, age, sex-specific growth rate and the population. The aims of this study are to determined changes in size/age, sex-specific growth rate and virtual population analysis of Southern Bluefin Tuna (SBT) in the spawning area. This study is important to find out the successful management of SBT in spawning area by looking at the catch at age/size movement, sex-specific growth analysis and the estimation of the population by virtual population analysis. In this study, we were used 452 pairs of otolith with fish sized from 134-196 cmFL and fish aged from 8-20 years. The growth equation was $L_t = 191\ (1\text{-}e^{-0{,}167(t+1{,}081)})$. Catch at age structure was distributed from 5-22 years with mean and mode of age were 9.63 and 9 years. The distribution of mode changed from year to year shifting to a younger fish. In 2012, the mode was 10 years but entering 2013-2014 the mode was shifted to 6 years. In 2015-2017, the mode was increased from 7 years (2015) to 8 years (2016) and 9 years (2017). The fishing pressure happened in the age group under 20 years. In 2012 to 2014, the highest fishing pressure respectively obtained in the age group of 13 to 11 years with an average length of 167 to 174 cmFL. Entering 2015 and 2016, the highest fishing pressure obtained in the age group of 6 years with an average length of 138 cmFL. The exploitation rate ranged from 0.14/year to 0.25/year meaning that the exploitation was in optimal condition.

Keywords: Southern Bluefin Tuna; spawning area; otolith, catch at age structure, virtual population analysis

INTRODUCTION

Growth rate, catch at age structure and virtual population analysis (VPA) can provide an overview and information about fishing pressure, population and exploitation status of the fish stock in certain water. High fishing pressure can be seen from a reduction of the relative abundance of larger fish or older fish (Sparre & Venema, 1998). In some cases, fish stock assessments only seen from spawning stock biomass (SSB) reproductive potential and ignoring the change that may occur in size and age structure of the spawning stock population (Farley *et al*., 2014; Setyadji, 2015). Therefore it is necessary to recognize and carry out a comprehensive monitoring of size and age change in spawning population as well as the impact of fishing pressure on the species in stock assessment process The population and exploitation status of the species can also be determined by interpreting statistical data using the VPA method (Sparre & Venema, 1998). Age determination using a hard part of the body such as otolith is important for long-lived species where not all fish size can be a good predictor of age (Farley *et al*., 2014). Changes in the catch at age structure and VPA of spawning stock biomass can be used as the main indicator of the stock status of this species (Farley *et al*., 2014; Rochman, 2019).

Southern Bluefin Tuna (SBT) *Thunnus maccoyii*, is a long-lived, late-maturing and reaching maximum size of at least 200 cmFL and maximum age 40 years old (Gunn *et al*., 2008). Spawning ground area of SBT is known in the eastern of the Indian Ocean between Indonesia and west coast of Australia where the Indonesian fisheries in particular longline fishery operated. Mature fish begin to migrate to this area from the southern Indian Ocean (Tasman Sea, Australia) in September until April each year (Farley & Davis, 1998; Patterson *et al*., 2008; Evans *et al*.,

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2012). Indonesia began a member of the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) in 2008, and in periods of 2018-2020 Indonesia has 1,023 tonnes of the Total Allowable Catch (TAC) as CCSBT member (CCSBT, 2018). Indonesian Tuna Fishery has began to catch this species in spawning ground area since 1976 (CCSBT, 2018). The production increased rapidly from only a few tonnes in year 1976 to 2,504 tonnes in 1999 and then declined to only 565 tonnes in 2003 and 633 tonnes in 2004 (CCSBT, 2018). The decreasing number of SBT caught by the Indonesian longliners caused by the increasing number of the exploitation which was signed by the decreasing number of nominal CPUE globally in the period of 1970 to 2007 (CCSBT, 2017). Generally, Southern Bluefin Tuna is the main target of Indonesian longliner along with Yellowfin Tuna and Bigeye Tuna. However, during the SBT season (September-April) in each year, this species become the first target compared to the Yellowfin Tuna and Bigeye Tuna. Indonesian longline fisheries are high capital fisheries with the highest capital expenditure is in fuel cost reaching up to 50-60% of the total cost (Rochman *et al*., 2016). Indonesian tuna longliner tries to reduce this cost with stayed at sea for much longer periods (±9 month) and used carrier vessel to bring back fish to the fishing port and to support a logistic to the fishing vessel (Rochman *et al*., 2016).

Actually, spawning stock biomass of SBT in the Indian Ocean remain at a low level to be 13% of the initial stock in 2017 but there has been an improvement of spawning stock biomass since the previous stock assessment at level 5% of original biomass 2011 and 9% of the original biomass 2014 (CCSBT, 2018). Therefore, it was important to estimate the size and age distribution of SBT caught by Indonesian longliner for monitoring on the changes of size and age structure in spawning population.

Even though SBT caught by Indonesia's tuna longliner cannot represent all of the whole tuna in spawning ground area but historically, Indonesian SBT was larger than those Japan SBT caught in spawning ground area (Farley *et al*., 2014). The majority of SBT caught by Indonesia's tuna longliners were in shallow water inside the Indonesian Exclusive Economic Zone (IEEZ) and teritorial water nearshore off Java island 10-15°S and 100-120°E (Rochman, 2019) and Japan longliner operated in deep water outside the IEEZ (Farley *et al*., 2014). A larger size of SBT was found in shallow water of tropical water where Indonesian longliner able to catch (Farley *et al*., 2014; Rochman, 2019). Therefore, it's recommended that Southern Bluefin Tuna caught by Indonesia's longliner can be used as a reference point in spawning stock assessment of SBT in the Indian Ocean.

Data used in this study were based from a long-term monitoring program (enumeration) in the past six years and combined with otolith data used for age estimation. The aims of this research are to determined changes in size/age, sex-specific growth rate and virtual population analysis of SBT in the spawning ground area.

MATERIALS AND METHODS

Data Source and Collection

In this study, we used two types of primary data that is otolith data and catch monitoring data of SBT caught in spawning ground area of the Eastern Indian Ocean. The otoliths data used in this study were sagittal otolith data obtained from 462 SBT landed in Benoa port Bali during the fishing season in the period of January to December 2017. The reading of the otolith aging was occurred in Research Institute for Tuna (RITF) laboratory in April 2018. We used the Average Percentage Error (APE) to validate the precision of intra and inter-reader difference. The estimation of APE level can be known by the formula $APE_j = 100 * \frac{1}{R}\sum_{i=1}^{R}[\frac{Xij - Xj}{Xj}]$ given by Beamish & Fournier, (1981) Where X_{ij} is the *i*th age estimate of the *j*th fish, X_j is the mean of readings for the *j*th fish and *R* is the number of times each fish is aged. The APE level recommend a maximum level of 10%.

The otolith data includes fish morphometry data consisting of fork length (cmFL) and gilled gutted fish weight (kg). The proportion of the samples and fish morphometry consider being a balance between length class. All of the sagittal otoliths were removed, prepared and read following the techniques described by Clear *et al*. (2000) and also described by Shimose & Ishihara, (2015).

The enumeration data of Benoa port was chosen because Benoa port was the biggest fishing port in Indonesia where 85% of SBT landed (Satria *et al*., 2012; Farley *et al*., 2014). The enumeration data of SBT landed in Benoa port consist of the name and the number of the vessel, fish morphometry (length and weight), grade of fish quality (export, reject and local) and the coverage of data sample. The grade of fish depended on flesh quality which was influenced by fish handling, the condition of the fish at the first capture and length of trip (fresh and frozen fish). The catch of SBT obtained from spawning ground area located near the port base in the south of Java, Bali and Nusa Tenggara intended for the export market

(Figure 1). The frozen SBT was obtained from a nursery ground area which was far from the main fishing port and intended for the local market. The location of nursery ground area is in Western Australia in the coordinate of (20º-35ºS and 75º-110ºE) (Proctor *et al*., 2006; Lin & Tzeng, 2010; CCSBT, 2016).This study was focused on the data of fresh SBT because it was in accordance with the initial objectives of the study i.e. to determine the growth, catch at age structure and virtual population analysis of SBT as spawning stock biomass (SSB).

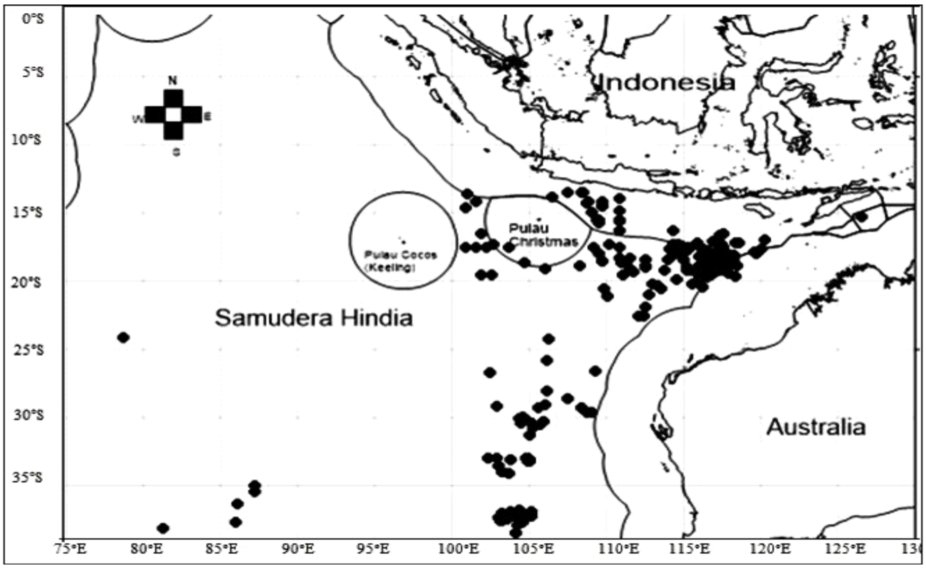

Figure 1. Fishing ground area of Indonesia Southern Bluefin Tuna (*Thunnus maccoyii*) in the Eastern Indian Ocean. (Rochman, 2019).

Growth and Catch at Age Structure Analysis

To determine the age structure of Indonesian SBT, age-length key (ALK) and Von Bertalanffy Growth Function (VBGF) were developed using the age samples of the otolith. ALK and VBGF are expected to interpret the catch monitoring data in the periods of 2012-2017. The ALK obtained based on the relationship between the growth rate ($\frac{\Delta L}{\Delta t}$) and the average of fork length $\overline{L}$ (*t*) using the equation = (*t*), given by Gulland & Holt, (1959) where *a* is the coefficient of direction, *b* is the intersection constanta on the Y axis, is length difference (cm) and is age difference (year).

Growth curve of SBT well described using the Von Bertalanffy Growth Model (VBGF) (Gunn *et al*., 2008; Lin & Tseng, 2010; Farley *et al*., 2014). The standard of VBGF used in this study was using the equation $L_t = L_{\infty}(1-e^{-K(t-t0)})$ (Sparre & Venema, 1998) where *Lt* is length at the age of *t* (cm), L_{∞} is the asymptotic length (cm), *K* is the growth coefficient, *t* is the time needed to reach a certain length (year) and t_o is theoretical age when the length is zero (year). The growth coefficient (*K*) recognized from the regression coefficient value of ALK, where *K=b* and L_{∞}= (Gulland & Holt, 1959). The theoretical age when the length is zero (t_0) is determined by Pauly (1984) with the empirical equation $Log_{10}(-t_0) = 0.3922-0.2752\ (Log_{10} L_{\infty}) – 1.038\ (Log_{10} K)$.

There was a total of 52,477 samples of fresh SBT in this study but only 13,701 specimens were fitted for length (L)-weight (W) relationship (LWR). This was because not all fish samples can be measured in length and weight together due to the fast handling and transport in sampling location. The relationship between length-weight of 13,701 samples can be used to estimate the length and weight of the other data samples. The parameter (*a,b*) of the power equation describing the length-weight relationship $W\ (ggt)=a\ FL\ (ggt)^b$ given by Klawe (1980) where *W(ggt)* is the total weight in gilled and gutted process (kg), *FL(ggt)* is fork length (cm) and *a,b* are parameters of the LWR.

Virtual Population Analysis (VPA)

Virtual Population analysis (VPA) is an analysis of fisheries commercial catch data obtained from fisheries statistic. This method is obtained by combining and analyzing the distribution of the cohort with the age reading of the catch. VPA is conducted to obtain the information on a fish population that should have been in water to produce the current catch. According to Fry (1949) virtual population is a population that is analyzed from the methods based on real catch data with the assumptions of natural mortality (M) and final fishery mortality. This method is used by the calculation of the total recruitment in the first cohort. The estimation of natural mortality (M) is based on the historical life of the fish itself. By knowing the natural mortality value, the countdown can be done to get to know how many fish in this cohort that lives year after year and ultimately can be known how much recruitment is there. In the end, it can be known as the coefficient value of fishing mortality (F) of the data.

The natural mortality (M) of SBT is estimated by the calculation of the natural mortality from the maximum age of the fish (otolith reading), for example, the maximum age of SBT is 25 years, the estimation of the natural mortality is (1:25) or 0.04 per year. Furthermore, the countdown is carried out from catch data monitoring (2012-2017) with the following formula: $N_{(t)} = [N_{(t+1)}*exp^{(M/2)}+C_{(t)}]*exp^{(M/2)}$ given by Pope (1972) where $N_{(t)}$ is the number of fish in year (t), *t* is age of fish, *M* is the natural mortality and $C_{(t)}$ is the number of catch in year (t). The estimation of fishing mortality (F) can be known by the formula $F_{(t)} = ln - M$ given by Pope (1972). The total mortality (Z) was determined by adding the natural mortality (M) and fishing mortality (F).

RESULTS AND DISCUSSION

Results

Growth

There were 462 pairs of sagittal otolith in this study but only 452 pairs of sagittal otolith can be read of 189 pairs of male fish, 220 pairs of female fish and 43 others were unidentified. The result of otolith age reading are presented in Appendix 1 and the tabulation of length, weight, and age based on sex are shown in Table 1.

Table 1. The number of otolith samples, range (max, min and mean) of length, weight, and age of fish based on the reading of otolith increment of Southern Bluefin Tuna (*Thunnus maccoyii*) on January to December 2017.

Sex		Length (cmFL)	Weight (kg)	Age (year)
Male (n=189)	Minimum	138.0	46.0	8.0
	Maximum	196.0	140.0	18.0
	Mean	164.0	86.6	12.7
Female (n=220)	Minimum	134.0	45.0	9.0
	Maximum	195.0	157.0	18.0
	Mean	159.4	79.2	13.0
Unidentified (n=43)	Minimum	140.0	45.0	10.0
	Maximum	184.0	160.0	20.0
	Mean	158.7	80.8	12.4

The relationship between the growth rate () and the average of fork length (t) (ALK) in each sex were *Y*=-0.2297*FL*+44.046 (R^2=0.9471) for males, *Y*=-0.1268*FL*+24.88 (R^2=0.9426) for females and *Y*=-0.167*FL*+31.815 (R^2=0.9355) for combined sexes. Furthermore, The ALK was used to fit in Von Berthalanffy Growth Function (VBGF) to recognize a real growth pattern in SBT stock assessment. Growth coefficient (K) were 0.2297 for males, 0.1268 for females and 0.167 for combined sexes. The asymptotic length (L_∞) were 192 cmFL for males, 196 cmFL for females and 191 cmFL for combined sexes. After all of this parameters were known, t_0 can be recognized by Pauly (1984) equation where t_0 were -0.439 for males, -0.809 for females and -1.081 for combined sexes. The three of those growth parameter were then substituted into Von Berthalanffy Growth Function as follow: $L_t = 192\ (1-e^{-0,2297(t+0,439)})$ for males, $L_t = 196\ (1-e^{-0,1268(t+0,809)})$ for female and $L_t = 191\ (1-e^{-0,167(t+1,081)})$ for combined sexes (Figure 2).

Catch at Age Structure

Catch at age structure of fresh SBT was distributed from the age of 5 years to the age of 22 years with an average of age was 9.63 years and a mode at age of 9 years. Catch at age structure also showed the normal distribution pattern where mode value was under the age of the first maturity (Figure 3). The distribution of catch at age structure showed that the mode changed from year to year leading to a younger fish. In 2012, the mode was 10 years but entering 2013-2014 the mode was shifted to 6 years. In 2015-2017, the mode was increased from 7 years (2015) to 8 years (2016) and 9 years (2017) (Figure 4).

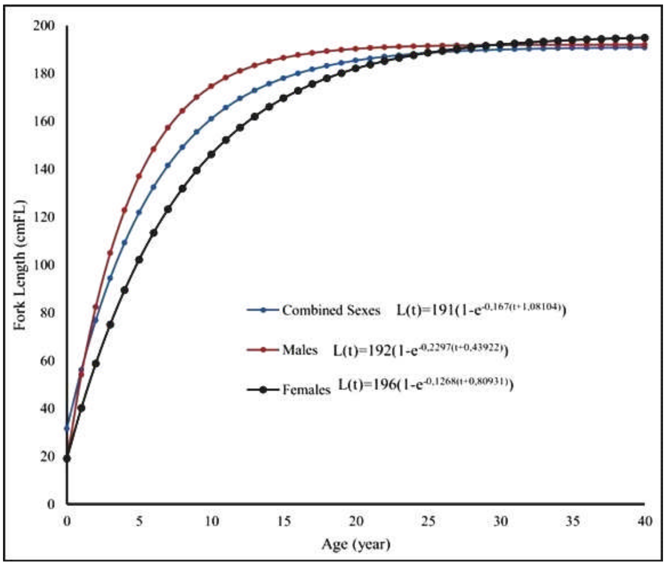

Figure 2. Von Bertalanffy growth curve of Southern Bluefin Tuna (*Thunnus maccoyii*) caught by Indonesian tuna longliner based on the otolith age estimation in the periods of January-December 2017.

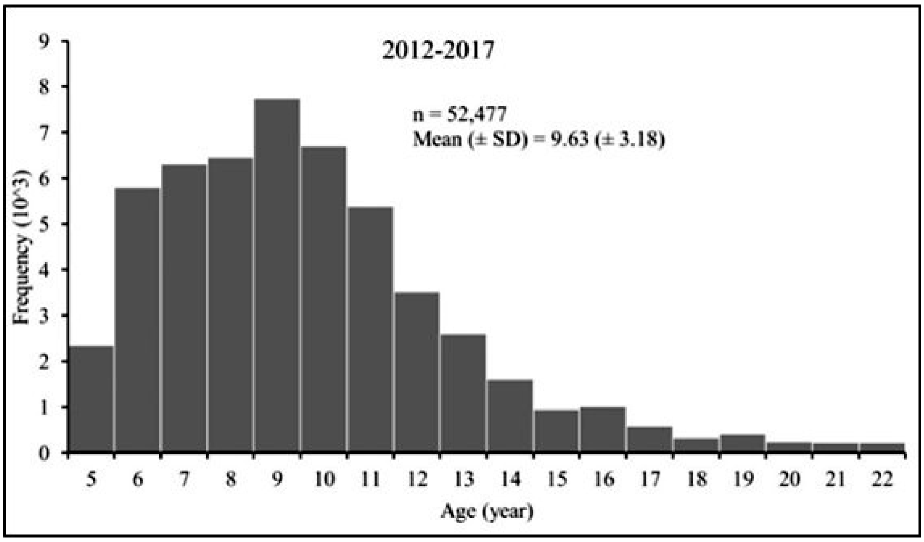

Figure 3. Catch at age structure of fresh Southern Bluefin Tuna (*Thunnus maccoyii*) caught and landed by Indonesia's tuna longliner in spawning ground area of Indian Ocean in a period of 2012-2017.

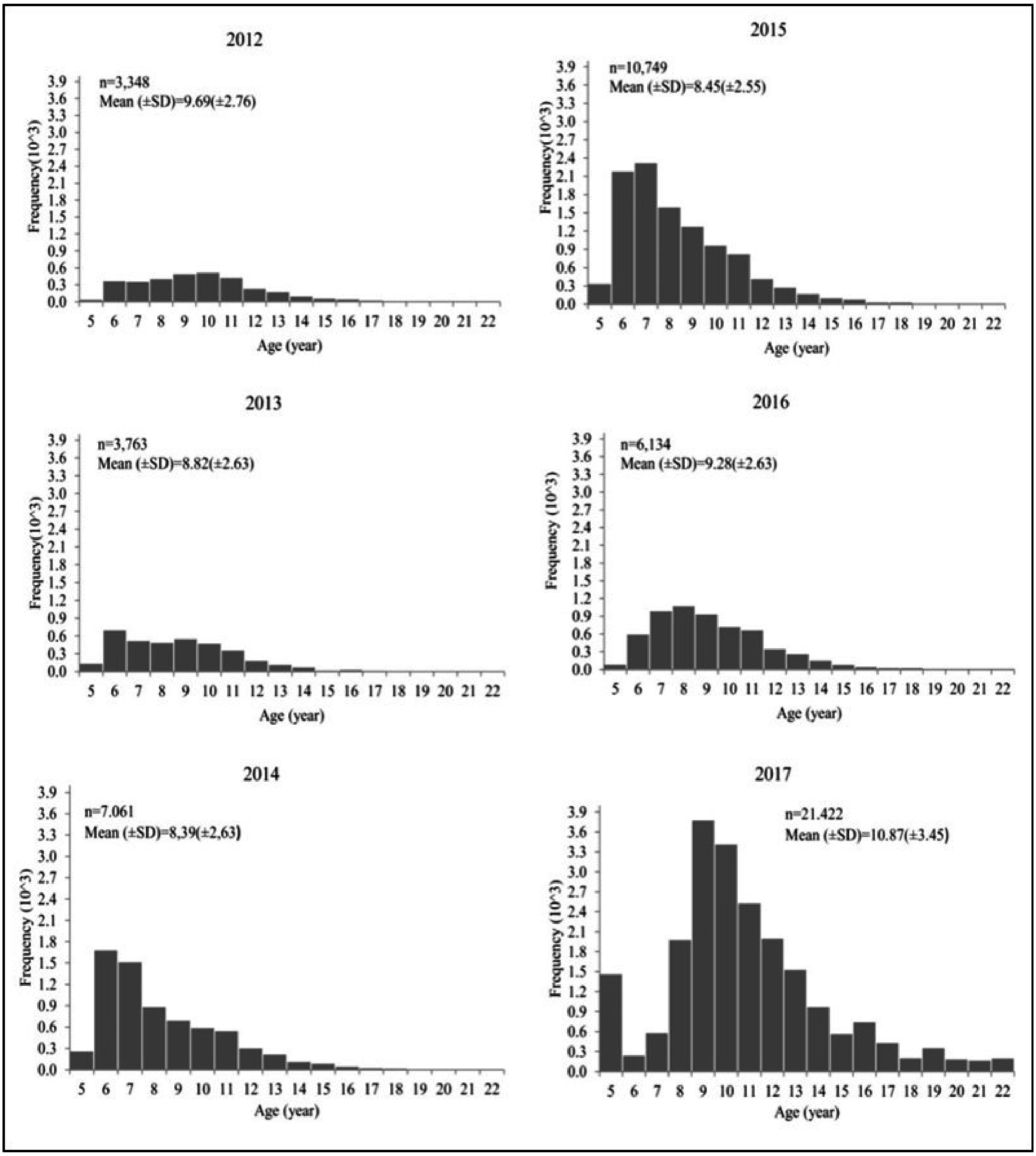

Figure 4. Catch at age structure of fresh Southern Bluefin Tuna (Thunnus maccoyii) caught and landed by Indonesian tuna Longliners in spawning ground area of Indian Ocean in a period of 2012-2017.

Virtual Population Analysis (VPA)

The result of the age structure virtual population analysis (VPA) indicated that the mode of the fish population in the periods of 2012-2016 shifted to the right position (positive) toward an older fish. SBT population mode is in the age group of 5 years in 2012 and 2013. Respectively, entering 2014 to 2016 the population mode moves to the age group of 6 years, 7 years and 8 years. The percentage of fish caught has increased from 8% in 2012 and 2013 to 15% in 2014, 27% in 2015 and 22% in 2016. The fishing pressure of SBT caught by Indonesian longliners can be seen in the age group under 20 years. This is caused by the significant number of fish populations in the age group under 20 years compared to fish populations in the age group above 20 years. In 2012, the highest fishing pressure obtained in the age group of 13 years with a fishing mortality value of 0.27/year. In 2013 and 2014 the highest fishing pressure shifted towards younger fish at the age of 11 years with a value of fishing mortality of 0.22/ year (2013) and 0.26/year (2014). Entering 2015, fishing pressure moved to younger fish at the age group of 6 years with the fishing mortality of 0.52/ year. The same thing happened in 2016 with the highest fishing pressure at the age of 6 years with a fishing mortality value of 0.68/year (Figure 5) and (Appendix 3).

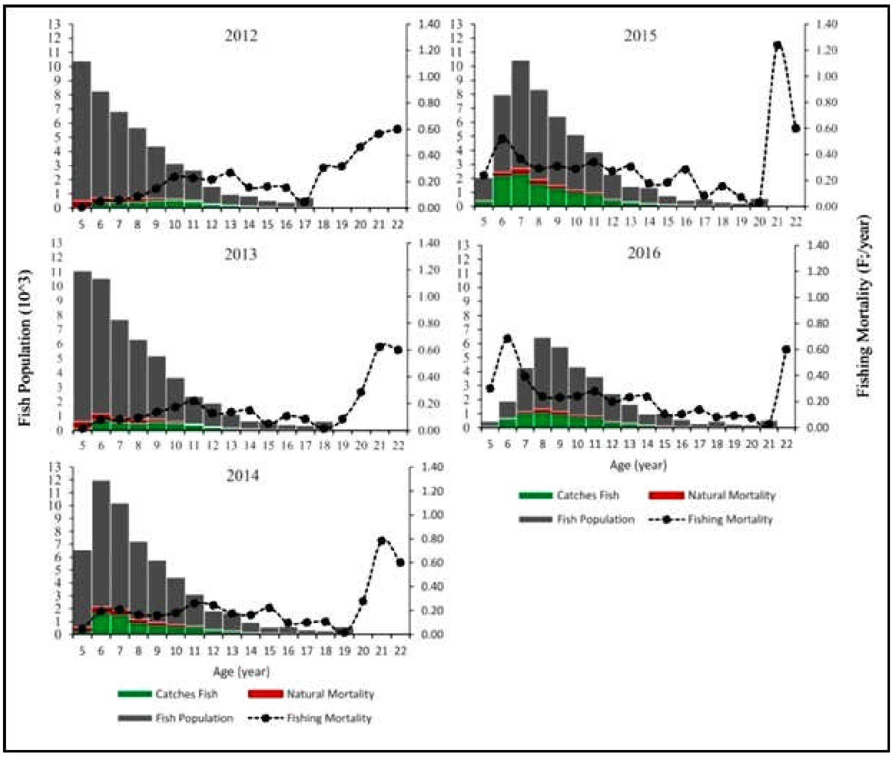

Figure 5. The Virtual Population Analysis (VPA) based on the age structure of Southern Bluefin Tuna (*Thunnus maccoyii*) caught by Indonesian Longliners in the Indian Ocean in the periods of 2012-2017.

Discussion

Growth

The results of the overall otolith analysis showed that the lowest age was 8 years and the highest was 20 years with a minimum length of 134 cmFL and maximum length of 196 cmFL. However, the longest fish is not the oldest fish: The 196 cmFL fish length is 18 years old, younger than the fish with a length of 195 cmFL and 180 cmFL which is 20 years old. It showed that SBT is a species with slow growth and has a high variation in natural size especially fish with age above 10 years. That was reinforced by Gunn *et al*. (2008) and Shiao, Chang, Lin, and Tzeng (2008) which said that the species of SBT is a long-lived species, has a slow growth coefficient per year and has a high variation in size, especially at the age above 10 years.

The Age-Length Key (ALK) has a narrow life span of 8 to 20 years and a large size of fish (> 138 cmFL) so that the ALK produced can only be used specifically to predict the growth and population structure of non-frozen SBT landed by the Indonesian longline fleet which has specific fishing areas in the South off Java, Bali, Nusa Tenggara and within the Indonesian EEZ (Appendix 1). Frozen SBT obtained from the nursery ground area (>20 °S, 75°-110°E) cannot be included in this analysis. This is supported by Farley *et al*. (2014) which states that the catch of SBT captured in spawning ground areas has special criteria compared to fish caught in the nursery ground area. Fish caught in spawning areas are relatively larger in size and caught in shallow waters or low fishing depths.

Southern Bluefin Tuna has a slow type of growth, but at the beginning of the year its development can be grown rapidly (Gunn *et al*., 2008; Farley *et al*., 2014). Previous research conducted by Gunn *et al*. (2008) reported that the SBT at one year of age has an average fork length of 55 cmFL. The growth coefficient (male and female) in this study (0.167/year) is slightly higher than the study by Lin and Tzeng (2010) which was informed (xx/year) (2010) in the Central and Southern Indian Ocean of Java, Bali and Nusa Tenggara and Gunn *et al*. (2008) in the Central

Indian Ocean. The increasing of the growth coefficient (K) is caused by sexual dimorphism where the coefficient of growth of SBT is higher in spawning area than that the other areas. This size length suggested as the main factor when the early gonad maturity in male and female fish (Farley & Davis 2003). This sexual dimorphism also occurs in other temperate tuna species, such as albacore (*Thunnus alalunga*) (Williams *et al*., 2012). The otolith data showed that there was a sexual dimorphism (length-at-age) between male fish and female fish characterized by the differences in the coefficient of growth. The growth coefficient of male fish is higher than that of female fish so that at the same age has a higher length. This is similar finding from a previous study conducted by Gunn *et al*. (2008) and Farley *et al*. (2014). Comparison of Von Bertalanffy's growth curve of this study which is compared with several previous studies (Appendix 2).

The Von Bertalanffy growth model generated from this study shows that the catches of the SBT caught by the Indonesian tuna longliners in spawning areas have a different age structure and length compared with the other fishing area. This study showed that to achieve the ideal length of gonadal maturity > 140 cmFL as reported by (Davis & Farley, 2001; Gunn *et al*., 2008; Lin & Tzeng, 2010) were obtained at ages 6 to 7 years.

While the previous research conducted by Lin and Tzeng (2010) suggested that the level of gonad maturity with a minimum size of 140 cmFL was obtained at the age of 10 to 11 years while Gunn *et al*. (2008) obtained at the age of 7 years. Farley *et al*. (2009) found indications that all female fish entering the spawning ground were thought to have matured starting at the age of 6 years with an average length of 145 cmFL. The difference in the growth curve that occurred between the studies with the previous research was due to differences in the characteristics of the fish samples that would be taken by the otolith. Different characteristics of fish samples include length interval differences, differences in age intervals, differences in sampling locations and differences in the sexes of SBT which will be used as otolith research material. This difference potentially be source of a difference in the growth coefficient (K), asymptotic length (L") and theoretical age when the length is zero (t_0) in the Von Bertalanffy growth equation. The otolith sampling location from the spawning area will be different from the otolith fish sample from the nursery ground or other areas. In addition there is sexual dimorphism between male and female fish with different growth coefficients (K) when it is separated or combined in the analysis. Male fish has a growth coefficient (K) higher than that female fish but has an asymptotic length lower than female fish so that at an adult age (> 30 years) individual female fish will continue to grow up to more than 40 years old and male individuals will stop growing at ± 30 years of age (Figure 2). The same thing was found in the previous studies conducted by Farley *et al*. (2014) in the SBT otolith in the spawning area south off Java, Bali and Nusa Tenggara, which states that at the age of more than 30 years male fish will stop growing and female individuals will continue to grow until it approaches the asymptotic length.

Catch at Age Structure

Age frequency data is an important component in stock assessment which serves to reconstruct catch-at-age data structures (Sparre & Venema, 1998; Herrera & Pierre, 2011). Fishing pressure could be also recognized by the movement of mean age and age mode of SBT caught by Indonesian tuna longliners. The results showed that there was a high fishing pressure in the period 2012-2014 which was marked by the decreasing in the mean age of the catch from 9.69 years to 8.39 years. In addition, the fishing pressure was also marked by the decreasing of the age mode from 10 years in 2012 to 6 years age in 2014. In 2015 to 2017, this research indicated that the fishing pressure was decreased which recognized by the increase of mean age from 8.45 years (2015), 9.28 years (2016) and 10.87 years (2017). The increasing of mode age from 7 years (2015), 9.28 years (2016) and 10.87 years (2017). However, the average age of SBT caught by Indonesian longliners in the Indian Ocean in recent years is still far below the average value of catches in 2000 of 19.5 years and in 2011 of 16.8 years (Farley *et al*., 2014).

Besides that there are other reasons related to the smaller size and the declining the number of old fish (> 20 years) entering the spawning area where the Indonesian tuna longliners operates, namely the reduction in fishing quotas from 40,000 tons in 1980 to only 10,000 tons in 2006 in the entire area of the Indian Ocean (CCSBT, 2013). This reduction was also seen in juvenile fishing (± 2 years) of SBT in Australian waters from 21,000 tons in 1982 to 5,000 tons in 1990 (Farley *et al*., 2014). Reduction of juvenile capture in the upbringing area is thought to result in high recruitment of young fish in the spawning area as a pulse 8 to 10 years later. Data on the capture of Indonesia's Southern Bluefin Tuna from 2012 to 2017 is thought to have been a boost (pulse) from juvenile stock from 2004 to 2009 in the nursery ground area. While the decline in the number of old fish (> 20 years) tends to be suspected due to the fishing pressure and fishing efforts to both juvenile and adult phases.

Virtual Population Analysis (VPA)

Based on the virtual population analysis (VPA), it can be seen the value of natural mortality (M), fishing mortality (F), total mortality (Z) and exploitation rate (U) for the period 2012 to 2016. The detailed information such as a total fish population, natural mortality, fishing mortality and exploitation rates for each age group of the catches can be determined by VPA analysis (Appendix 3). The fishing mortality (F) in the period of 2012 to 2016 was still in the range of 0.17/year to 0.32/year. The highest fishing pressure was found in the age group of 13 years and 11 years in 2012-2014 with an average length of 167 to 174 cmFL. Whereas in the period of 2015 and 2016 the fishing pressure occurred at the age of 6 years with an average length of 138 cmFL. This is supported by the previous research by Evans *et al*. (2012) by using Pop-up satellite archival tags on SBT which will start spawning activities in the Indian Ocean, which are known to have ± SD lengths of 169.22 cmFL ± 8.73 and tend to choose areas that have sea surface temperatures between 21.5°C to 29.5°C at the beginning of February and March. The area with such temperature ranges is a region which not far from the south coast of the islands of Java, Bali and Nusa Tenggara which is the traditional fishing area of the Indonesian tuna longline fleet which may target of SBT.

Fish stock is said to be overfishing or not overfishing is based on the optimal assumption of the exploitation rate U (U_{opt}) H" 0.5 (Gulland, 1971). The value of the exploitation rate of SBT caught in the spawning area is presented in (Appendix 3). In the period of 2012-2016, the average exploitation rate ranged from 0.14/year to 0.25/year. This means that the level of exploitation of SBT caught in the spawning area of the Indian Ocean is based on the catch of Indonesia's longline tuna fleet is underfishing. The catch at age structure of SBT caught by Indonesia's longliners also showed that the stock rebuilding is still on going in this time due to the movement of age mode from younger to older fish (7-9 years) from 2015 to 2017. It was suitable with studied conducted by CCSBT (2017) which uses the MSY reference point as a base of the model. It was stated that the stock status of the SBT caught in the Indian Ocean is not in overfishing or subject to overfishing and still in rebuilding stock. The value of fishing mortality (F) relative to the value of fishing mortality at MSY (F_{MSY}) is not more than 0.5/year by compiling the fishing quota for CCSBT member countries. The value of MSY in 2017 was 33,036 tons (30,000-36,000 tons) and the total allowable catch (TAC) was 14,647 tons in 2017 and 17,647 tons in the period 2018 to 2020 (CCSBT, 2017).

Population, mortality rate (natural mortality and fishing mortality) and the exploitation rate of SBT can be clearly described in this study. Although the enumeration which was carried out by the RITF (Research Institute for Tuna Fisheries) were not cover the entire capture data of SBT landed at Benoa port, but the VPA size population can be adjusted to the existing data coverage. The average of port based enumeration coverage in Benoa-Bali port from the period of 2012 to 2016 was ± 60% (IOTC, 2017; IOTC, 2018) so that the actual VPA estimation was 40% higher than the VPA theoretical calculation. But the value of the mortality rate and the rate of exploitation remain the same even though the fishing data and fish populations that live in the natural area have increased by 40%. This research showed that the estimation of adult SBT population that lives in spawning areas was ranged from 4,324 tons to 6,045 tons or 46,478 fish to 78,553 fish and the population was obtained from the addition of about 40% of the VPA theoretical data from the analysis.

CONCLUSION

Catch at age structure of SBT caught in spawning area of Indian Ocean ranged from 5 to 22 years old which is dominated by 9 years old with an average age of 9.63 years. SBT has a slow growth type with the Von Bertalanffy growth equation were: $L_t = 192\ (1-e^{-0,2297(t+0,439)})$ for males, $L_t = 196\ (1-e^{-0,1268(t+0,809)})$ for female and $L_t = 191\ (1-e^{-0,167(t+1,081)})$ for combined sexes. VPA indicated that the mode of the fish population in the periods of 2012 to 2016 has increased from younger to older fish but fishing pressure changes from older fish to younger fish. The exploitation rate of SBT in the spawning ground area ranged from 0.14/year to 0.25/year, meaning that the level of exploitation was in underfishing status and rebuilding stock

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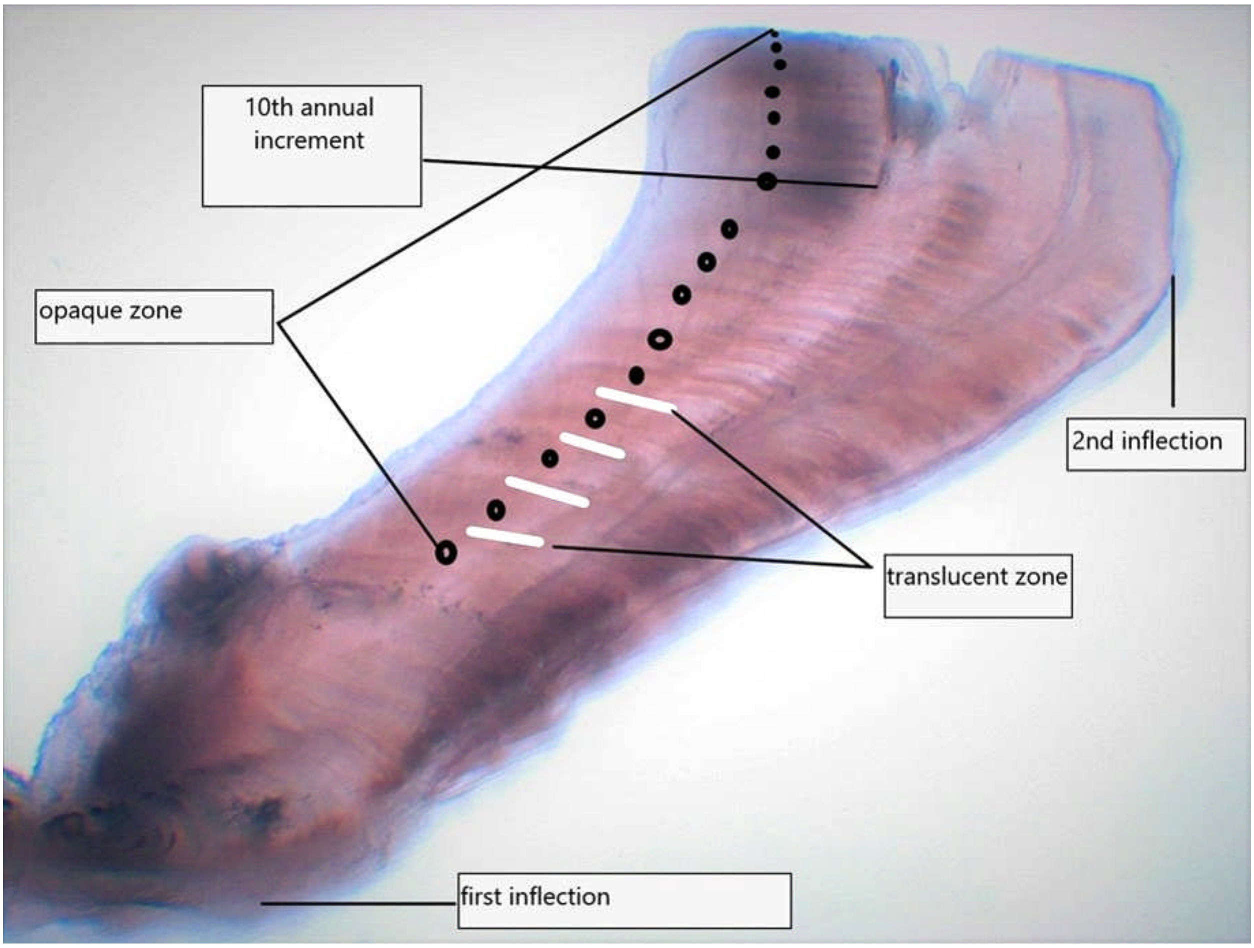
Appendix 1. Otolith image reading of Southern Bluefin Tuna sample of this research study



Appendix 2. Mean of length (cmFL) and standard deviation of Southern Bluefin Tuna (*Thunnus maccoyii*) based on the otolith age reading.

Age Group (Year)	*Otolith Age Reading* The Average of Length (cmFL)	SD (±)	n
8	138	4.24	2
9	140.75	0.96	4
10	148.30	8.29	43
11	150.75	6.77	75
12	156.89	7.27	83
13	162.62	8.99	89
14	170.41	8.57	63
15	171.36	6.36	53
16	173.90	7.37	20
17	175.50	5.39	9
18	181.37	10.25	8
19	187	-	1
20	187.50	10.6	2
Total			452

Appendix 3. The result of several studies regarding the age and growth of Southern Bluefin Tuna (*Thunnus maccoyii*) in the Indian Ocean.

L_∞ (cm)	K (1/Year)	t_0	Sex	Methods	Location	Refference
219.70	0.135	-0.040	Combination	Annulus scale	Japan	Yukinawa, 1970
180.84	0.146	-0.011	Combination	Tagging	Australia	Murphy, 1977
222.50	0.140	0.011	Combination Combination	Annulus scale	Japan	Shingu, 1978
207.60	0.128	-0.394	Combination	Tagging and length freq., at the age <9 years	Central Indian Ocean	Kirkwood, 1983
261.30	0.108	-0.157	Combination	Otolith, mainly at the age of <6 years	Central Indian Ocean	Thorogood, 1987
183.90	0.180	-1.322	Combination	Tagging and length freq, at the age of 1-12 years and >12 years	Australia	Polacheck *et al*.,1996
183.18	0.185	-0.923	Combination	Otolith, at the age of 1-41 years	Central Indian Ocean and Indian Ocean South off Java, Bali and Nusa Tenggara island	Gunn *et al*., 2008
211.66	0.093	-1.602	Male	Otolith, at the age of 2-21 years	Central Indian Ocean and Indian Ocean South off Java, Bali and Nusa Tenggara island	Lin dan Tzeng, 2010
192.38	0.109	-1.753	Female	Otolith, at the age of 2-21 years	Central Indian Ocean and Indian Ocean South off Java, Bali and Nusa Tenggara island	Lin dan Tzeng, 2011
192.00	0.230	-0.439	Male	Otolith, at the age of 8-20 years	Indian Ocean South off Java, Bali dan Nusa Tenggara island	2019 (This study)
196.00	0.127	-0.809	Female	Otolith, at the age of 8-20 years	Indian Ocean South off Java, Bali dan Nusa Tenggara island	2019 (This study)
191.00	0.167	-1.081	Combination	Otolith, at the age of 8-20 years	Indian Ocean South off Java, Bali dan Nusa Tenggara island	2019 (This study)

Information:
L_∞: Asymptotic length (cmFL)
K:Growth coefficient (1/year)
t_0:Theoretical age when the length equal to 0

Appendix 4. Virtual Population Analysis (VPA) of Southern Bluefin Tuna caught from Indonesia's tuna longliner of the Indian Ocean, ranged from 2012-2016.

Age (year)	$\bar{x}$ Weight (kg)	$\bar{y}$ Length (cmFL)	∑ Population (fish)	∑ Population (kg)	∑ Catches (fish)	∑ Catches (kg)	Natural Mortality (M) (M:/year)	∑ Natural Mortality (fish)	∑ Natural Mortality (kg)	Fishing Mortality (F) (F:/year)	Exploitation Rate (U:/year)	Coverage Data (%)	Year
5	48	130	9,903	476,850	46	2,215	0.045	446	21,458	0.00	0.005	58.32	2012
6	57	137	7,571	431,675	372	21,210	0.045	341	19,425	0.05	0.049		
7	68	145	6,208	419,765	360	24,342	0.045	279	18,889	0.06	0.058		
8	78	153	5,050	393,797	412	32,128	0.045	227	17,721	0.09	0.082		
9	87	158	3,709	323,434	498	43,428	0.045	167	14,555	0.15	0.134		
10	96	163	2,527	241,343	522	49,851	0.045	114	10,860	0.24	0.207		
11	103	167	2,164	223,825	432	44,676	0.045	97	10,072	0.23	0.200		
12	110	171	1,243	137,081	237	26,136	0.045	56	6,169	0.22	0.191		
13	116	174	771	89,633	177	20,588	0.045	35	4,033	0.27	0.230		
14	122	177	733	89,384	104	12,674	0.045	33	4,022	0.16	0.142		
15	126	179	448	56,614	66	8,335	0.045	20	2,548	0.16	0.147		
16	130	181	357	46,610	50	6,520	0.045	16	2,097	0.15	0.140		
17	134	182	662	88,536	29	3,876	0.045	30	3,984	0.05	0.044		
18	137	184	55	7,455	14	1,915	0.045	2	335	0.30	0.257		
19	139	185	41	5,766	11	1,532	0.045	2	259	0.32	0.266		
20	141	186	22	3,114	8	1,131	0.045	1	140	0.46	0.364		
21	143	187	17	2,382	7	1,003	0.045	1	107	0.56	0.422		
22	145	187	7	984	3	435	0.045	0	44	0.60	0.442		
Total			41,489	3,038,247	3,348	301,995		1,867	136,721				
Average	110	169	2,305	168,792	186	16,778	0.045	104	7,596	0.23	0.188	58.32	
(±SD)	31	18	2,991	170,340	193	16,773	0.000	135	7,665	0.17	0.127		

Appendix 4. Extension

Age (year)	$\bar{x}$ Weight (kg)	$\bar{y}$ Length (cmFL)	∑ Population (fish)	∑ Population (kg)	∑ Catches (fish)	∑ Catches (kg)	Natural Mortality (M) (M:/year)	∑ Natural Mortality (fish)	∑ Natural Mortality (kg)	Fishing Mortality (F) (F:/year)	Exploitation Rate (U:/year)	Coverage Data (%)	Year
5	45	129	10,440	469,792	141	6,345	0.045	470	21,141	0.01	0.014	57.24	2013
6	57	137	9,422	532,357	707	39,946	0.045	424	23,956	0.08	0.075		
7	68	145	6,874	464,011	524	35,370	0.045	309	20,880	0.08	0.076		
8	78	153	5,583	432,671	492	38,130	0.045	251	19,470	0.09	0.088		
9	87	158	4,425	384,966	554	48,198	0.045	199	17,323	0.14	0.125		
10	96	163	3,059	292,113	477	45,554	0.045	138	13,145	0.17	0.156		
11	104	167	1,906	197,226	366	37,881	0.045	86	8,875	0.22	0.192		
12	110	171	1,647	181,810	192	21,199	0.045	74	8,181	0.13	0.117		
13	117	174	957	111,446	119	13,864	0.045	43	5,015	0.14	0.124		
14	122	177	564	68,762	76	9,272	0.045	25	3,094	0.15	0.135		
15	127	179	600	75,837	28	3,542	0.045	27	3,413	0.05	0.047		
16	131	181	364	47,506	36	4,698	0.045	16	2,138	0.11	0.099		
17	134	182	293	39,239	23	3,082	0.045	13	1,766	0.08	0.079		
18	137	184	605	82,873	8	1,096	0.045	27	3,729	0.01	0.013		
19	140	185	38	5,378	3	420	0.045	2	242	0.08	0.078		
20	142	186	29	4,079	7	991	0.045	1	184	0.29	0.243		
21	144	187	13	1,899	6	861	0.045	1	85	0.62	0.454		
22	145	187	9	1,312	4	580	0.045	0	59	0.60	0.442		
Total			46,826	3,393,277	3,763	311,027		2,107	152,697				
Average	110	169	2,601	188,515	209	17,279	0.045	117	8,483	0.17	0.142	57.24	
(±SD)	32	18	3,359	188,809	240	18,109	0.000	151	8,496	0.17	0.125		

Appendix 4. Extension

Age (year)	x̄ Weight (kg)	ȳ Length (cmFL)	∑ Population (fish)	∑ Population (kg)	∑ Catches (fish)	∑ Catches (kg)	Natural Mortality (M) (M:/year)	∑ Natural Mortality (fish)	∑ Natural Mortality (kg)	Fishing Mortality (F) (F:/year)	Exploitation Rate (U:/year)	Coverage Data (%)	Year
5	47	129	6,050	286,668	264	12,509	0.045	272	12,900	0.05	0.044	60.72	2014
6	57	138	9,843	564,531	1,685	96,645	0.045	443	25,404	0.19	0.171		
7	67	145	8,316	560,696	1,517	102,277	0.045	374	25,231	0.21	0.183		
8	78	152	6,059	470,529	890	69,111	0.045	273	21,174	0.16	0.147		
9	87	158	4,856	422,770	697	60,680	0.045	219	19,025	0.16	0.144		
10	96	163	3,689	352,371	592	56,555	0.045	166	15,857	0.18	0.161		
11	103	167	2,458	253,575	548	56,538	0.045	111	11,411	0.26	0.223		
12	110	171	1,464	161,619	310	34,226	0.045	66	7,273	0.24	0.212		
13	116	174	1,386	161,476	218	25,389	0.045	62	7,266	0.18	0.157		
14	122	177	798	97,363	117	14,272	0.045	36	4,381	0.16	0.147		
15	126	179	465	58,684	90	11,370	0.045	21	2,641	0.22	0.194		
16	130	181	546	71,214	49	6,394	0.045	25	3,205	0.10	0.090		
17	134	183	313	41,960	29	3,890	0.045	14	1,888	0.10	0.093		
18	137	184	257	35,323	25	3,430	0.045	12	1,590	0.10	0.097		
19	140	185	570	79,653	8	1,117	0.045	26	3,584	0.01	0.014		
20	141	186	34	4,777	8	1,131	0.045	2	215	0.28	0.237		
21	144	187	21	2,975	11	1,580	0.045	1	134	0.78	0.533		
22	145	187	7	984	3	435	0.045	0	44	0.60	0.442		
Total			47,132	3,627,168	7,061	557,549		2,121	163,223				
Average	110	169	2,618	201,509	392	30,975	0.045	118	9,068	0.22	0.183	60.72	
(±SD)	31	18	3,114	195,917	517	34,096	0.000	140	8,816	0.19	0.127		

Appendix 4. Extension

Age (year)	x̄ Weight (kg)	ȳ Length (cmFL)	? Population (fish)	? Population (kg)	? Catches (fish)	? Catches (kg)	Natural Mortality (M) (M:/year)	? Natural Mortality (fish)	? Natural Mortality (kg)	Fishing Mortality (F) (F:/year)	Exploitation Rate (U:/year)	Coverage Data (%)	Year
5	47	129	1,645	78,114	343	16,286	0.045	74	3,515	0.24	0.209	68.24	2015
6	57	138	5,526	317,423	2,188	125,689	0.045	249	14,284	0.52	0.397		
7	67	145	7,762	522,773	2,330	156,927	0.045	349	23,525	0.37	0.301		
8	77	152	6,467	499,154	1,599	123,415	0.045	291	22,462	0.29	0.248		
9	87	158	4,923	428,464	1,282	111,586	0.045	222	19,281	0.31	0.261		
10	95	163	3,961	378,045	974	92,961	0.045	178	17,012	0.29	0.246		
11	103	167	2,947	304,249	833	85,988	0.045	133	13,691	0.34	0.283		
12	110	171	1,814	200,184	422	46,574	0.045	82	9,008	0.27	0.233		
13	116	174	1,096	127,494	282	32,794	0.045	49	5,737	0.31	0.258		
14	122	177	1,112	135,458	176	21,433	0.045	50	6,096	0.18	0.158		
15	126	179	649	81,949	107	13,518	0.045	29	3,688	0.18	0.165		
16	130	181	356	46,456	86	11,220	0.045	16	2,091	0.28	0.242		
17	134	182	474	63,390	37	4,950	0.045	21	2,853	0.08	0.078		
18	137	184	271	37,142	38	5,214	0.045	12	1,671	0.15	0.140		
19	140	185	222	30,932	15	2,093	0.045	10	1,392	0.07	0.068		
20	142	186	538	76,097	16	2,265	0.045	24	3,424	0.03	0.030		
21	144	187	24	3,516	17	2,441	0.045	1	158	1.24	0.698		
22	145	187	9	1,312	4	580	0.045	0	59	0.60	0.442		
Total			39,795	3,332,152	10,749	855,934		1,791	149,947				
Average	110	169	2,211	185,120	597	47,552	0.045	99	8,330	0.32	0.248	68.24	
(±SD)	31	18	2,460	176,108	770	53,018	0.000	111	7,925	0.27	0.154		

Appendix 4. Extension

Age (year)	$\bar{x}$ Weight (kg)	$\bar{y}$ Length (cmFL)	∑ Population (fish)	∑ Population (kg)	∑ Catches (fish)	∑ Catches (kg)	Natural Mortality (M) (M:/year)	∑ Natural Mortality (fish)	∑ Natural Mortality (kg)	Fishing Mortality (F) (F:/year)	Exploitation Rate (U:/year)	Coverage Data (%)	Year
5	47	129	357	16,782	91	4,274	0.045	16	755	0.30	0.255		
6	58	138	1,237	71,390	599	34,558	0.045	56	3,213	0.68	0.485		
7	68	146	3,143	213,184	998	67,687	0.045	141	9,593	0.39	0.318		
8	77	152	5,142	398,083	1,077	83,375	0.045	231	17,914	0.24	0.210		
9	87	158	4,619	401,215	939	81,560	0.045	208	18,055	0.23	0.203		
10	95	163	3,452	329,389	724	69,074	0.045	155	14,823	0.24	0.210		
11	103	167	2,834	292,800	674	69,627	0.045	128	13,176	0.28	0.238		
12	110	171	2,003	221,291	353	38,995	0.045	90	9,958	0.20	0.176		
13	116	174	1,321	153,677	269	31,284	0.045	59	6,915	0.23	0.204	60.28	2016
14	122	177	772	94,099	160	19,493	0.045	35	4,234	0.24	0.207		
15	126	179	891	112,639	88	11,121	0.045	40	5,069	0.11	0.099		
16	130	181	515	67,235	49	6,391	0.045	23	3,026	0.10	0.095		
17	134	182	256	34,275	32	4,279	0.045	12	1,542	0.14	0.125		
18	137	184	417	57,088	32	4,383	0.045	19	2,569	0.08	0.077		
19	140	185	222	30,947	19	2,653	0.045	10	1,393	0.09	0.086		
20	142	186	197	27,926	14	1,982	0.045	9	1,257	0.08	0.071		
21	143	187	498	71,480	13	1,865	0.045	22	3,217	0.03	0.026		
22	145	187	7	984	3	435	0.045	0	44	0.60	0.442		
Total			27,887	2,594,483	6,134	533,036		1,255	116,752				
Average	110	169	1,549	144,138	341	29,613	0.045	70	6,486	0.24	0.196	60.28	
(±SD)	31	18	1,610	132,945	386	30,991	0.000	72	5,983	0.18	0.124		