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POPULATION DYNAMICS OF YELLOWFIN TUNA *Thunnus albacares* (BONNATERRE, 1788) IN THE FISHERIES MANAGEMENT AREA 573 OF THE INDIAN OCEAN

Abdul Ghofar[1*], Suradi W. Saputra[1], Agus Sabdono[2], Anhar Solichin[1], Wiwiet T. Taufani[1], Sigit Febrianto[1]

[1] *Aquatic Resources Department, Faculty of Fisheries and Marine Science, Diponegoro University, Semarang, Indonesia*
[2] *Marine Science Department, Faculty of Fisheries and Marine Science, Diponegoro University, Semarang, Indonesia*

*Corresponding Author: aghofar099@gmail.com

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ABSTRACT

Yellowfin tuna *Thunnus albacares* is one of the major species of tuna caught in the Fisheries Management Area (FMA) 573 of the Indian Ocean. Its production contributed to 35.83% of the total production of tuna in 2013. The study was conducted to assess the population dynamics of this species in FMA 573, based on length-frequency data collected in 2013-2017, and was analysed using FiSAT II software. The results obtained show length-weight relationship of $W = 0.000052\ FL^{2.78}$, negative allometric growth and growth equation of $Lt = 194.25\ (1-e^{-0.51\ (t + 0.1889)})$. The length at first capture was estimated at 140 cm FL. Recruitment season occurs between July and September, with a peak in August. The rate of total mortality (Z) was 2.32 yr^{-1}, including natural mortality rate (M) of 0.69 yr^{-1} and fishing mortality rate (F) of 1.63 yr^{-1}. The exploitation rates of yellowfin tuna were estimated to be 0.70, indicating that it has exceeded the optimum exploitation rate (E = 0.5) and that overexploitation had occurred. There is an obvious need for consistent monitoring and surveillance of fishing fleet, type and size of fishing gear, as well as the fish size and quantity of the catch.

How to Cite

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INTRODUCTION

The Indian Ocean south off Java, Bali and Nusa Tenggara has been recognized for its tuna resources (Novianto et al., 2016; Widodo and Mahulete, 2012). The main target species are yellowfin tuna *T. albacares*, bigeye tuna *Thunnus obesus*, albacore *T. alalunga* and southern bluefin tuna *T. maccoyii*. This study focused on yellowfin tuna, one of the most dominant species caught in FMA 573. The Annual Report of the Research Institute for Tuna Fisheries (2013) suggested that the catch composition of tuna longline fishery in the fishing port of Benoa, Bali was dominated by yellowfin tuna. Increasing market demand for tuna export leads to increased exploitation that could threaten the sustainability of tuna resources (Gillett and Harrera, 2009). The exploitation of yellowfin tuna in the Indian Ocean in 2011-2014 has also increased, as indicated by the increasing catches from 329,184 tons in 2011 to 430,327 tons in 2014 (Indian Ocean Tuna Commission, IOTC, 2014). This study aims to assess the length-weight relationship, growth pattern, optimum size caught, parameters of population growth, recruitment patterns, mortality and exploitation rates of yellowfin tuna.

MATERIAL AND METHODS

The data used for the analysis of length-weight relationship was collected during April and May 2016; it amounted to the total of 753 specimens. Length-frequency data was obtained from daily landings by tuna longline activity operating in FMA 573 (Fig. 1) between 2013 and 2014. The definition of length used in this study is the length from the mouth to the tip of the central tail fin indentation (fork length). The length was measured using a modified aluminium calliper up to 2 meters long, with a 0.5 cm precision. Individual dressed weight (DW) was recorded to the nearest kilogram. Weight and length were fitted by a non-linear regression (power function) using DW as the dependent variable, where $DW= \alpha FL^b$ (α and b are parameters). To test b=3 or b≠3, Student's t-test was used with the hypothesis H_0: β=3 (isometric) and H1: β≠3 (allometric).

Assuming that fish dynamics is under an equilibrium state, growth parameters (K, L_∞, t_0) were analyzed using ELEFAN I which is included in FISAT II software. The rate of total mortality (Z) was estimated using the length-converted catch curve (Sparre and Venema, 1998; Gayanilo and Pauly, 2001). The rate of natural mortality (M) was estimated using the empirical equation of Pauly (1979). Age at the changing growth rate (t_{tp}) was identified using Alverson and Carney’s methods (Merta, 1993). Analysis of the length of the first capture was carried out using the standard logistics method of Spearman-Karber.

RESULTS

Size distribution

The length range of yellowfin tuna caught in FMA 573 was 78-185 cm. Monthly length-frequency data shows that yellowfin tuna caught in the Indian Ocean from 2013 to 2017 consisted of two cohorts. The dominant length caught ranges from 140-155 cm FL (Fig. 2). The number of yellowfin tuna that are above 100 cm FL constitutes more than 95%, suggesting that yellowfin tuna caught were

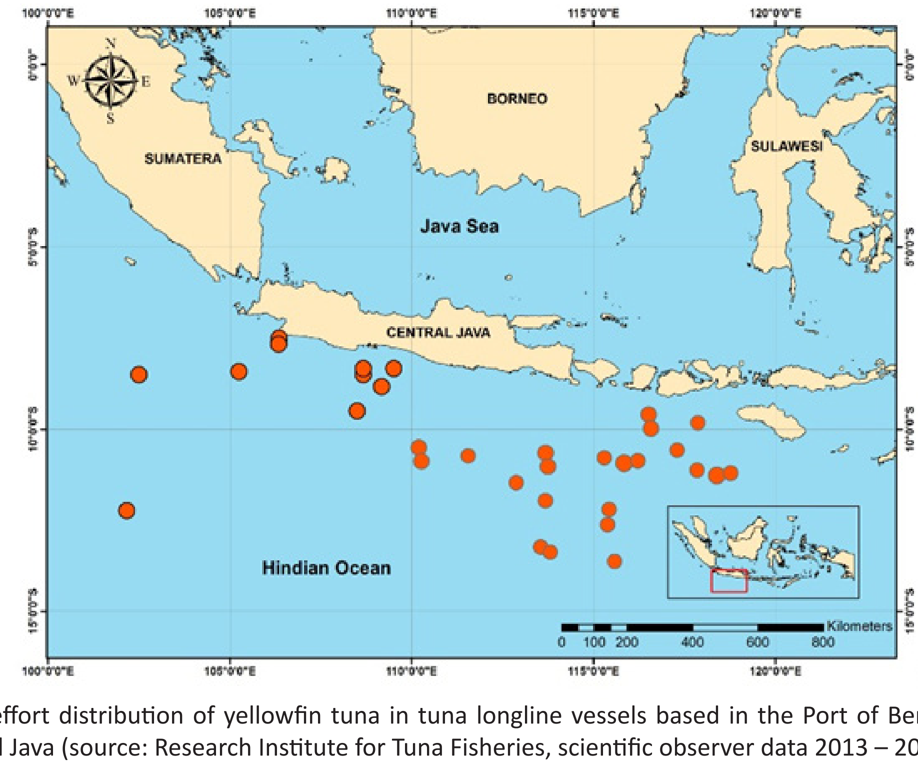

Fig 1. Fishing effort distribution of yellowfin tuna in tuna longline vessels based in the Port of Benoa, Bali and PPN Cilacap, Central Java (source: Research Institute for Tuna Fisheries, scientific observer data 2013 – 2017)

dominated by adult fish. The seasonality of yellowfin tuna size from the tuna longline fishery is illustrated in Fig. 3, where sizes have been grouped into quarters. Between January and March, the fish caught indicated two cohorts with modes of 115 cm FL and 150 cm FL. Between April and June, the cohort with 115 cm FL mode was drastically reduced, and the cohort with 150 cm FL mode became dominant. In the third quarter, the smaller cohort reappeared in 120 cm FL mode, whereas the large cohort shifted to 150 cm FL. In the fourth quarter, the small cohort was replaced with a new cohort, measuring 95 cm FL, and a large fish cohort with a mode of 145-150 cm FL.

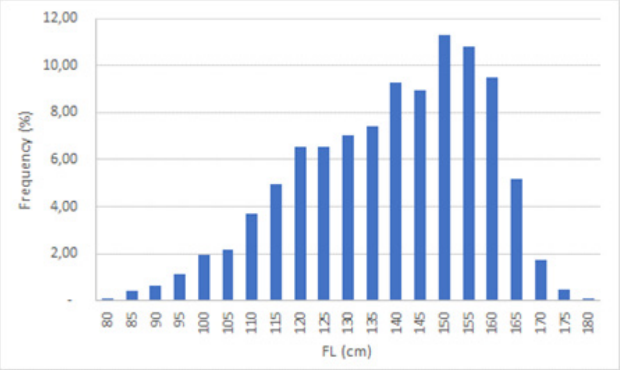

Fig 2. Length-frequency distribution of yellowfin tuna in FMA 573 of the Indian Ocean

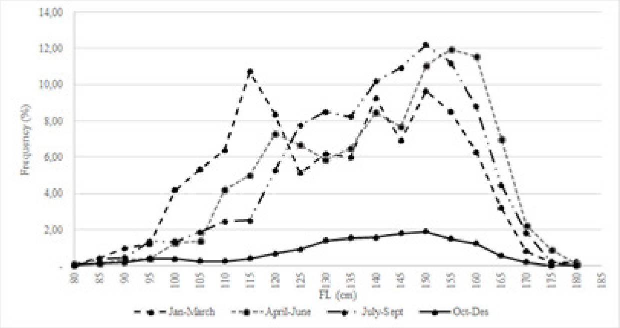

Fig 3. Length-frequency distribution of yellowfin tuna caught by tuna longline fishery in the Indian Ocean (2013-17)

Length at first capture (L_c)

The length at first capture of yellowfin tuna was analysed using the standard logistics method of Spearman-Karber, showing a value of L_c = 137.5 cm FL (Fig. 4).

Length-weight relationship

The length-weight relationship of yellowfin tuna in FMA 573 of the Indian Ocean was identified as a non-linear regression model with the power function W = 0.000052 * $FL^{2.78}$ (Fig. 5). The result of the t-test shows the value of the slope (b) that differs from 3. Thus, the growth pattern was identified as a negative allometric growth in which the growth in length is faster than in weight.

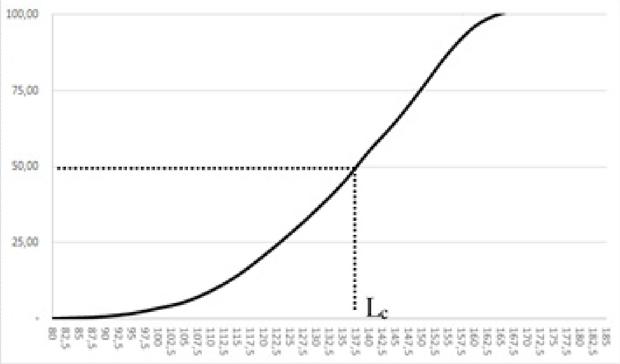

Fig 4. $L_{50\%}$ curve of yellowfin tuna in FMA 573 of the Indian Ocean

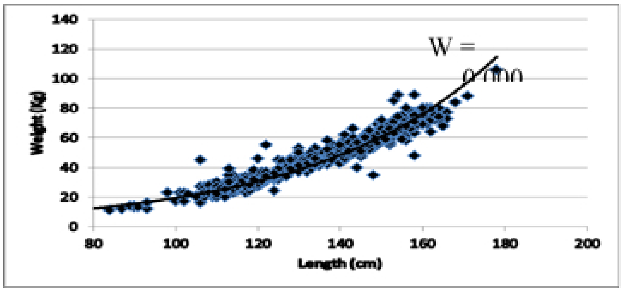

Fig 5. Length-weight relationship model of yellowfin tuna in FMA 573 of the Indian Ocean

Recruitment pattern

The results of the analysis indicated that the recruitment of yellowfin tuna occurred almost throughout the year, with a peak occurring in August (Fig. 6).

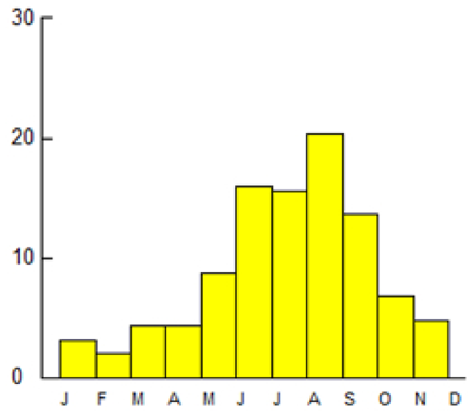

Fig 6. Recruitment pattern of yellowfin tuna in the Indian Ocean south off Java, Bali and Nusa Tenggara (FMA 573)

Growth parameters

The von Bertalanffy growth equation of yellowfin tuna was estimated based on the data collected in 2013, 2014, 2015 and 2017. The analysis indicates the values of L_∞ = 194.25 cm FL, K = 0.51 yr^{-1} and t_0 = -0.1889 year. Based on these parameters, the von Bertalanffy growth equation of yellowfin tuna is fitted as Lt = 194.25 (1 - $e^{-0.51(t + 0.1889)}$).

Table 1 shows the relationship between the length and age of yellowfin tuna. The von Bertalanffy curve (Fig. 7) showed that the growth rate of the fish is faster when the fish is still young, approximately 0-2 years of age. It then declined until reaching stable length size (L_∞). The changing growth rate (t_{tp}) occurs at the age of 2.47 years with 124.4 cm FL.

Table 1. Relationships between age and length of yellowfin tuna in the Indian Ocean south off Java, Bali and Nusa Tenggara (FMA 573)

Age (yr)	Length (cm FL)
0	17.90
0.5	57.70
1	88.52
2	130.86
4	171.47
6	186.06
8	191.31
10	193.19
12	193.87
14	194.11
16	194.20
18	194.23
20	194.24
22	194.25

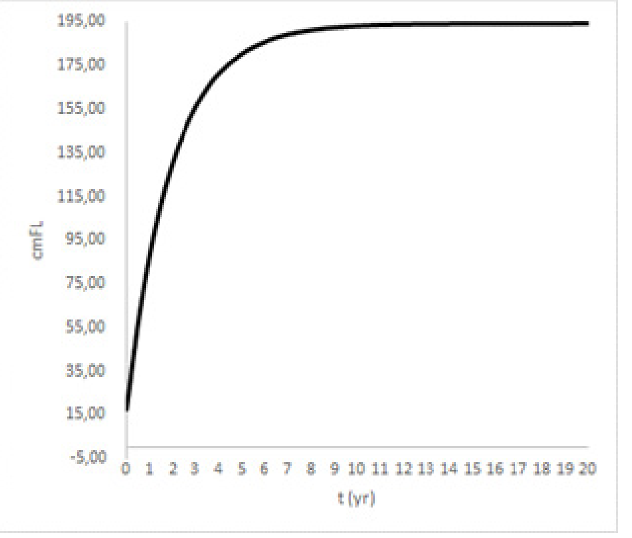

Fig 7. Growth pattern of yellowfin tuna in FMA 573 of the Indian Ocean

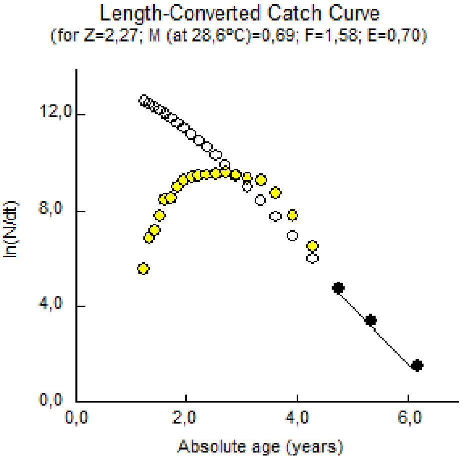

Fig 8. Length-converted catch curve of yellowfin tuna in the Indian Ocean south off Java, Bali and Nusa Tenggara (FMA 573)

Mortality rate

Based on the value of K and L_∞, the total mortality rate (Z) was estimated by means of Length Converted Catch Curve (LCCC) as 2.27 yr^{-1}. Based on Pauly's empirical equation, with an annual average temperature (T) = 28.56°C, the natural mortality (M) was estimated as 0.69 yr^{-1}. Additionally, the mortality rate (F=Z-M) was estimated as 1.58 $year^{-1}$ (Fig. 6). Based on these results, it is shown that the determinant of mortality is primarily related to fishing.

Exploitation rate

The total mortality rate can be used to predict the level of exploitation of fish in respective areas. The level of exploitation of yellowfin tuna in FMA 573 of the Indian Ocean is 0.7 (Fig. 6). It is well over the optimum level, E_{opt} = 0.50 yr^{-1}, suggesting that the yellowfin tuna stock has been overexploited.

DISCUSSION

The length range of yellowfin tuna caught during the period 2013-2017 was 78-185 cm FL. In general, it indicates that the catch from FMA 573 of Indian Ocean waters consists of two cohorts. Based on monthly data, a small-sized yellowfin tuna cohort appears in the range of 95-120 cm FL in relatively small numbers. This small-sized yellowfin tuna was recruited from October to December until the following months (January-March), when their size increased to 100-115 cm FL. The second cohort, the larger yellowfin tuna, shows a range of 140-160 cm FL that dominates the population throughout the year.

The study conducted by Rohit et al. (2012) on the east coast of India obtained yellowfin tuna length range between 20-185 cm FL, whereas in the Sea of Oman lengths ranged between 37-172 cm FL. Zuidare et al.

(2010) reported the length of yellowfin tuna caught in the central and western Indian Ocean ranged between 30-161 cm FL. In the Banda Sea, Haruna et al. (2018) reported yellowfin tuna caught by handline which was in the range of 25-178 cm FL, dominated by medium- to large-sized groups contributing 71% of the catch. The study in the waters of the Simeulue Islands, Aceh showed that the fork length of yellowfin tuna was 45.5-111.5 cm (Burhanis and Radmi 2017). Yellowfin tuna caught in FMA 573 of Indian Ocean waters is larger than in the Sea of Oman, Banda Sea and Simeulue Islands but smaller than the fish caught in the Pacific Ocean, ranging between 93 and 167 cm FL (Zhu, 2011).

The length-weight relationship of yellowfin tuna in FMA 573 of the Indian Ocean was $W = 0.000052 * FL^{2.78}$. The value of the slope (b) of the equation is 2.78 and a = 0.000052. Based on the t-test, where b value differs from 3, yellowfin tuna indicates a negative allometric growth, meaning that growth in length is faster than in weight. The same results obtained from other studies suggest negative allometric growth (b <3) of yellowfin tuna in the Atlantic Ocean, Pacific Ocean and Indian Ocean (Zhu et al., 2010; Andamari et al., 2012; Miazwir, 2012). The research in the Indian Ocean by Muhammad and Barata (2012) resulted in a positive allometric growth (b> 3). Different growth patterns may be due to differences in the size composition of the fish caught.

The length at first capture (L_c) was estimated at 137.5 cm FL. To ensure the sustainability of yellowfin tuna fishery, L_c should be greater than or equal to L_m (length at first maturity). According to Zhu et al. (2008), the length at first maturity of yellowfin tuna is 100 cm FL. FAO (2010) states that mature gonad size of yellowfin tuna caught in the Indian Ocean is in the range of 100-110 cm FL at the age of 2.5-3 years. A smaller estimate was suggested by Romena (2000) who found that the gonadal maturity of yellowfin tuna was between 75.9 and 134.5 cm FL. Yellowfin tuna from Pacific Ocean waters reaches the length at first maturity at 108 cm FL (McPherson, 1991), and at 92 cm FL in the Eastern Pacific Ocean. Haruna et al. (2018) reported length at first maturity of yellowfin tuna in the Banda Sea, Indonesia of 115.2 cm FL. Based on these findings, the value of Lc obtained from the current study is generally larger than the length at first maturity. Therefore, it may be suggested that the yellowfin tuna caught in FMA 573 of the Indian Ocean in 2013-2017 largely spawned, and that it does not likely cause growth and recruitment overfishing.

Yellowfin tuna reach asymptotic length (L_∞) at 194.25 cm FL, with curvature parameter (K) of 0.51 and t_0 of -0.1889 yr. The L_∞ value is greater than that obtained by Zhu et al. (2011) in the East and West Pacific Ocean (175.9 cm FL), and K is 0.52 yr^{-1}. Kar et al. (2012) reported in their study in Indian waters that L_∞ value was 173.3 cm FL and K was 0.39. A study conducted by Haruna et al. (2018) in the Banda Sea, Indonesia reported K value of 0.31, L_∞ = 215 cm FL and t_0 of -0.311. Burhanis and Radmi (2017) reported in their study in Aceh, Indonesia that L_∞, K and to values were 117.08 cm FL, 0.93 and -0.10 years, respectively. Tumulyadi et al. (2019) suggested for the Indian Ocean K value of 0.20 and L_∞ = 178.95 cm FL. A study by Nurdin et al. (2016) in Palabuhanratu waters, west Java (eastern Indian Ocean) estimated that L_∞ = 178 cm FL, K = 0.47 and t_0 = -0.213 year. In all, it shows that yellowfin tuna in FMA 573 of the Indian Ocean attained larger size than in the Pacific Ocean.

The estimates of total mortality (Z), natural mortality (M) and fishing mortality rates of yellowfin tuna were 2.027 yr^{-1}, 0.69 yr^{-1} and 1.58 yr^{-1}, respectively. The Z value is relatively similar to that obtained by Hartaty and Ririk (2014) in the Indian Ocean, which was 2.16 yr^{-1}, 2.04 yr^{-1} in the Oman Sea (Kaymaram, 2014) and 2.11 yr^{-1} in the Simeulue Islands, Indonesia (Burhanis and Radmi 2017). Smaller estimates of Z were reported by Tumulyadi et al. (2019) in the South Malang Regency of the Indian Ocean (1.32 yr^{-1}), by Nurdin et al. (2016) in Palabuhanratu, West Java (1.27 yr^{-1}) and by Haruna et al. (2018) in the Banda Sea, Indonesia (1.47 yr^{-1}).

The natural mortality of yellowfin tuna obtained in this study is 0.69 yr^{-1}. Similar values were reported by Nurdin et al. (2016) in Palabuhan Ratu, West Java (0.66 $year^{-1}$) and by Zhu et al. (2011) in the Pacific Ocean (0.65 $year^{-1}$). A slightly smaller value of M was obtained by Hartaty and Ririk (2014) in the Eastern Indian Ocean (0.54 yr^{-1}) and by Kar et al. (2012) in the Andaman Sea (0.51 yr^{-1}). Burhanis and Radmi (2017), however, reported natural mortality of 1.22 yr^{-1} in the seas of the Simeulue Islands, Indonesia. According to the above findings, the natural mortality rate (M) of yellowfin tuna varies by locality.

The fishing mortality rate (F) of yellowfin tuna estimated in this study is 1.58 yr^{-1}, which agrees with that of Kaymaran et al. (2014) in the Oman Sea (1.56 yr^{-1}). However, more reported F values for adjacent areas were relatively smaller: 1.02 yr^{-1} in the Indian Ocean south off Malange Regency (Tumulyadi et al., 2019); 0.66 yr^{-1} in Palabuhanratu West Java (Nurdin et al., 2016); 0.89 yr^{-1} in the waters of the Simeulue Islands, Aceh, Indonesia (Burhanis and Radmi 2017); and 0.98 yr^{-1} in the Banda Sea, Indonesia (Haruna et al., 2018).

Sparre and Venema (1998) underlined that high fishing mortality leads to overfishing of fish stocks in the waters. Sustainable production was attained when F = M and the rate of exploitation (E) = F/Z = 0.5 (Gulland, 1971). The exploitation rate estimated in this study is 0.70, suggesting that fishing effort of yellowfin tuna in FMA 573 of the Indian Ocean has led to the overexploitation of yellowfin tuna. This finding is consistent with the IOTC (2014) which indicates that the stock of yellowfin tuna in the Indian Ocean was overfished. Various studies of yellowfin tuna from different waters have also shown the occurrence of overfishing. Estimates of exploitation rates (E) in the Banda Sea, Indonesia of 0.67 year (Haruna et al., 2018); 0.77 in the South of Malang (Tumulyadi et al., 2019) and 0.76 in the Oman Sea (Kaymaran, 2014).

Table 2. Results of growth parameter estimates using length frequencies in different waters

L_∞ (cm FL)	K (yr^{-1})	t_0 (years)	Location	References
137.5	0.51	-0.1889	FMA 573 of Indian Ocean	This research
189	0.25		Philippines waters	White, 1982 in Zhu et al., 2011
175	0.3		Philippines waters	Yesaki, 1983 in Zhu et al., 2011
166.07	0.38		Indian Ocean	Shono et al., 2007 in Rohit, 2013
184	0.395		WC Pacific	Hampton and Fournier, 2001
183	0.45		Oman sea	Kaymaram, 2010
175	0.392	0.00306	Taiwanese offshore	Chi et al., 2005
175.9	0.54		East and West Pacific Ocean	Zhu et al., 2011
197.42	0.30	-0.1157	Andhra Pradesh along the east coast of India	Rohit, 2013
173.3	0.39		Indian waters	Kar et al., 2012
178	0.47	-0.213	Palabuhanratu waters, west Java (eastern Indian Ocean)	Nurdin et al., 2016
178.95	0.20		Indian Ocean	Tumulyadi et al., 2019
215	0.31	-0,311		Haruna et al., 2018

Based on the facts described earlier, it is suggested that overfishing has not been caused by the capture of smaller-sized tuna, but due to high fishing intensity leading to the production level that exceeds the biological capacity for its renewal. Therefore, since tuna live in extensive waters beyond a country, tuna fisheries management requires a joint effort between the district, provincial and national governments, in addition to regional fisheries organizations (RFMO). Martosubroto (2012) emphasized the need for consistent monitoring and surveillance of fishing fleet, type and size of fishing gear, as well as the species, fish size and quantity of the catch. All data and information related to this would contribute to the preparation of a Fisheries Management Plan (FMP) which is needed to support fisheries sustainability.

CONCLUSION

The structure of yellowfin tuna size caught by tuna longline fishery in the FMA 573 of the Indian Ocean ranged between 78 and 185 cm FL. The growth pattern of yellowfin tuna follows the von Bertalanffy equation of $L_t = 194.25\ (1 - e^{-0.51\ (t+0,1889)})$, with length-weight relationship of $W = 0.000052\ FL^{2.78}$. The length at first capture (L_c) was estimated at 137.5 cm FL or larger than L_m, showing that yellowfin tuna stocks do not experience growth due to overfishing. However, the rates of total mortality (Z) of 2.27 yr^{-1}, natural mortality (M) of 0.69 yr^{-1} and fishing mortality (F) of 1.58 yr^{-1} suggest that a greater proportion of mortality of yellowfin tuna was caused by fishing intensity. The exploitation rate was estimated at 0.7 or greater than the optimum exploitation rate of 0.5. The quantity of fish harvested has exceeded the biological capacity to produce new biomass that is responsible for overexploitation.

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DINAMIKA POPULACIJE ŽUTOPERAJNE TUNE *Thunnus albacares* (BONNATERRE, 1788) U PODRUČJU RIBARSKOG UPRAVLJANJA 573 INDIJSKOG OCEANA

SAŽETAK

Žutoperajna tuna *Thunnus albacares* je jedna od glavnih vrsta tuna koje se love u području ribarskog upraljanja 573 Indijskog oceana. Njezina proizvodnja činila je 35,83% ukupne proizvodnje tune u 2013. godini. Ovo istraživanje je provedeno kako bi se procijenila dinamika populacije ove vrste u FMA 573, na temelju podataka o dužinskoj frekvenciji prikupljenih u razdoblju od 2013. do 2017. godine, koji su analizirani pomoću softvera FiSAT II. Dobiveni rezultati pokazuju dužinsko-maseni odnos W = 0,000052 $FL^{2.78}$, negativni alometrijski rast i jednadžbu rasta L_t = 194.25 (1-$e^{-0.51\ (t\ +\ 0.1889)}$). Pri prvom hvatanju procijenjena je duljina od140 cm FL. Sezona izlova bila je između srpnja i rujna, a vrhunac izlova bio je u kolovozu. Stopa ukupne smrtnosti (Z) iznosila je 2,32 $godina^{-1}$, uključujući stopu prirodne smrtnosti (M) Procjenjuje se da su stope iskorištavanja žutoperajne tuna 0,70, što ukazuje da je premašila optimalnu brzinu iskorištavanja (E = 0,5) i da je došlo do prekomjernog iskorištavanja. Očigledna je potreba za dosljednim praćenjem i nadzorom ribolovne flote, vrste i veličine ribolovnog alata, kao i veličine i količine ulova.

Ključne riječi: FMA, stopa rasta, stopa smrtnosti, stopa eksploatacije, raspodjela ribolovnog napora, dužinsko-maseni odnos

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