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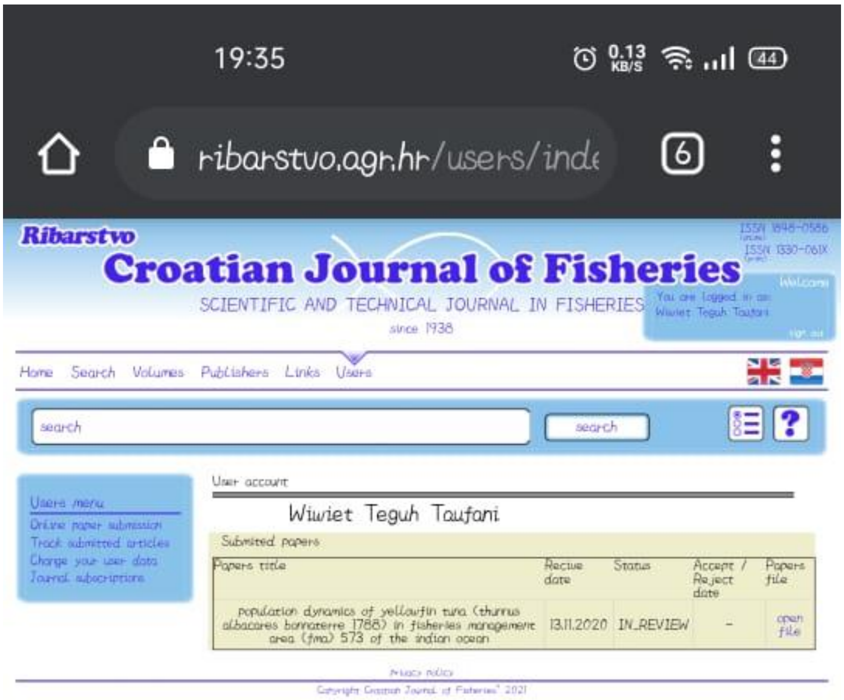

Dari: **Tea Tomljanović** <ttomljanovic@agr.hr>
Date: Sen, 21 Des 2020 pukul 15.19
Subject: Reviews for MS 083-20-CJF
To: <aghofar099@gmail.com>

Dear Dr. Abdul Ghofar,
both reviews of your paper MS 083-20-CJF "Population Dynamics of Yellowfin Tuna (Thunnus albacares Bonnaterre 1788) in Fisheries Management Area (FMA) 573 of the Indian Ocean" were received. Both reviewers, who are experts for this field, think that we can publish your research after some modificationes. Please, find their reviews just below. Make suggested modificitiones and sent us back your manuscript because it is interesting for publication in Croatian Jorunal of Fisheires

This manuscript deals with a higly important tuna species, yellowfin tuna in Indian Ocean. Authors in this paper used quite old length frequency data (2013-2014) and length-weight data from single year (2016) collected from local commercial fishing vessels operating with pelagic long-lines, targeting tunas in the Eastern part of Indian Ocean, at their landing places. With aim to assess growth parameters, mortalities (F,M,Z) and estimate exploitation rates of yellowfin tuna population, authors used length-based assessment method (ELEFAN I) as available within software package FISAT II.
The principal problem with this manuscript is the fact that yellowfin tuna (as all other tuna species) is a highly migratory fish with population widely distributed in Indian Ocean, and being exploited by multiple stock users (countries) and several different fishing fleets. For these reason, it is not scientificaly sound to make assessments estimating population dynamics and exploitation rates with spatialy and temporaly very limited data-set (a part of one fishing fleet only) collected in just one part of yellowfin stock distribution area. Therefore, it is necessary to emphasize that this limited dataset which do not representative for entire population of yellowfin tuna in the Indian Ocean.
Authors mentioned in the paper that the latest stock assessment by Indian Ocean Tuna Commission (IOTC) was in 2015. That is no correct! So, find latest data or just add this date at 2015. without latest.
Authors need to follow Guide for authors in manuscript preparation(i.e. Tables without vertical lines, References, etc.)

In atachment there is some modification in your manuscript done by reviwers.

Kind Regards,
Tea Tomljanović, PhD
Editor In Chief "Croatian Journal of Fisheries"
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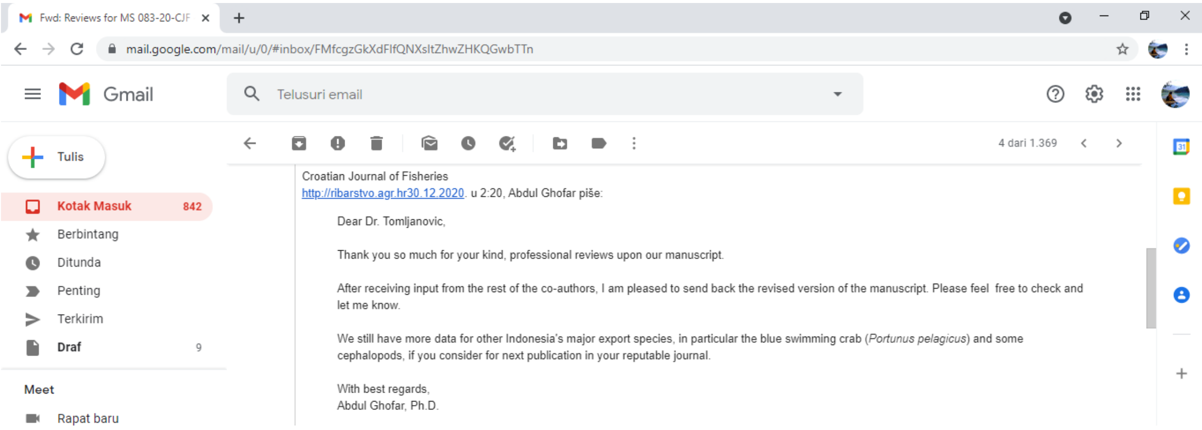
2:20, Abdul Ghofar piše:
Dear Dr. Tomljanovic,

Thank you so much for your kind, professional reviews upon our manuscript.

After receiving input from the rest of the co-authors, I am pleased to send back the revised version of the manuscript. Please feel free to check and let me know.

We still have more data for other Indonesia's major export species, in particular the blue swimming crab (*Portunus pelagicus*) and some cephalopods, if you consider for next publication in your reputable journal.

With best regards,
Abdul Ghofar, Ph.D.



Review 1

Population Dynamics of Yellowfin Tuna (*Thunnus albacares* Bonnaterre 1788) in the Fisheries Management Area (FMA) 573 of the Indian Ocean

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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 (FMA)-573, based on length frequency data collected in 2013-2017, and was analysed using the software of FiSAT II. The results obtained show length-weight relationship of $W = 0.000052\ FL^{2,78}$, negative allometric growth and growth equation of $Lt = 194,25\ (1\text{-}e^{-0.51\ (t\ +\ 0.1889)})$. The length at first capture was estimated at 140 cmFL. Recruitment season occurs in July to September, with 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 the 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.

Keyword: Thunnus albacares; population dynamics, FMA, growth pattern, mortality rate, exploitation rate, effort distribution, length-weight relationship, Indian Ocean off Indonesia.

1. Introduction

The Indian Ocean south off Java, Bali and Nusa Tenggara have 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 was focused on yellowfin tuna (YFT), one of the most dominant species caught in FMA-573. The Research Institute for Tuna Fisheries (LP2T)'s Annual Report (2013) suggested that the catch composition of longline tuna 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, 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, the optimum size caught, the parameters of population growth, recruitment patterns, the mortality and the exploitation rates of the yellowfin tuna.

2. Material and Methods

The data used for the analysis of length-weight relationship was collected during April and May 2016, amounted to 753 total specimens. Length frequency data was obtained from daily landing in tuna longline activity operating in FMA-573 (Figure 1) during the period of 2013-2014. 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). Length was measured using a modified aluminium calliper up to 2 meters long, with 0.5 cm precision. Individual dressed weight (DW) was recorded to the nearest kilogram. Weight and length were fitted by 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: $\beta=3$ (isometric) and H_1: $\beta\neq3$ (allometric).

Assuming that fish dynamics is under an equilibrium state, growth parameters (K, L_∞, t_o) were analyzed using ELEFAN I which is accommodated in the software FISAT II. 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. 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 standard logistics method of Spearman-Karber.

3. Results

3.1. Size distribution

The length range of yellowfin tuna from WPP-573 caught was 78 – 185 cm. Monthly length frequency data shows that yellowfin tuna caught from the Indian Ocean from 2013 to 2017, consisted of two cohorts. The dominant length caught ranges from 140 - 155 cmFL (Figure 2). The number of yellowfin tuna that is above 100 cmFL constitutes more than 95%, suggesting that yellowfin tuna caught were dominated by adult fish.

The seasonality of yellowfin tuna size from the tuna longline is illustrated in Figure 3, where sizes have been grouped by quarter.

In January-March the fish caught indicated two cohorts with modes of 115 cmFL and 150 cmFL. In April-June period, the cohort with 115 cmFL mode was drastically reduced, and the cohort with 150 cmFL mode became dominant. In the 3rd quarter, the smaller cohort reappeared in 120 cmFL mode, while the large cohort shifted to 150 cmFL. In the 4th quarter, the small cohort was replaced with a new cohort measuring 95 cmFL mode, and a large fish cohort with a mode of 145-150 cmFL.

3.2. Length at first capture (L_c)

The length at first capture of yellowfin tuna was analysed using standard logistic from Spearman-Karber, showing a value of Lc = 137.5 cmFL (Figure 4).

3.3. Length-weight relationship

Length-weight relationship of yellowfin tuna in FMA-573 of the Indian Ocean was identified as non-linear regression model with power function, $W = 0.000052 * FL^{2,78}$ (Figure 5). The result of the t-test shows the value of the slope (b) that do differ from 3. Thus, the growth pattern identified as negative allometric, in which the growth in length is faster than that of weight.

3.4. Recruitment Pattern

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

3.5. Growth Parameters

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 cmFL, K = 0.51 yr^{-1}, and t_o = -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 yellowfin tuna. The von Bertalanffy curve (Figure 7) showed that the growth rate of the fish is faster when the fish is still as 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 of 124.4 cmFL length.

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 cmFL)
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

3.6. 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}. With these, the mortality rate (F=Z-M) was estimated as 1.58 $year^{-1}$ (Figure 6). Based on these results, it is shown that the determinant of mortality is primarily related to fishing.

3.7. 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

(Figure 6). It is well over the optimum level, E_{opt} = 0.50 yr^{-1}, suggesting that the YFT stock has been overexploited.

4. Discussion

The length range of YFT caught during the period of 2013-2017 was 78 – 185 cmFL. In general, it indicates that the catch from FMA-573 of the Indian Ocean waters consists of two cohorts. Based on monthly data, a small-sized YFT cohort appears with mode of 95-120 cmFL in relatively small number. This small-sized YFT recruits from October/November/December, until the following month, January/February/March, when their size increased to 100-115 cmFL. The second cohort, the larger YFT shows mode of 140-160 cmFL that dominate the population throughout the year.

The study conducted by Rohit *et al*. (2012) in the east coast of India obtained yellowfin length range between 20-185 cmFL, whereas in the Sea of Oman lengths ranged between 37-172 cmFL. Zuidare *et al*. (2010) reported the length of yellowfin caught in the central and western Indian Ocean ranged between 30-161 cmFL. In the Banda Sea, Haruna et al. (2018) reported YFT caugh caught by Handline was of the order of 25-178 cm FL, which was dominated by medium to large size group contributing to 71% of the catch. The study in in the waters of Simeulue Islands, Aceh showed that fork length of YFT was 45.5-111.5 cm (Burhanis et al. 2017). In all these show that the YFT caught in the FMA-573 of the Indian Ocean waters is larger than the three waters but smaller than the fish caught in the Pacific Ocean ranging between 93-167 cmFL (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, YFT indicates a negative allometric growth, meaning that growth in length is faster than in weight. The same results obtained from the other studies suggesting negative allometric (b <3) growth of YFT in the Atlantic Ocean and the Pacific Ocean and the Indian Ocean (Zhu *et al*., 2010; Andamari *et al*., 2012; Miazwir, 2012). Muhammad & Barata (2012) research in the Indian Ocean in the Pacific Ocean resulted in positive allometric (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 cmFL. To ensure the sustainability of YFT 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 YFT is 100 cmFL. FAO (2010) states that mature gonad size yellowfin tuna caught in the Indian Ocean is in the range of 100-110 cmFL at the age of 2.5 - 3 years. A smaller estimate was suggested by Romena (2000) that the gonadal maturity of yellowfin tuna was between 75.9 to 134.5 cmFL. Yellowfin tuna from the Pacific Ocean waters reaches the length at first maturity at 108 cmFL (McPherson, 1991), and 92 cmFL in the Eastern Pacific Ocean. Haruna et al. (2017) reported length at first maturity of YFT in the in the Banda Sea, Indonesia of 115,2 cmFL. Based on these findings, the value of Lc obtained from the current study is generally larger than length at first maturity. Therefore, it may be suggested that the YFT caught in the FMA-573 of the Indian Ocean in 2013-2017 has largely been spawned, and that it does not likely to cause growth and recruitment overfishing.

Yellowfin tuna reach asymptotic length (L_∞) at 194,25 cmFL, with curvature parameter (K) of 0.51, and t_o of -0.1889 yr. The L_∞ value is greater than that obtained by Zhu *et al*. (2011) in the East and the West Pacific Ocean, which is 175.9 cmFL and K is 0.52 yr^{-1}. Kar *et al*. (2012) reported his study in Indian waters where L_∞ value was 173.3 cmFL, and K is 0.39. A study conducted by Haruna *et al.* (2018) in the Banda Sea, Indonesia reported K value of 0.31, L_∞ = 215 cmFL, and t_o of -0.311. Burhanis *et al.* (2017) reported his study in Aceh, Indonesia, that L_∞, K and t_o values were 117.08 cmFL, 0.93, and -0.10 years respectively. Tumulyadi *et al*. (2019) observations in the Indian Ocean suggested K value of 0.20, and L_∞ 178.95 cmFL. A study by Nurdin *et al.* (2016) in Palabuhanratu waters, west Java (eastern Indian Ocean) estimated $L\infty$ = 178 cm fork length (cmFL), K = 0.47, and t_o = -0.213 year. In all, it shows that the YFT in FMA 573 of the Indian Ocean attained larger size than that in the Pacific Ocean.

Table 2. Results of growth parameters estimates using length frequencies in various waters

L_∞ (cmFL)	K (yr^{-1})	t_o (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

L_∞ (cmFL)	K (yr^{-1})	t_o (years)	Location	References
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 a*l.2003.
175.9	0.54		East and the 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

The estimates of total mortality (Z), natural mortality (M) and fishing mortality rates of the yellowfin tuna were 2.027yr^{-1}, is 0.69 yr^{-1} and 1.58 yr^{-1} respectively. The Z value is relatively similar with that obtained by Hartaty and Ririk (2014) in the Indian Ocean which was 2.16 yr^{-1}, and 2.04 yr-1 in the Oman Sea (Kaymaram, 2014) and 2.11 yr^{-1} in Simeulue Islands, Indonesia (Burhanis *et al.* 2017). A smaller estimates of Z were reported by Tumulyadi *et al*. (2019) in the South Malang Regency of 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 the 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) research in the Pacific Ocean also resulted in 0.65 year^{-1}. A slightly smaller value of M by was obtained by Hartaty and Ririk (2014) in Eastern Indian Ocean (0.54 yr^{-1}), by Kar *et al*. (2012) in the Andaman Sea (0.51 yr^{-1}). Burhanis *et al*. (2017), however, reported natural mortality of 1.22 yr^{-1} in the seas of Simeulue Islands, Indonesia. The above findings, the natural mortality rate (M) of yellowfin tuna varies by locality.

The fishing mortality rate (F) of the yellowfin tuna estimated in this study is 1.58 yr^{-1}, which agrees well with that of Kaymaran *et al.* (2013) in the Oman Sea (1,56 yr^{-1}). However, more reported F values for adjacent areas were relatively smaller: 1.02 yr^{-1} 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 Simeulue Islands, Aceh Indonesia (Burhanis *et al.* , 2019); and 0.98 yr^{-1} in the Banda Sea, Indonesia (Haruna *et al.*, 2018) obtained.

Sparre and Venema (1998) underlined that high fishing mortality leads to overfishing on 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 overexploitation of YFT. 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 several 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 South of Malang (Tumulyadi *et al.*, 2019) and 0.76 in the Oman Sea (Kaymaran, 2014).

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 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 preparation and of a Fisheries Management Plan (FMP), which is needed to support fisheries sustainability.

5. Conclusion

The conclusions of this study are:

1. The structure of yellowfin tuna size caught by longline tuna in the FMA 573 of the Indian Ocean ranged between 78 – 185 cmFL.
2. 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 $W = 0.000052\ FL^{2,78}$
3. The length at first capture (L_c) was estimated at 137,5 cmFL or larger than L_m, showing that yellowfin, tuna stocks do not experience growth overfishing.

4. 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 yellowfin tuna was caused by fishing intensity.
5. 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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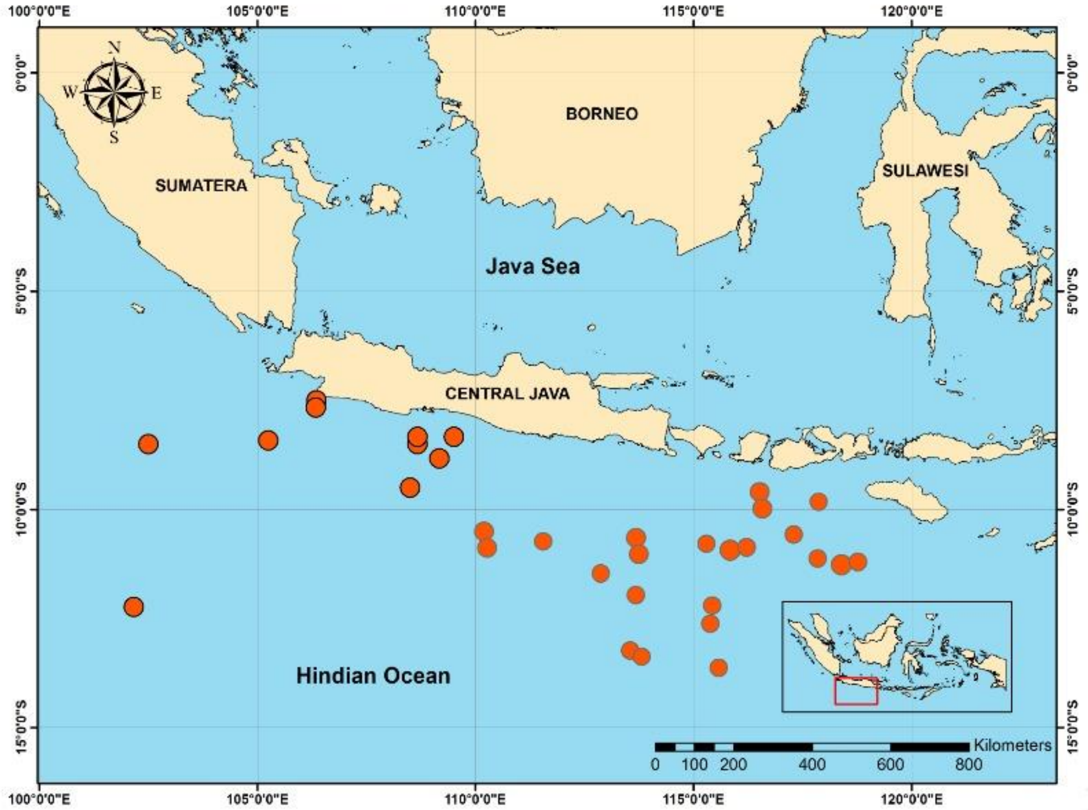

Figure 1. Fishing effort distribution of yellowfin tuna in Tuna longline vessels based in the Port of Benoa, Bali and PPN Cilacap, Central Java. *(Source: LP2T scientific observer data 2013 – 2017.)*

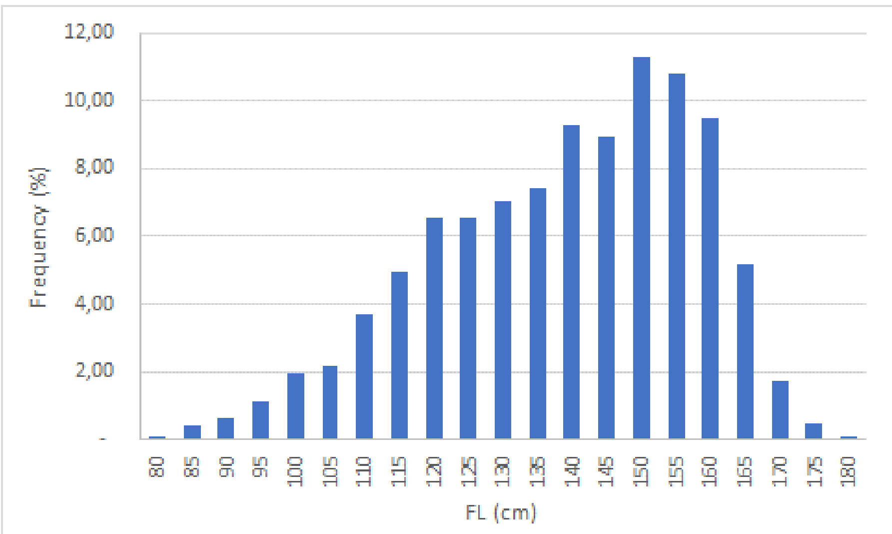

Figure 2. Length frequency distribution of yellowfin tuna in FMA-573 of the Indian Ocean.

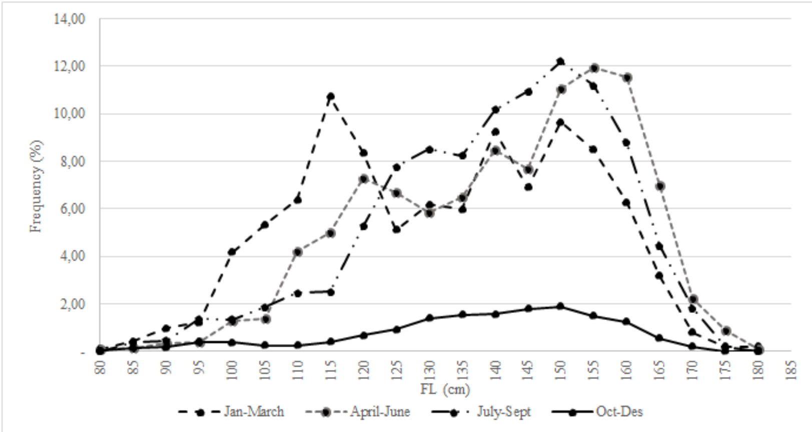

Figure 3. Length frequency distribution of yellowfin tuna caught by tuna longline in the Indian Ocean (2013-17)

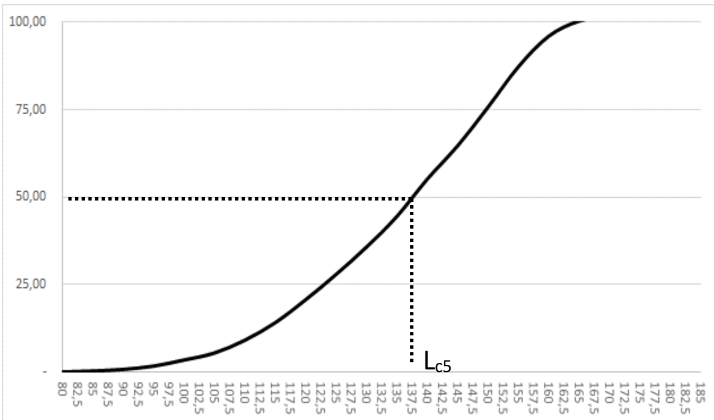

Figure 4. $L_{50\%}$ curve of yellowfin tuna in FMA-573 of the Indian Ocean.

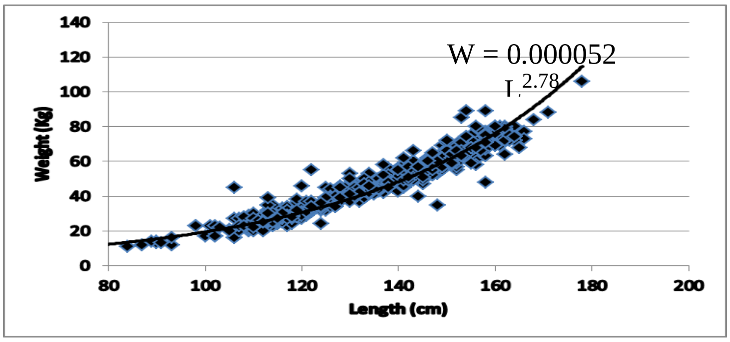

Figure 5. Length-weight relationship model of yellowfin tuna in FMA-573 of the Indian Ocean.

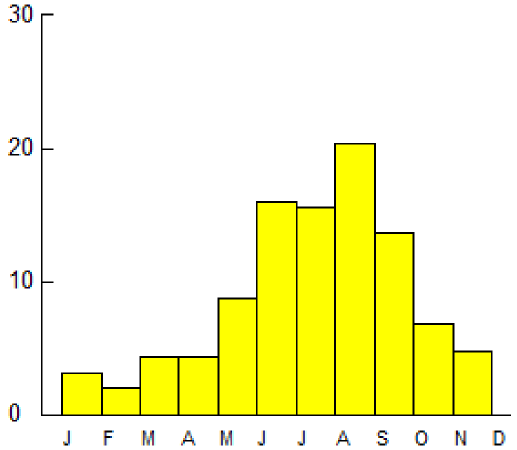

Figure 6. Recruitment pattern of yellowfin tuna in the Indian Ocean south off Java, Bali and Nusa Tenggara (FMA-573).

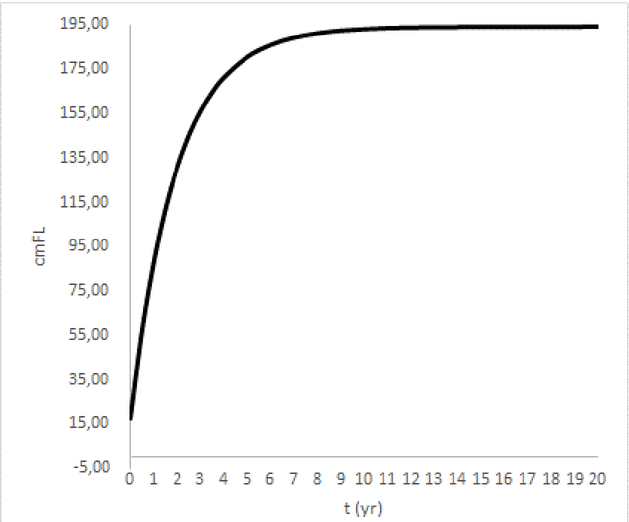

Figure 7. Growth pattern of yellowfin tuna in FMA-573 of the Indian Ocean.

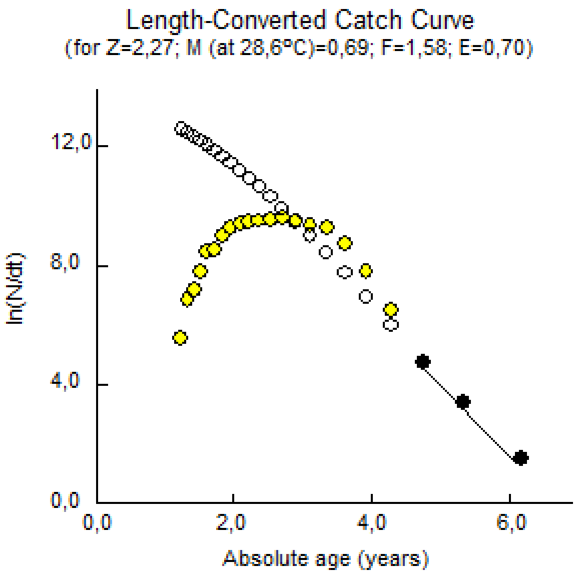

Figure 8. Length-converted catch curve of yellowfin tuna in the Indian Ocean south off Java, Bali, and Nusa Tenggara (FMA-573).

Dari: **Abdul Ghofar** <aghofar099@gmail.com>
Date: Sel, 12 Jan 2021 pukul 20.30
Subject: Re: Reviews for MS 083-20-CJF
To: Tea Tomljanović <ttomljanovic@agr.hr>

Dear Dr. Tomljanovic,

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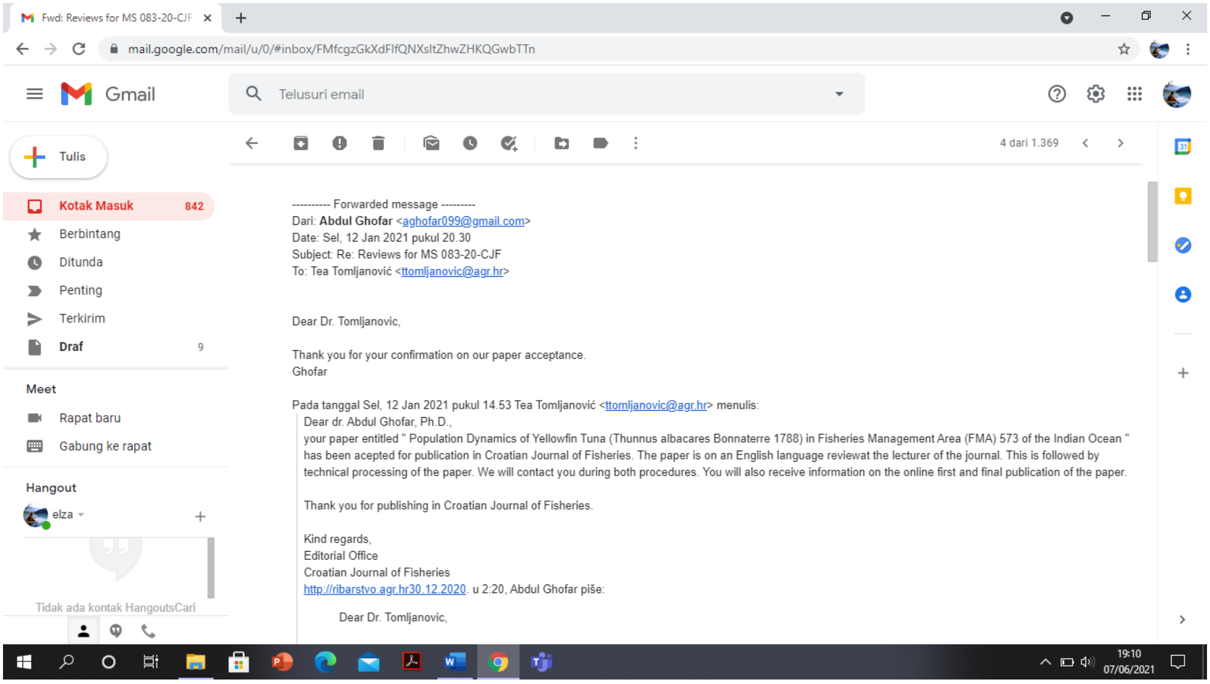
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Pada tanggal Sel, 12 Jan 2021 pukul 14.53 Tea Tomljanović <ttomljanovic@agr.hr> menulis:

Dear dr. Abdul Ghofar, Ph.D.,
your paper entitled " Population Dynamics of Yellowfin Tuna (Thunnus albacares Bonnaterre 1788) in Fisheries Management Area (FMA) 573 of the Indian Ocean " has been acepted for publication in Croatian Journal of Fisheries. The paper is on an English language reviewat the lecturer of the journal. This is followed by technical processing of the paper. We will contact you during both procedures. You will also receive information on the online first and final publication of the paper.

Thank you for publishing in Croatian Journal of Fisheries.

Kind regards,
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http://ribarstvo.agr.hr30.12.2020. u 2:20, Abdul Ghofar piše:

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However, after checking the English language our lecturer decided that, the whole manuscript needs careful reexamination and substantial rewriting and rewording.
So please, ask the native English speaker to read and correct the text (or hire an English academic language editing service). After that return the paper so they can publish it.

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Tea Tomljanović

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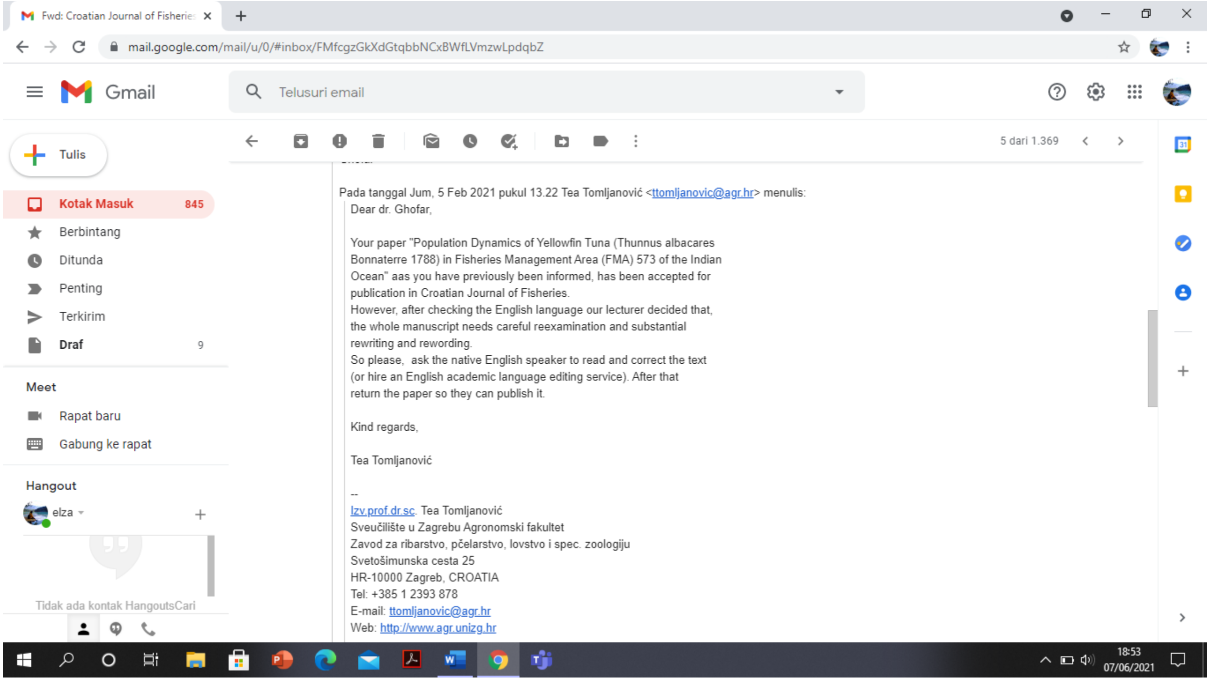

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Population Dynamics of Yellowfin Tuna (*Thunnus albacares* Bonnaterre 1788) in Fisheries Management Area (FMA) 573 of the Indian Ocean

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Abstract

Yellowfin tuna (*Thunnus albacores*) is one of the dominant species of tuna caught in Fisheries Management Area (FMA) 573 of Indian Ocean waters. Its production amounted to 35.83% of the total production of tuna in 2013. The study was conducted to assess the population dynamics yellowfin tuna in FMA (FMA)573 of Indian Ocean, based on length frequency data 2013-2017. Data analysis using the software FiSAT II. The results have been obtained long-weight relationship equations $W = 0.000052 * FL^{2,78}$, with allometric growth pattern. The length of the first capture was 140 cmFL. Recruitment season occurs in July to September, with peak in August. Obtained von Bertalanffy growth equation $Lt = 194,25\ (1-e^{-0.51\ (t + 0.1889)})$. The rate of total mortality (Z) was 2.32 yr^{-1}, the rate of natural mortality (M) was 0.69 yr^{-1}, and the fishing mortality (F) 1.63 yr^{-1}. Yellowfin tuna exploitation rates are 0.70; the show has exceeded the optimum exploitation rate (E = 0.5) or overexploitation.

Keyword: Thunnus albacores; population dynamics, FMA, growth pattern, mortality rate, exploitation rate, effort distribution, length-weight relationship model, Indian Ocean,

1. Introduction

The Indian Ocean south of Java, Bali and Nusa Tenggara which are included in FMA 573 have been potentially known for its tuna resources (Novianto et al, 2016; Widodo and Mahulete, 2012). The main target species are bigeye tuna (*Thunnus obesus*), albacore (*T. alalunga*), bluefin tuna (*T. maccoyii*) and yellowfin tuna (*T. albacares*). This research focused on yellowfin tuna since it is the most dominant species and can be found in FMA 573. Research Institute for Tuna Fisheries (LP2T)'s Annual Report (2013) suggested that the catch composition of longline tuna in the port of Benoa, Bali was dominated by yellowfin tuna. The amount of tuna export market demand led to increased exploitation that could threaten the sustainability of tuna resources (Gillet, 2009). The exploitation of yellowfin tuna in the Indian Ocean in 2011- 2014 has increased. It is indicated by the increasing number of catches from 329,184 tons in 2011 to 430,327 tons in 2014 according to the latest stock assessment by Indian Ocean Tuna Commission (IOTC) in 2015. Therefore, the study of population dynamics is very important. This study aims to assess the length-weight relationship and pattern of growth, the optimum size caught, the parameters of population growth, recruitment patterns, the mortality rate, the exploitation rate of yellowfin tuna.

2. Material and Methods

The data used for the analysis of length-weight relationship was collected during April and May 2016, with 753 total specimens. The length of frequency data was obtained from daily landing tuna longline activity operating in FMA 573 (Figure 1) during 2013-2014 (report of Research Institute for Tuna Fisheries (LP2T). The definition of length used in this study is the length of the mouth to the tip of the central tail fin indentation (fork length) (IOTC, 2002). Length measurement used a modified aluminum caliper up to 2 meters long, with 0.5 cm precision. Individual dressed weight (DW) was recorded to the nearest kilogram. Weight and length were fitted by 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, we used Student's t-test for testing the hypothesis H_0: β=3 (isometric) and H_1: β≠3 (allometric).

Given the assumption of fish, dynamics is under an equilibrium state, and the stocks are shared in both waters. The growth parameters (K, L_∞, t_o) was analyzed by using ELEFAN I which is accommodated in the software FISAT II. The rate estimation of total mortality (Z) was analyzed by using the length-converted catch curve (Sparre and Venema 1998; Gayanilo and Pauly 2001). Analysis of the rate of natural mortality (M) use the empirical equation of Pauly. All the methods are accommodated in the soft-ware FISAT II. Age at the change in growth rate (t_{tp}) was predicted using Alverson and Carney’s methods (Merta, 1993). Analysis of the length of the first capture is conducted by standard logistics method of Spearman-Karber.

3. Results

3.8. Catch-at-size distribution

The length of yellowfin tuna from WPP 573, are caught ranging from 78 – 185 cm. Based on monthly data, shows that yellowfin tuna caught from the Indian Ocean, from 2013 to 2017, consisted of 2 cohorts. The dominant length caught ranges from 140 - 155 cmFL (Figure 2). Yellowfin tuna that is above 100 cmFL is more than 95%. Indicates that caught yellowfin tuna are dominated by adult fish.

The seasonality of yellowfin tuna length from the tuna longline is illustrated in Figure 3, where sizes have been grouped by quarter.

In January-March the fish caught two cohorts with a mode of 115 cmFL and between 145-155 cmFL. In the April-June period, the cohort with 115 cmFL mode was drastically reduced, and the cohort with the 150 cmFL mode became dominant. In the 3rd quarter, the small cohort reappeared in 120 cmFL mode, while the large cohort shifted to 155 cmFL. While in the 4th quarter, the small cohort was replaced with a new cohort measuring 95 cmFL mode, and a large fish cohort with a mode of 145-150 cmFL.

3.9. Length at first capture (L_c)

The calculation of the first length capture yellowfin used analisys of standard logistic from Spearman-Karber, which obtained a value of 137.5 cmFL (Figure 4).

3.10. Length-weight relationship

Length-weight relationship of yellowfin tuna in FMA 573 of the Indian Ocean was identified as non-linear regression model with power function, $W = 0.000052 * FL^{2,78}$ (Figure 2). Results of the t-test, the value of the slope (b) did not differ by 3. Thus, the growth pattern identified as isometric, which the length aligned proportionally with the accretion of weight.

3.11. Recruitment Pattern

The results of the analysis indicated that the recruitment of yellowfin tuna occurred almost throughout the year, with the peak occurred in May (Figure 4).

3.12. Growth Parameters

Von Bertalanffy growth equation of yellowfin tuna was estimated based on the data in 2013, 2014, 2015 and 2017. The analysis showed L_∞ was 194,25 cmFL, the value of K was

0.51 yr^{-1}, and t_o was -0.1889 year. Based on these parameters, the von Bertalanffy growth equation yellowfin tuna is Lt = 194,25 (1 - e $^{-0,51(t + 0.1889)}$). Table 1 shows the relationship between the length and age yellowfin tuna. The von Bertalanffy curve (Figure 5) showed that the growth rate of the fish is faster when the fish is still as young, approximately 0-2years of age. It is then declining until reach stable length size (L_∞). The change point of the growth rate (t_{tp}) was at the age of 2.47 years with of 124.4 cmFL lengths.

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

Length cmFL)	Age (yr)
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

3.13. Mortality Rate

Based on the value of K and L_∞, the total mortality rate was obtained by Length Converted Catch Curve (LVCC) inside the FiSAT II package. Total mortality rate (Z) was estimated at 2.27 yr^{-1}. Based on Pauly empirical equations, with an annual average temperature (T) = 28,56°C, the natural mortality (M) was estimated at 0.69 yr^{-1}. Thus, the mortality rate of fishing (F) can be estimated by subtracting Z and F, resulting in 1.58 $year^{-1}$ (Figure 6). Based on these results, it can be seen that the determinants of mortality are caused by fishing.

3.14. Exploitation rate

The total mortality rate can be used to predict the level of utilization of fish in its waters. The level of exploitation of yellowfin tuna in FMA 573 of the Indian Ocean waters is 0.7 (Figure 6). The rate of exploitation has been exceedingly high (overexploited), because it has crossed the line of optimum utilization, $E_{opt} = 0.50\ yr^{-1}$.

4. Discussion

The length range of fish caught during the years 2013-2017 was 78 – 185 cmFL. In general, it appears that the catch from FMA 573 of the Indian Ocean waters consists of two cohorts. Based on the monthly average, a small-sized YFT cohort with modes between 95 and 120 cmFL, the number is relatively small. Small-sized YFT recruits from October/November/December. In the following month, January/February/March their size increased to 100-115 cmFL. The second cohort, the large YFT, mode ranges from 140-160 cmFL, and the size is dominant throughout the year.

Research conducted by Rohit *et al*. (2012) on the east coast of India obtained yellowfin length range between 20-185 cmFL, whereas in the Sea of Oman lengths ranged between 37-172 cmFL. Zuidare *et al*. (2010) reported the length of yellowfin caught in the central and western Indian Ocean ranged between 30-161 cmFL. It shows that the fish caught in the FMA 573 of the Indian Ocean waters is larger than the three waters but smaller than the fish caught in the Pacific Ocean which ranged between 93-167 cmFL (Zhu, 2011). In the Banda Sea, Haruna et al. (2018) reported yellowfin tuna caught by Handline measuring 25-178 cm FL, which was dominated by medium-large size group with the total of catching 71%. The research in in the waters of Simeulue Islands, Aceh results showed that fork length of Yellowfin tuna was 45.5-111.5 cm (Burhanis et al. 2017). According to the description, yellowfin tuna caught by longline tuna in the Indian Ocean are larger in other waters.

Length-weight relationship of yellowfin tuna in FMA 573 of the Indian Ocean obtained by the equation $W = 0.000052 * FL^{2.78}$. The value of the slope (b) of the equation is 2.78, and a = 0.000052. Based on t-test to b, the value is different from 3. It means that growth is negative allometric, meaning the growth in length faster than weight. The results obtained from the research Zhu, *et al.* (2010) are allometric negative (b <3) in the Atlantic Ocean and the Pacific Ocean to the east and the Indian Ocean (Zhu *et al*., 2010; Andamari *et al*., 2012; Miazwir, 2012). Muhammad & Barata (2012) research in the Indian Ocean and Zhu, *et al*. (2010) in the Pacific Ocean resulted in positive allometric (b> 3). Different growth patterns may be due to differences in the size composition of the fish caught. The composition of fish catches is dominated by small fish; the growth pattern will tend to be allometric negative ($b < 3$). On the contrary, the composition dominated by catches of large fish is likely to be positive allometric ($b > 3$).

The length of fish first caught (L_c) is 137,5 cmFL. To ensure continuity and sustainability of yellowfin tuna, then L_c should be greater than or equal to L_m (the length of the first mature gonads). According to Zhu *et al.* (2008), the length of 50% yellowfin tuna caught mature gonad is 100 cmFL. FAO (2010) states that mature gonad size yellowfin tuna caught in the Indian Ocean is in the range of 100-110 cmFL at the age of 2.5 - 3 years. This is in contrast with the results of Romena (2000) stating that the gonads mature of yellowfin tuna is between 75.9 to 134.5 cmFL. Yellowfin tuna from the Pacific Ocean waters reaches the length of first mature on 108 cmFL (McPherson, 1991), and it reaches 92 cmFL in the Eastern Pacific Ocean. Haruna et al. (2017) in reported the length of yellowfin mature gonads in the in the Banda Sea, Indonesia is 115,2 cmFL. Based on these descriptions, it indicates that yellowfin tuna caught in the FMA 573 of the Indian Ocean in 2013-2017 has largely been spawned, so it does not result in growth and overfishing recruitment.

Yellowfin tuna growth parameters reach 194,25 cmFL asymptotic lengths (L_∞), while index growth curve (K) is 0.51, and t_o was -0.1889 yr. The L_∞ value is greater than that obtained by Zhu *et al.* (2011) in the East and the West Pacific Ocean, which is 175.9 cmFL, with grades K is 0.52 yr^{-1}. Kar *et al.* (2012) reported his research in Indian waters get 173.3 cmFL L_∞ value, with K value is 0.39. Research Haruna *et al.* (2018) in the Banda Sea, Indonesia reported the coefficient of growth rate (K) = 0.31, L_∞ = 215 cmFL, and t_o is -0.311. While Burhanis *et al.* (2017) reported that L_∞ and K value was 117.08 cmFL and 0.93, respectively, and t_o is -0.10 years. Tumulyadi *et al.* (2019) in the Indian Ocean (Case south of Malang) obtained a K value of 0.20, and L_∞ 178.95 cmFL. While Nurdin *et al.* (2016) in Palabuhanratu waters, west Java (eastern Indian Ocean) was estimated at $L\infty$ = 178 cm fork length (cmFL), K value was 0.47, and t_o = -0.213 year. It shows that the size of yellowfin tuna in FMA 573 of the Indian Ocean can grow larger than the yellowfin tuna from the Pacific Ocean and the Indian waters. This condition is expected due to the higher capacity of waters for yellowfin tuna.

Table 2. Results of growth parameters research using length frequencies in various waters

L_∞ (cmFL)	K (yr^{-1})	t_o (years)	Location	References
137,5	0.51	-0.1889	FMA 573 of Indian Ocean waters	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 a*l.2003.
175.9	0.54		East and the 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

Total mortality rate (Z) of the yellowfin is 2.027yr^{-1}, natural mortality (M) is 0.69 yr^{-1}, so that the fishing mortality is 1.58 yr^{-1}. The Z value is smaller than that obtained by (Hartaty and Ririk, 2014) in the Indian Ocean which was 2.16 yr^{-1}, and 2.04 yr-1 in the Oman Sea (Kaymaram, 2014). Burhanis *et al.* (2017) in the waters of Simeulue Islands, Aceh Indonesian showed total mortality (Z) of 2.11 yr^{-1}. Research Tumulyadi *et al*. (2019) in the Indian Ocean (South arrest case of Malang Regency) obtained total mortality (Z) of 1.32 yr^{-1}, Nurdin *et al.* (2016), in Palabuhanratu waters, west Java (eastern Indian Ocean) reported the total mortality rate (Z) estimated was 1,27 yr^{-1}. *Haruna et al.* (2018) in the Banda Sea, Indonesia obtained total of mortality rate (Z) 1.47 yr^{-1}.

The natural mortality yellowfin tuna this research is 0.69 yr^{-1}. Nurdin *et al.* (2016) reported that the natural mortality rate in Palabuhan Ratu waters, West Java (eastern Indian Ocean) was 0.66 $year^{-1}$. Hartaty and Ririk (2014) reported the results of their research in the Indian Ocean obtained 0.54 yr^{-1} M value. Research conducted by Kar *et al*. (2012) in the Andaman Sea resulted in 0.51 yr^{-1} M value, whereas in the Pacific Ocean it reached 0.65 yr^{-1}, and in the Sea of Oman, it reached by 0.48 $year^{-1}$ (Kaymaram *et al.*, 2014. Zhu *et al.* (2011) research in the Pacific Ocean also resulted in 0.65 $year^{-1}$ M value. While Burhanis *et al*. (2017) reported the research in the waters of Simeulue Islands, Aceh Indonesia showed natural mortality of 1.22 yr^{-1}. Based on various studies, it can be seen that the natural mortality rate (M) of yellowfin tuna varies in the investigated waters. However, it shows that the natural mortality rate in this study has shown relatively higher than other waters, but still lower than Aceh waters (FMA 572).

Fishing mortality rate (F) Yellowfin tuna this research is 1.58 yr^{-1}. Kaymaran *et al.* (2013) in the Oman Sea obtained F is 1,56 yr^{-1}. Tumulyadi et al. (2019) in the Indian Ocean (Southern Malang Regency) reported ilia F of 1.02 yr^{-1}. Nurdin *et al.* (2016) in Palabuhanratu waters, west Java (eastern Indian Ocean) obtained fishing mortality rate (F) of 0.66 yr^{-1}. Burhanis *et al.* (2019) in the waters of Simeulue Islands, Aceh Indonesia reported F is 0,89 yr^{-1}. Haruna *et al.* (2018) obtained an F of 0.98 yr^{-1} in the Banda Sea, Indonesia. According to the description, the fishing mortality of yellowfin tuna in Indian Ocean waters this research is relatively higher than in other waters.

Sparre and Venema (1998) showed high F indicates overfishing on fish stocks in the waters. The assumption is that sustainable production was obtained when F = M and rate of exploitation is (E) = F/Z = 0.5 (Gulland, 1971). The results obtained by the exploitation rate is 0.70. It indicates that fishing effort of yellowfin tuna in FMA 573 of the Indian Ocean get more exploitation. It is consistent with the IOTC (2014), which states that the stock status of yellowfin tuna in the Indian Ocean was overfishing (overexploited). Various studies of yellowfin tuna from various waters have also shown overfishing. Haruna *et al*. (2018) in the Banda Sea, Indonesia obtained exploitation rate (E) of 0.67 year; Tumulyadi *et al.* (2019) in the Indian Ocean (South of Malang Regency), exploitation rate (E) of 0.77. Kaymaran (2014) in the Oman Sea, the exploitation ratio (E) was 0.76. The results of Komnas Kajiskan study in

2017 showed that the exploitation rate of large pelagic fish (including yellowfin tuna) has reached E = 1.06.

Based on the facts described earlier, it can be stated that overfishing is not the result of the number of small fish caught, or the number of mothers caught, but because of the exposure of MSY. Instead, it is due to production that exceeds the level of MSY. Therefore, since tuna live in broad waters and does not recognize the territory of a country, tuna fisheries management requires a joint effort between the local government, provincial, national governments, as well as regional fisheries organizations. Martosubroto (2012), confirms that the monitoring of fishing includes surveillance of the fishing fleet, the type, and size of fishing gear, as well as the number, type, and size of the catch. All data and information related to this would be the basic data for the preparation of a Fisheries Management Plan (FMP), which is needed to ensure fisheries sustainability.

5. Conclusion

The conclusions of this study are:

6. Structure of yellowfin tuna size caught by longline tuna in the FMA 573 of the Indian Ocean ranged between 78 – 185 cmFL.
7. The length of capture (L_c) is 137,5 cmFL bigger than L_m, meaning yellowfin tuna stocks are not growth overfishing, and new stock can be guaranteed.
8. The growth pattern of Yellowfin tuna is based on Von Bertalanffy equation i.e. L_t = 194,25 $(1 – e^{-0.51\ (t+0,1889)})$.
9. The total mortality rate (Z) is 2,27 yr^{-1}, the rate of natural mortality (M) is 0.69 yr^{-1}, and the rate of fishing mortality (F) is 1.58 yr^{-1}, means that more mortality Yellowfin tuna is caused by fishing.
10. The level of exploitation of 0.7, the show has exceeded the optimum exploitation rate, indicates that the amount of fish biomass harvested is greater than the ability of the waters to produce new biomass.

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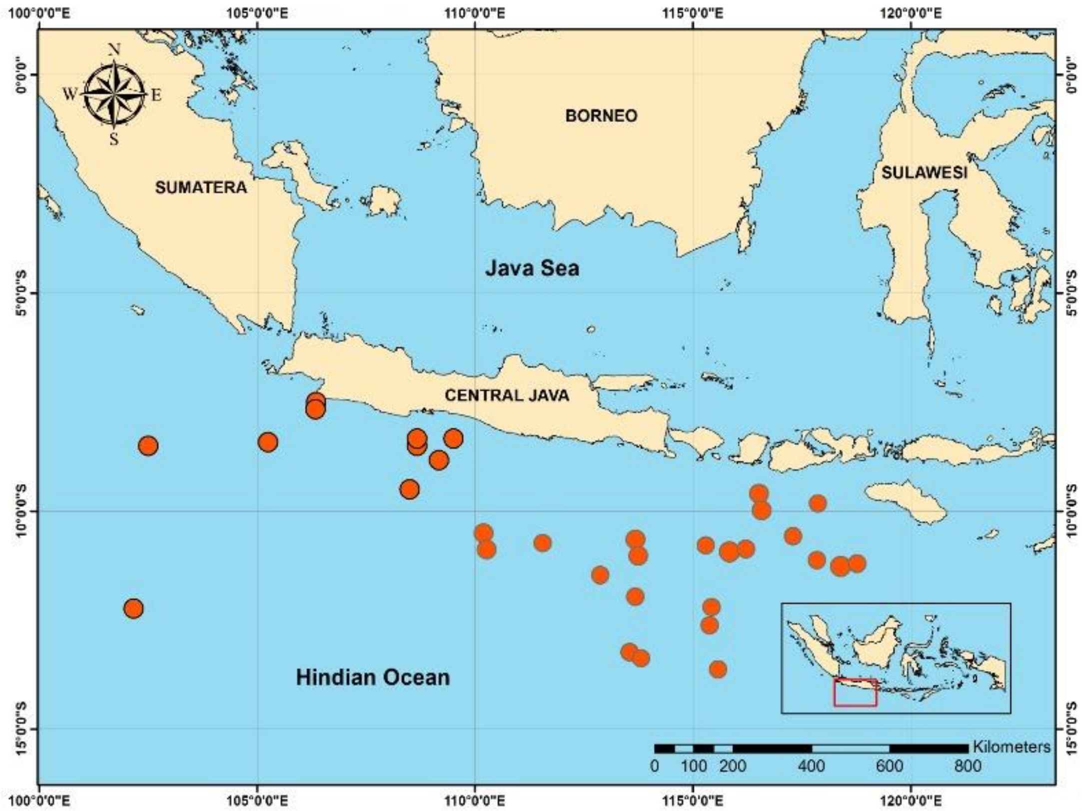
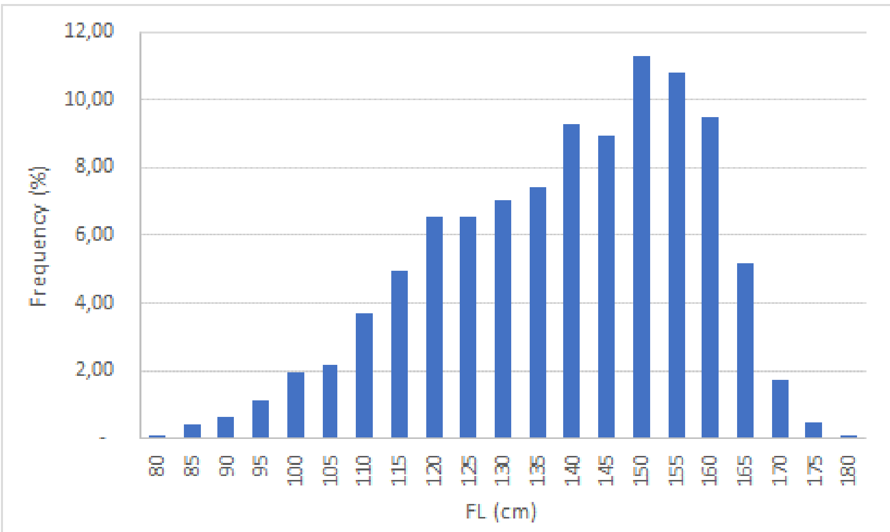


Figure 1. The effort distribution of yellowfin tuna from the Tuna longline vessels based in the Port of Benoa, Bali and PPN Cilacap, Central Java. *(Source: LP2T scientific observer data 2013 – 2017.)*

Figure 2.



Length frequency distribution on monthly of yellowfin tuna in 573 FMA of the Indian Ocean.

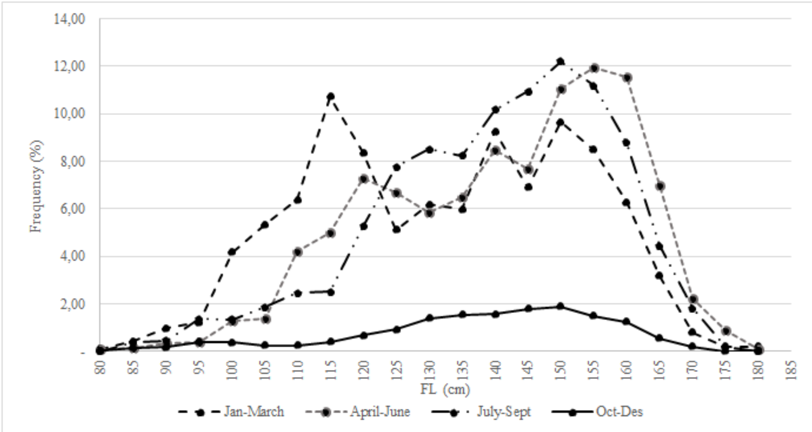


Figure 3. Length frequency distribution of yellowfin tuna taken by tuna longline in the Indian Sea (2013-17)

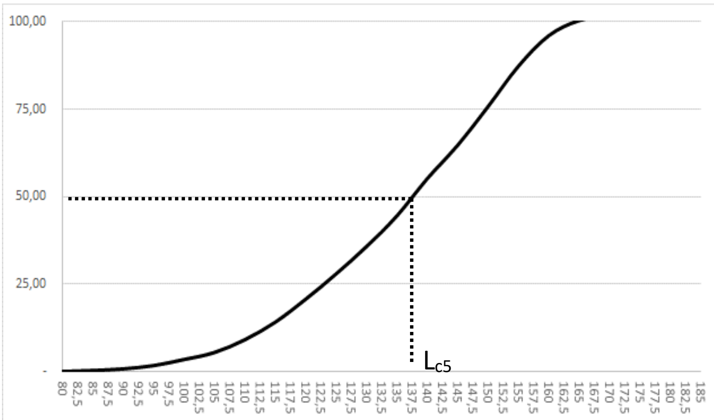


Figure 4. The curve $L_{50\%}$ of yellowfin tuna in FMA 573 of the Indian Ocean waters

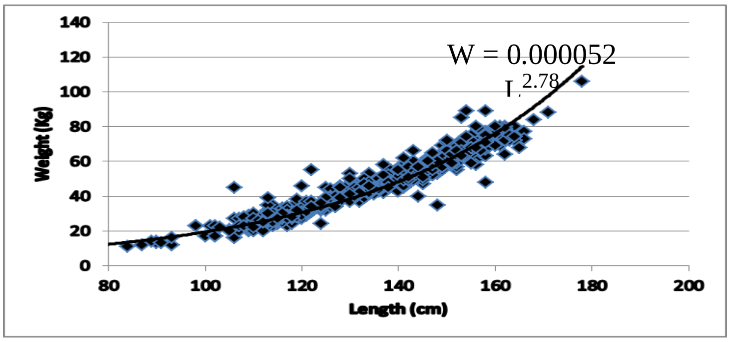


Figure 5. The length-weight relationship model of yellowfin tuna in 573 FMA of the Indian Ocean waters.

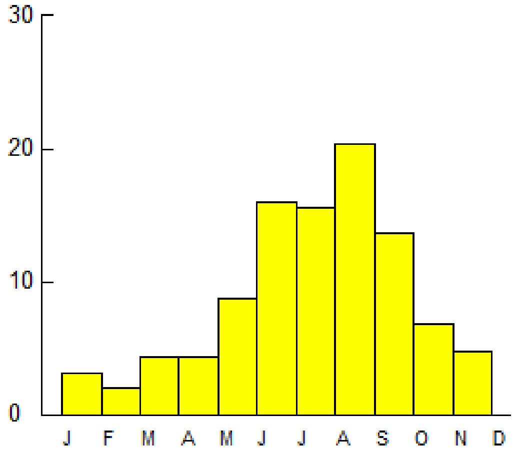


Figure 6. Recruitment pattern of yellowfin tuna in the Indian Ocean south of Java, Bali and Nusa Tenggara (FMA 573).

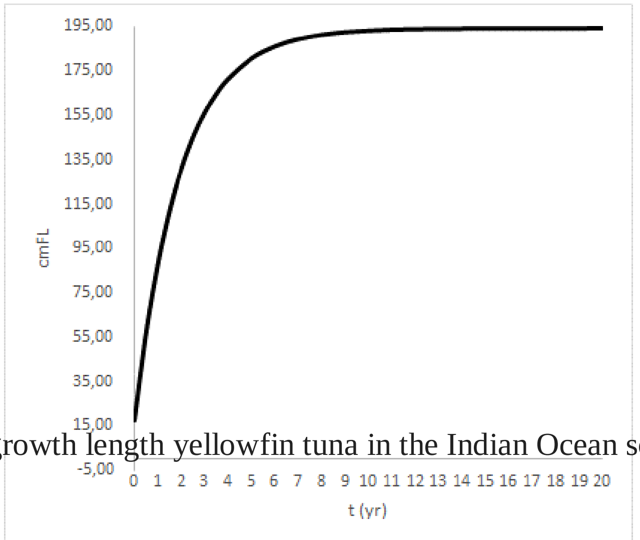


Figure 7. Curve of growth length yellowfin tuna in the Indian Ocean south of FMA 573 in 2013-2017.

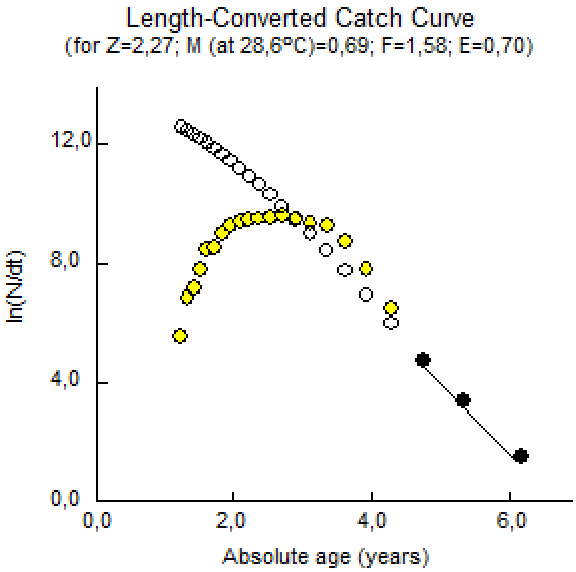


Figure 8. Catch curve converted to length data of yellowfin tuna in the Indian Ocean south of Java, Bali, and Nusa Tenggara (FMA 573) waters.

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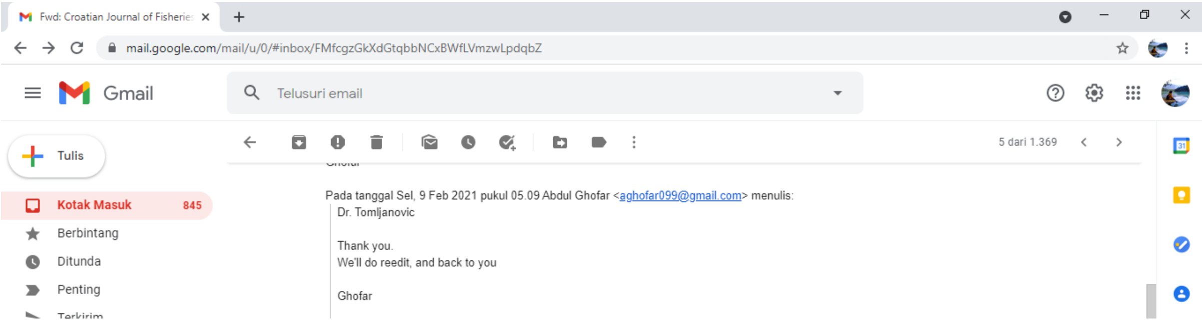

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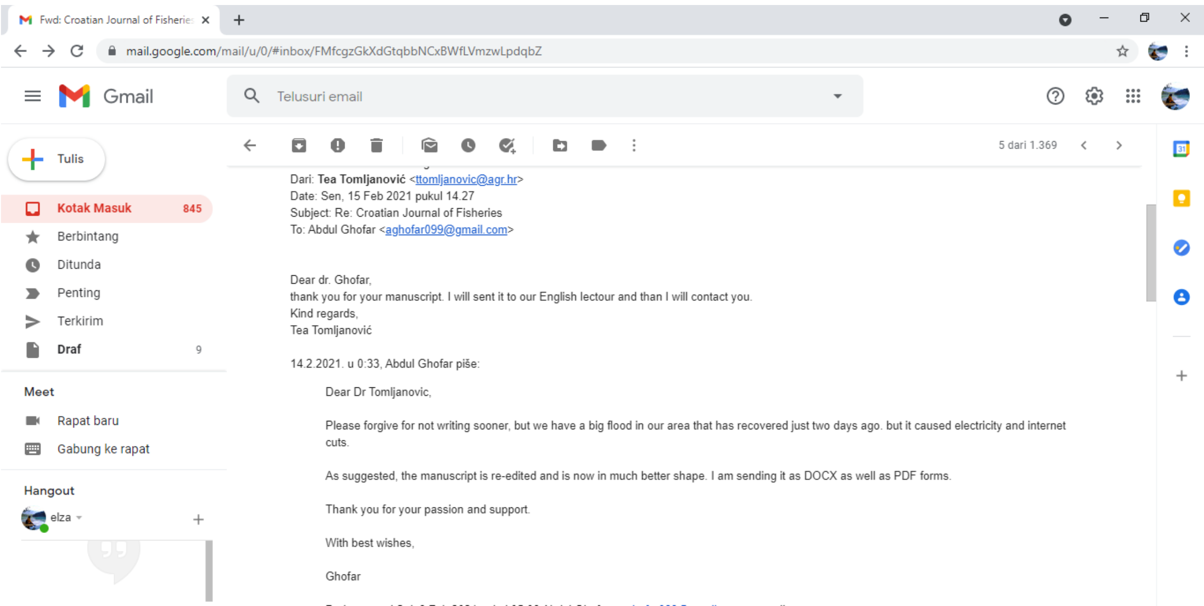

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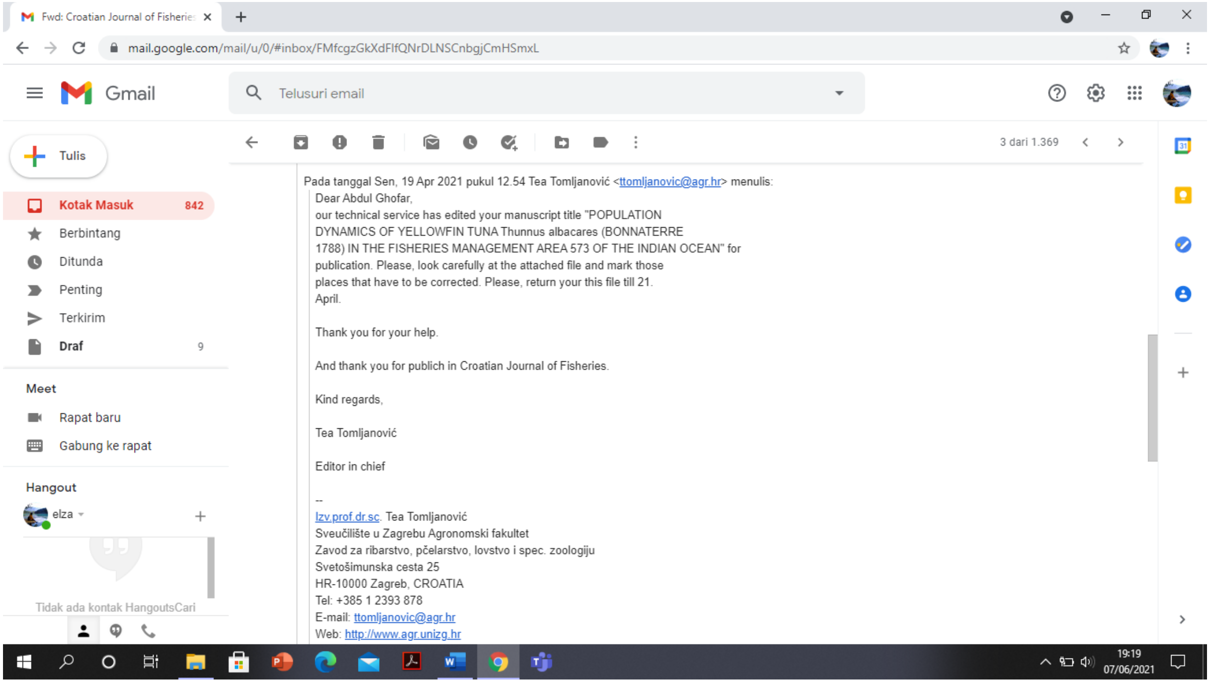

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Population Dynamics of Yellowfin Tuna (*Thunnus albacares* Bonnaterre 1788) in Fisheries Management Area (FMA) 573 of the Indian Ocean

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Abstract

Yellowfin tuna (*Thunnus albacores*) is one of the dominant species of tuna caught in Fisheries Management Area (FMA) 573 of Indian Ocean off Indonesia. Its production amounted to 35.83% of the total production of tuna in 2013. The study was conducted to assess the population dynamics of yellowfin tuna in FMA (FMA)573 of Indian Ocean, based on length frequency data 2013-2017. analysed using the software FiSAT II. The results obtained shows length-weight relationship of $W = 0.000052 * FL^{2,78}$, with allometric growth pattern. The length at first capture was 140 cm FL. Recruitment season occurs in July to September, with peak in August. The von Bertalanffy growth equation was estimated as $Lt = 194,25 (1-e^{-0.51 (t + 0.1889)})$. 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}. Exploitation rates of the Yellowfin tuna were estimated to be 0.70, indicating that it has exceeded the optimum exploitation rate (E = 0.5), thus overexploitation occurs.

Keyword: Thunnus albacores; population dynamics, FMA, growth pattern, mortality rate, exploitation rate, effort distribution, length-weight relationship, Indian Ocean,

1. Introduction

The Indian Ocean south off Java, Bali and Nusa Tenggara which are included in FMA 573 have been potentially known for its tuna resources (Novianto et al, 2016; Widodo and Mahulete, 2012). The main target species are bigeye tuna (*Thunnus obesus*), albacore (*T. alalunga*), bluefin tuna (*T. maccoyii*) and yellowfin tuna (*T. albacares*). This research focused on yellowfin tuna since it is the most dominant species and can be found in FMA 573. Research

Institute for Tuna Fisheries (LP2T)'s Annual Report (2013) suggested that the catch composition of longline tuna in the port of Benoa, Bali was dominated by yellowfin tuna. The amount of tuna export market demand led to increased exploitation that could threaten the sustainability of tuna resources (Gillett, 2009). The exploitation of yellowfin tuna in the Indian Ocean in 2011- 2014 has increased. It is indicated by the increasing number of catches from 329,184 tons in 2011 to 430,327 tons in 2014 according to the stock assessment by Indian Ocean Tuna Commission (IOTC) in 2015. Therefore, the study of population dynamics is very important. This study aims to assess the length-weight relationship, growth pattern, the optimum size caught, the parameters of population growth, recruitment patterns, the mortality and the exploitation rates of yellowfin tuna.

2. Material and Methods

The data used for the analysis of length-weight relationship was collected during April and May 2016, with 753 total specimens. The length frequency data was obtained from daily landing in tuna longline activity operating in FMA 573 (Figure 1) during 2013-2014 (report of Research Institute for Tuna Fisheries (LP2T). The definition of length used in this study is the length of the mouth to the tip of the central tail fin indentation (fork length) (IOTC, 2002). Length measurement used a modified aluminium calliper up to 2 meters long, with 0.5 cm precision. Individual dressed weight (DW) was recorded to the nearest kilogram. Weight and length were fitted by 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 $b\neq3$, we used Student's t-test for testing the hypothesis H_0: $\beta=3$ (isometric) and H_1: $\beta\neq3$ (allometric).

Assumption is that fish dynamics is under an equilibrium state, and the stocks are shared in both waters. The growth parameters (K, L_∞, t_o) was analyzed using ELEFAN I which is accommodated in the software FISAT II. The rate of total mortality (Z) was estimated using the length-converted catch curve (Sparre and Venema 1998; Gayanilo and Pauly 2001). Analysis of the rate of natural mortality (M) use the empirical equation of Pauly. All the methods are accommodated in the soft-ware FISAT II. Age at the change in growth rate (t_{tp}) was predicted using Alverson and Carney's methods (Merta, 1993). Analysis of the length of the first capture is conducted by standard logistics method of Spearman-Karber.

3. Results

3.15. Catch-at-size distribution

The length range of yellowfin tuna from WPP 573 caught was 78 – 185 cm. Based on monthly data, shows that yellowfin tuna caught from the Indian Ocean, from 2013 to 2017, consisted of two cohorts. The dominant length caught ranges from 140 - 155 cmFL (Figure 2). Yellowfin tuna that is above 100 cmFL is more than 95%. Indicates that caught yellowfin tuna are dominated by adult fish.

The seasonality of yellowfin tuna length from the tuna longline is illustrated in Figure 3, where sizes have been grouped by quarter.

In January-March the fish caught two cohorts with a mode of 115 cmFL and between 145-155 cmFL. In the April-June period, the cohort with 115 cmFL mode was drastically reduced, and the cohort with the 150 cmFL mode became dominant. In the 3rd quarter, the small cohort reappeared in 120 cmFL mode, while the large cohort shifted to 155 cmFL. While in the 4th quarter, the small cohort was replaced with a new cohort measuring 95 cmFL mode, and a large fish cohort with a mode of 145-150 cmFL.

3.16. Length at first capture (L_c)

The length at first capture of yellowfin was analysed using standard logistic from Spearman-Karber, which obtained a value of 137.5 cmFL (Figure 4).

3.17. Length-weight relationship

Length-weight relationship of yellowfin tuna in FMA 573 of the Indian Ocean was identified as non-linear regression model with power function, $W = 0.000052 * FL^{2,78}$ (Figure 2). Results of the t-test, the value of the slope (b) did not differ from 3. Thus, the growth pattern identified as isometric, in which the length aligned proportionally with the accretion of weight.

3.18. Recruitment Pattern

The results of the analysis indicated that the recruitment of yellowfin tuna occurred almost throughout the year, with peak occurring in May (Figure 4).

3.19. Growth Parameters

Von Bertalanffy growth equation of yellowfin tuna was estimated based on the data in 2013, 2014, 2015 and 2017. The analysis showed L_∞ was 194,25 cmFL, the value of K was

0.51 yr^{-1}, and t_o was -0.1889 year. Based on these parameters, the von Bertalanffy growth equation yellowfin tuna is $Lt = 194{,}25\ (1 - e^{-0{,}51(t\ +\ 0.1889)})$. Table 1 shows the relationship between the length and age yellowfin tuna. The von Bertalanffy curve (Figure 5) showed that the growth rate of the fish is faster when the fish is still as young, approximately 0-2 years of age. It then declined until reach stable length size (L_∞). The change point of the growth rate (t_{tp}) was at the age of 2.47 years with of 124.4 cmFL length.

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

Length cmFL)	Age (yr)
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

3.20. Mortality Rate

Based on the value of K and L_∞, the total mortality rate was obtained by Length Converted Catch Curve (LVCC) inside the FiSAT II package. Total mortality rate (Z) was estimated at 2.27 yr^{-1}. Based on Pauly empirical equations, with an annual average temperature (T) = 28,56°C, the natural mortality (M) was estimated at 0.69 yr^{-1}. Thus, the mortality rate of fishing (F) can be estimated by subtracting Z and F, resulting in 1.58 $year^{-1}$ (Figure 6). Based on these results, it can be seen that the determinants of mortality are caused by fishing.

3.21. Exploitation rate

The total mortality rate can be used to predict the level of utilization of fish in repective waters. The level of exploitation of yellowfin tuna in FMA 573 of the Indian Ocean waters is 0.7 (Figure 6). The rate of exploitation has been exceedingly high (overexploited), because it has crossed the line of optimum utilization, $E_{opt} = 0.50\ yr^{-1}$.

4. Discussion

The length range of fish caught during the years 2013-2017 was 78 – 185 cmFL. In general, it indicates that the catch from FMA 573 of the Indian Ocean waters consists of two cohorts. Based on the monthly average, a small-sized YFT cohort with modes between 95 and 120 cmFL, the number is relatively small. Small-sized YFT recruits from October/November/December. In the following month, January/February/March their size increased to 100-115 cmFL. The second cohort, the large YFT, mode ranges from 140-160 cmFL, and the size is dominant throughout the year.

Research conducted by Rohit *et al*. (2012) on the east coast of India obtained yellowfin length range between 20-185 cmFL, whereas in the Sea of Oman lengths ranged between 37-172 cmFL. Zuidare *et al*. (2010) reported the length of yellowfin caught in the central and western Indian Ocean ranged between 30-161 cmFL. It shows that the fish caught in the FMA 573 of the Indian Ocean waters is larger than the three waters but smaller than the fish caught in the Pacific Ocean which ranged between 93-167 cmFL (Zhu, 2011). In the Banda Sea, Haruna et al. (2018) reported yellowfin tuna caught by Handline measuring 25-178 cm FL, which was dominated by medium-large size group with the total of catching 71%. The research in in the waters of Simeulue Islands, Aceh results showed that fork length of Yellowfin tuna was 45.5-111.5 cm (Burhanis et al. 2017). According to the description, yellowfin tuna caught by longline tuna in the Indian Ocean are larger in other waters.

Length-weight relationship of yellowfin tuna in FMA 573 of the Indian Ocean obtained by the equation $W = 0.000052 * FL^{2.78}$. The value of the slope (b) of the equation is 2.78, and a = 0.000052. Based on t-test to b, the value is different from 3. It means that growth is negative allometric, meaning the growth in length faster than weight. The results obtained from the research Zhu, *et al.* (2010) are allometric negative (b <3) in the Atlantic Ocean and the Pacific Ocean to the east and the Indian Ocean (Zhu *et al*., 2010; Andamari *et al*., 2012; Miazwir, 2012). Muhammad & Barata (2012) research in the Indian Ocean and Zhu, *et al*. (2010) in the Pacific Ocean resulted in positive allometric (b> 3). Different growth patterns may be due to differences in the size composition of the fish caught. The composition of fish catches is dominated by small fish; the growth pattern will tend to be allometric negative (b <3). On the contrary, the composition dominated by catches of large fish is likely to be positive allometric (b> 3).

The length of fish first caught (L_c) is 137,5 cmFL. To ensure continuity and sustainability of yellowfin tuna, then L_c should be greater than or equal to L_m (the length of the first mature gonads). According to Zhu *et al.* (2008), the length of 50% yellowfin tuna caught mature gonad is 100 cmFL. FAO (2010) states that mature gonad size yellowfin tuna caught in the Indian Ocean is in the range of 100-110 cmFL at the age of 2.5 - 3 years. This is in contrast with the results of Romena (2000) stating that the gonads mature of yellowfin tuna is between 75.9 to 134.5 cmFL. Yellowfin tuna from the Pacific Ocean waters reaches the length of first mature on 108 cmFL (McPherson, 1991), and it reaches 92 cmFL in the Eastern Pacific Ocean. Haruna et al. (2017) in reported the length of yellowfin mature gonads in the in the Banda Sea, Indonesia is 115,2 cmFL. Based on these descriptions, it indicates that yellowfin tuna caught in the FMA 573 of the Indian Ocean in 2013-2017 has largely been spawned, so it does not result in growth and overfishing recruitment.

Yellowfin tuna growth parameters reach 194,25 cmFL asymptotic lengths (L_∞), while index growth curve (K) is 0.51, and t_o was -0.1889 yr. The L_∞ value is greater than that obtained by Zhu *et al*. (2011) in the East and the West Pacific Ocean, which is 175.9 cmFL, with grades K is 0.52 yr^{-1}. Kar *et al.* (2012) reported his research in Indian waters get 173.3 cmFL L_∞ value, with K value is 0.39. Research Haruna *et al.* (2018) in the Banda Sea, Indonesia reported the coefficient of growth rate (K) = 0.31, L_∞ = 215 cmFL, and t_o is -0.311. While Burhanis *et al.* (2017) reported that L_∞ and K value was 117.08 cmFL and 0.93, respectively, and t_o is -0.10 years. Tumulyadi *et al*. (2019) in the Indian Ocean (Case south of Malang) obtained a K value of 0.20, and L_∞ 178.95 cmFL. While Nurdin *et al.* (2016) in Palabuhanratu waters, west Java (eastern Indian Ocean) was estimated at $L\infty$ = 178 cm fork length (cmFL), K value was 0.47, and t_o = -0.213 year. It shows that the size of yellowfin tuna in FMA 573 of the Indian Ocean can grow larger than the yellowfin tuna from the Pacific Ocean and the Indian waters. This condition is expected due to the higher capacity of waters for yellowfin tuna.

Table 2. Results of growth parameters research using length frequencies in various waters L_∞ (cmFL)	K (yr^{-1})	t_o (years)	Location	References
137,5	0.51	-0.1889	FMA 573 of Indian Ocean waters	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 a*l.2003.
175.9	0.54		East and the 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

Total mortality rate (Z) of the yellowfin is 2.027yr^{-1}, natural mortality (M) is 0.69 yr^{-1}, so that the fishing mortality is 1.58 yr^{-1}. The Z value is smaller than that obtained by (Hartaty and Ririk, 2014) in the Indian Ocean which was 2.16 yr^{-1}, and 2.04 yr-1 in the Oman Sea (Kaymaram, 2014). Burhanis *et al.* (2017) in the waters of Simeulue Islands, Aceh Indonesian showed total mortality (Z) of 2.11 yr^{-1}. Research Tumulyadi *et al.* (2019) in the Indian Ocean (South arrest case of Malang Regency) obtained total mortality (Z) of 1.32 yr^{-1}, Nurdin *et al.* (2016), in Palabuhanratu waters, west Java (eastern Indian Ocean) reported the total mortality rate (Z) estimated was 1,27 yr^{-1}. *Haruna et al.* (2018) in the Banda Sea, Indonesia obtained total of mortality rate (Z) 1.47 yr^{-1}.

The natural mortality yellowfin tuna this research is 0.69 yr^{-1}. Nurdin *et al.* (2016) reported that the natural mortality rate in Palabuhan Ratu waters, West Java (eastern Indian Ocean) was 0.66 $year^{-1}$. Hartaty and Ririk (2014) reported the results of their research in the Indian Ocean obtained 0.54 yr^{-1} M value. Research conducted by Kar *et al*. (2012) in the Andaman Sea resulted in 0.51 yr^{-1} M value, whereas in the Pacific Ocean it reached 0.65 yr^{-1}, and in the Sea of Oman, it reached by 0.48 $year^{-1}$ (Kaymaram *et al.*, 2014. Zhu *et al.* (2011) research in the Pacific Ocean also resulted in 0.65 $year^{-1}$ M value. While Burhanis *et al*. (2017) reported the research in the waters of Simeulue Islands, Aceh Indonesia showed natural mortality of 1.22 yr^{-1}. Based on various studies, it can be seen that the natural mortality rate (M) of yellowfin tuna varies in the investigated waters. However, it shows that the natural mortality rate in this study has shown relatively higher than other waters, but still lower than Aceh waters (FMA 572).

Fishing mortality rate (F) Yellowfin tuna this research is 1.58 yr^{-1}. Kaymaran *et al.* (2013) in the Oman Sea obtained F is 1,56 yr^{-1}. Tumulyadi et al. (2019) in the Indian Ocean (Southern Malang Regency) reported ilia F of 1.02 yr^{-1}. Nurdin *et al.* (2016) in Palabuhanratu waters, west Java (eastern Indian Ocean) obtained fishing mortality rate (F) of 0.66 yr^{-1}. Burhanis *et al.* (2019) in the waters of Simeulue Islands, Aceh Indonesia reported F is 0,89 yr^{-1}. Haruna *et al.* (2018) obtained an F of 0.98 yr^{-1} in the Banda Sea, Indonesia. According to the description, the fishing mortality of yellowfin tuna in Indian Ocean waters this research is relatively higher than in other waters.

Sparre and Venema (1998) showed high F indicates overfishing on fish stocks in the waters. The assumption is that sustainable production was obtained when F = M and rate of exploitation is (E) = F/Z = 0.5 (Gulland, 1971). The results obtained by the exploitation rate is 0.70. It indicates that fishing effort of yellowfin tuna in FMA 573 of the Indian Ocean get more exploitation. It is consistent with the IOTC (2014), which states that the stock status of yellowfin tuna in the Indian Ocean was overfishing (overexploited). Various studies of yellowfin tuna from various waters have also shown overfishing. Haruna *et al*. (2018) in the Banda Sea, Indonesia obtained exploitation rate (E) of 0.67 year; Tumulyadi *et al.* (2019) in the Indian Ocean (South of Malang Regency), exploitation rate (E) of 0.77. Kaymaran (2014) in the Oman Sea, the exploitation ratio (E) was 0.76. The results of Komnas Kajiskan study in 2017 showed that the exploitation rate of large pelagic fish (including yellowfin tuna) has reached E = 1.06.

Based on the facts described earlier, it can be stated that overfishing is not the result of the number of small fish caught, or the number of mothers caught, but because of the exposure of MSY. Instead, it is due to production that exceeds the level of MSY. Therefore, since tuna live in broad waters and does not recognize the territory of a country, tuna fisheries management requires a joint effort between the local government, provincial, national governments, as well as regional fisheries organizations. Martosubroto (2012), confirms that the monitoring of fishing includes surveillance of the fishing fleet, the type, and size of fishing gear, as well as the number, type, and size of the catch. All data and information related to this would be the basic data for the preparation of a Fisheries Management Plan (FMP), which is needed to ensure fisheries sustainability.

5. Conclusion

The conclusions of this study are: per

11. The structure of yellowfin tuna size caught by longline tuna in the FMA 573 of the Indian Ocean ranged between 78 – 185 cmFL.
12. The length at first capture (L_c) is 137,5 cmFL or larger than L_m, showing that yellowfin tuna stocks do not experience growth overfishing, and new stock can be guaranteed.
13. The growth pattern of Yellowfin tuna is based on Von Bertalanffy equation i.e. $L_t = 194{,}25\ (1 - e^{-0.51\ (t+0{,}1889)})$.
14. The total mortality rate (Z) is 2,27 yr^{-1}, the rate of natural mortality (M) is 0.69 yr^{-1}, and the rate of fishing mortality (F) is 1.58 yr^{-1}, indicating that more mortality Yellowfin tuna is caused by fishing.
15. The level of exploitation of 0.7, showing has exceeded the optimum exploitation rate, indicates that the amount of fish biomass harvested is greater than the biological capability to produce new biomass.

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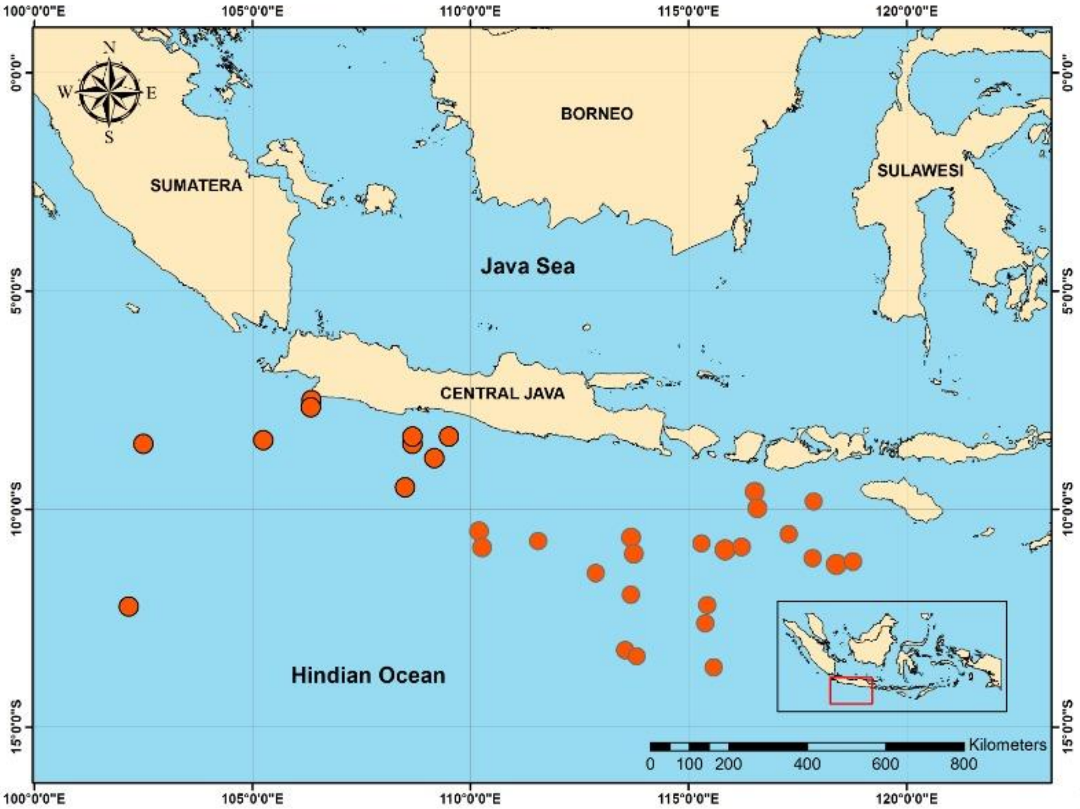

Figure 1. The effort distribution of yellowfin tuna from the Tuna longline vessels based in the Port of Benoa, Bali and PPN Cilacap, Central Java. *(Source: LP2T scientific observer data 2013 – 2017.)*

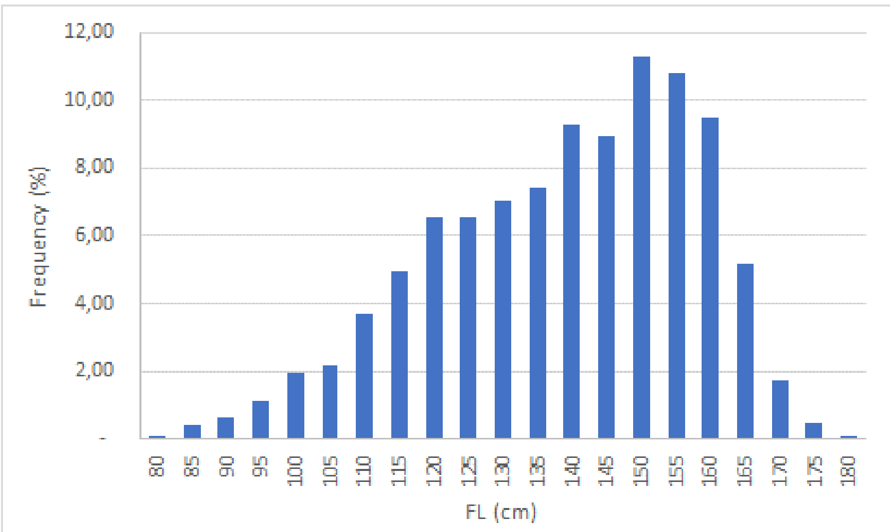

Figure 2. Length frequency distribution on monthly of yellowfin tuna in 573 FMA of the Indian Ocean.

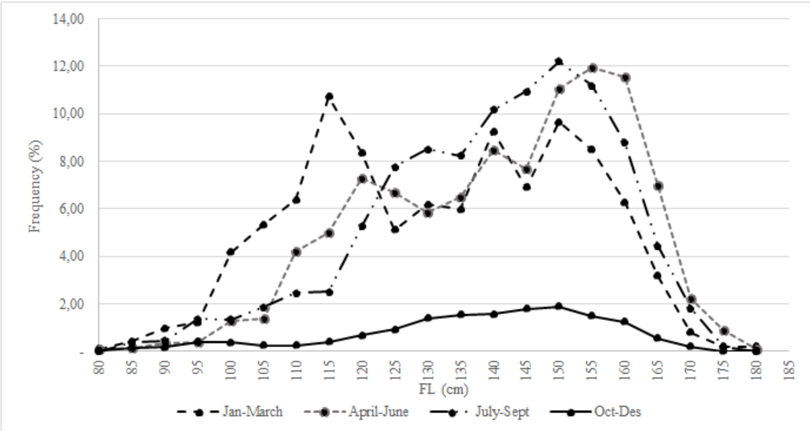

Figure 3. Length frequency distribution of yellowfin tuna taken by tuna longline in the Indian Sea (2013-17)

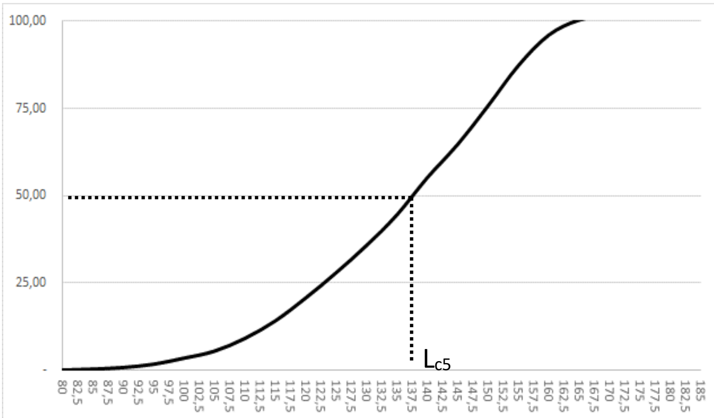

Figure 4. The curve $L_{50\%}$ of yellowfin tuna in FMA 573 of the Indian Ocean waters

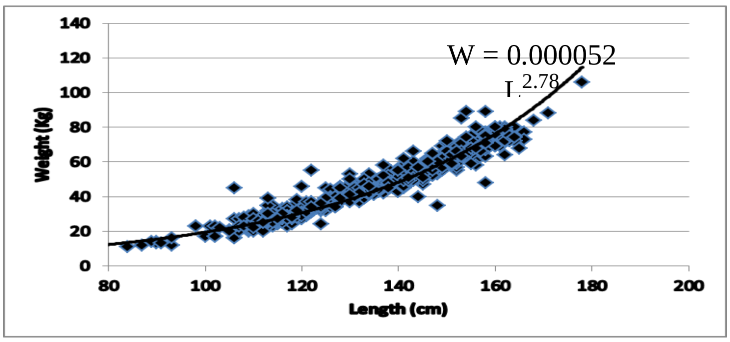

Figure 5. The length-weight relationship model of yellowfin tuna in 573 FMA of the Indian Ocean waters.

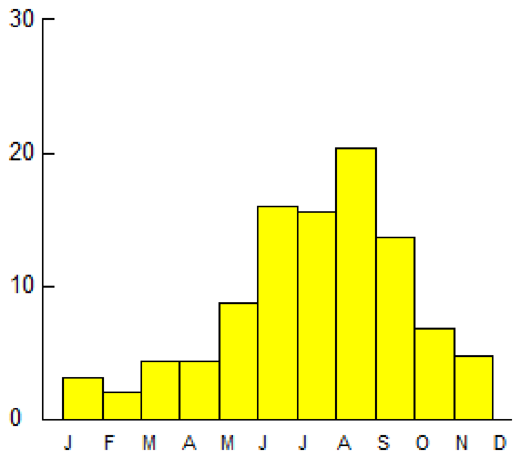

Figure 6. Recruitment pattern of yellowfin tuna in the Indian Ocean south of Java, Bali and Nusa Tenggara (FMA 573).

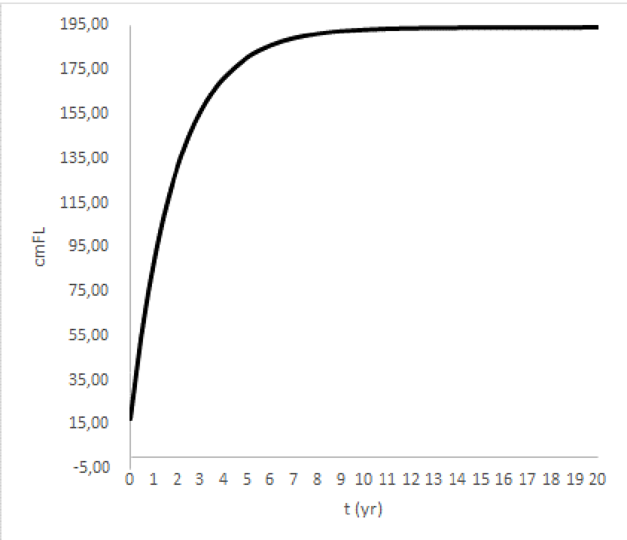

Figure 7. Curve of growth length yellowfin tuna in the Indian Ocean south of FMA 573 in 2013-2017.

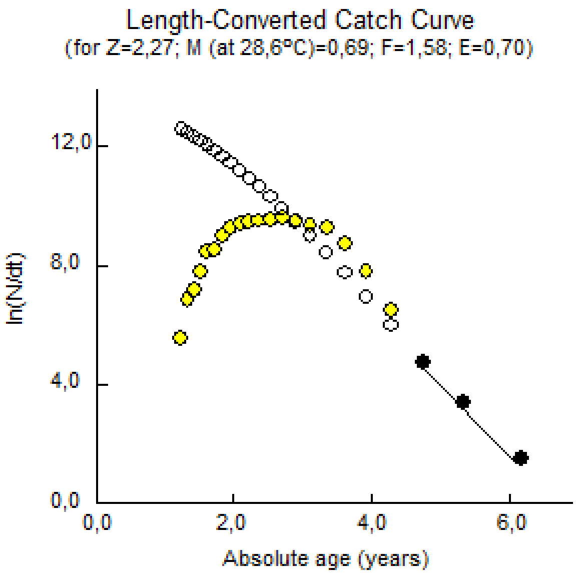

Figure 8. Catch curve converted to length data of yellowfin tuna in the Indian Ocean south of Java, Bali, and Nusa Tenggara (FMA 573) waters.

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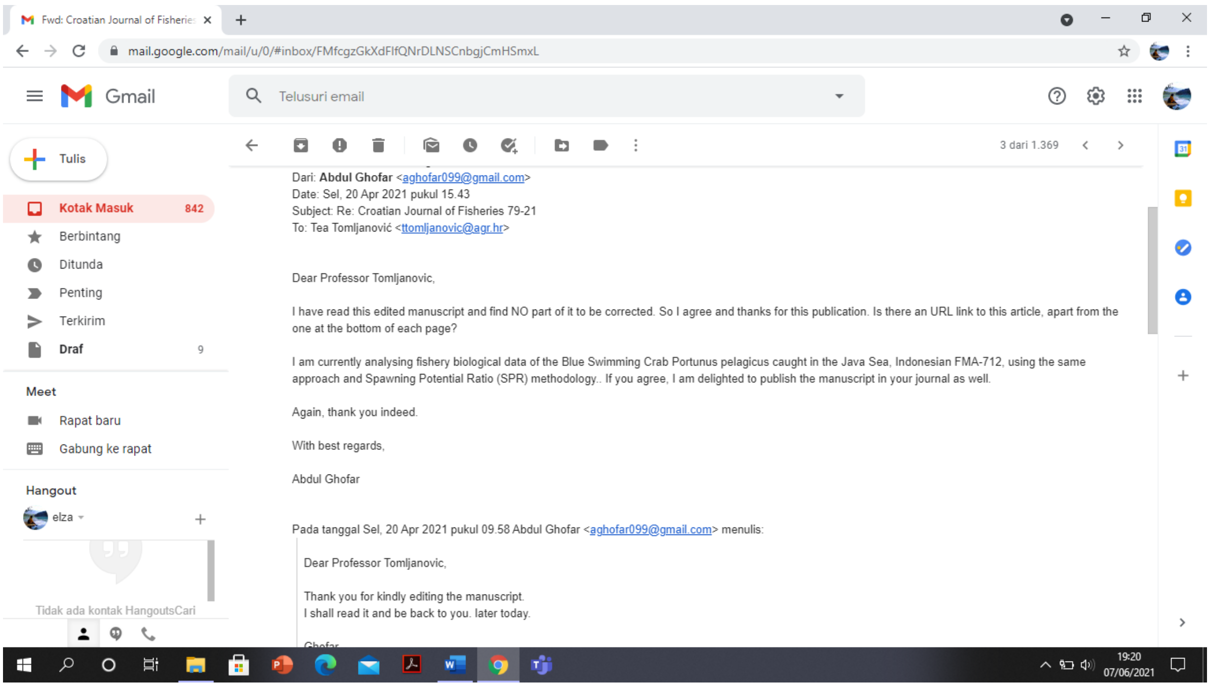

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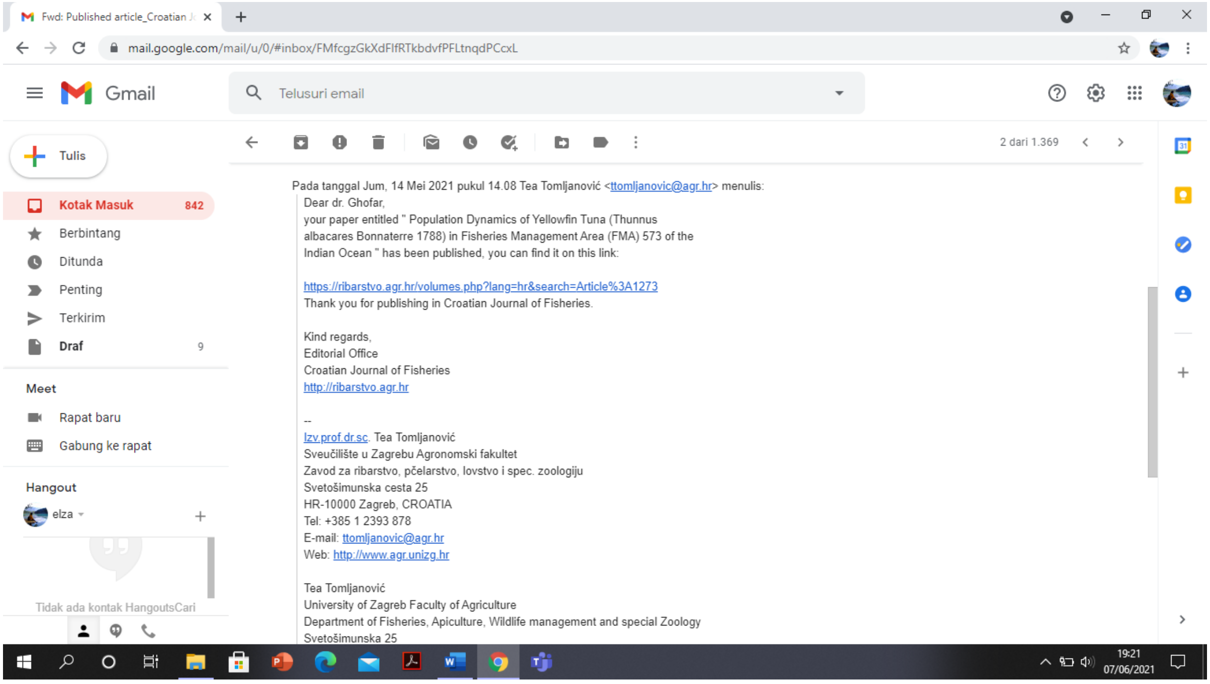

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