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Estimation of population parameters and exploitation rate of the yellowfin tuna in West Morotai Island waters, Indonesia

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ABSTRACT

The Yellowfin tuna is an economically important fish, representing a leading non-oil and gas export commodity in Morotai Island Regency. This species is highly demanded and its exploitation is intensively increasing every year. Thus, the sustainability of its resources is assumed to be under threat. To maintain this status, management efforts are required to regulate the intensity of fishing so that the level of exploitation remains optimal and sustainable. Efforts may include the estimation of population parameters and exploitation level. No documented accurate study or biological information has been recorded on the yellowfin tuna population parameters in West Morotai waters. Consequently, this research focused on the estimation and analysis of the population parameters of yellowfin tuna fish. The current data can provide informative material for local governments, fishery entrepreneurs and fishermen to attain optimal and sustainable management. Data on fish length measurement were recorded during the period from October to December 2020, followed by the analysis of the recorded values of population parameters and the level of the species exploitation using Microsoft Excel and the Physical program II. The population parameters of yellowfin tuna in the study site were as follows: maximum length ($L\infty$= 242 cm), growth coefficient (K= 0.32 per year) and age (t0= -0.41). The rate of total mortality (Z) was 0.79, natural mortality (M) was 0.46 and fishing mortality (F) was 0.33. The current level of exploitation has reached its optimum condition with an estimated value of E 0.42.

INTRODUCTION

Morotai Island Regency is located on the tips of the Pacific Ocean, precisely in the northern part of North Maluku Province at coordinates of 2^o 00 '- 2^o 40' N and 28^o 15 '- 28^o 40' E. It consitutes an area of sea water reaching 1,970.93 km^2 or around 45.82% of the total area. The large area of the sea has a big impact on the diversity and potential of fisheries resources, among which the yellowfin tuna is recognized. Yellowfin tuna or nationally better known as madidihang, with the Latin name Thunnus albacares is an economically significant species and a leading non-oil and gas export commodity that has a high selling price with the amount of production that tends to increase each year, reaching 23,865.89 tonnes per year. in 2020 in the waters of West Morotai Regency **(DKP, 2020)**.

Efforts to increase the amount of yellowfin tuna annual production would have a positive impact on the development of capture fisheries, especially on fishermen's income. Nevertheless, this increase would negatively affect the exploitation pressure on yellowfin tuna resources if it becomes more intensive. Thus, the sustainability of these resources could become under threat, which reuires decisive management to regulate the intensity of catching yellowfin tuna resources so that the level of exploitation remains optimal, sustainable, heading the Maximum Sustainable Yield (MSY) approach and the estimation of population parameters as well as the level of exploitation of fish resources.

Population parameter estimation aims to study the basic changes occuring in the population, such as age group, maximum length, growth rate, mortality rate and exploitation text rate to apply rational and generally quantitative fisheries resource management principles **(Suman *et al*., 2015**; **Lelono *et al*., 2018)**. **Tangke (2014)** spotlighted the significance of knowledge about population parameters since it provides information on the number and size of fish yearly caught by fishermen to maintain the sustainability of fish resources.

The determination of growth parameters is fundamental in assessing the population parameters of fish resources. The current study provides information that can be used to explain resource growth models, the effects of environmental changes and the survival factors that affect recruitment success. Knowledge of age groups and growth is used to estimate the effect of fishing on fish resource stocks with respect to its life cycle and evaluate the maximum catches while considering the sustainability of these fish resources **(Tangke, 2014; Tangke *et al*,. 2018)**.

The sustainability of fishery resources can be maintained by means of fishing management based on information on fish population parameters, with respect to the bio-ecological nature of exploited fish resources **(Tangke, 2014; Tangke *et al*., 2021)**. Until now, no information was recorded on the population parameters of yellowfin tuna in West Morotai waters, so real and accurate information on bio-ecology, especially the yellowfin tuna population parameters, is needed for optimal and sustainable management of these fish resources. In this context, this research was conducted to estimate and analyze the population parameters of yellowfin tuna in West Morotai waters, which can be used as information in optimal and sustainable management of the species under study.

MATERIALS AND METHODS

This research was conducted from May to December 2022 in West Morotai waters (Fig. 1), addressing the catch of yellowfin tuna caught by hand line tuna fishermen. The procedure of research data collection was carried out by measuring the total length of the fish caught by tuna fishermen per fishing trip for 3 months using a meter with a unit (cm) and an accuracy of 1 mm.

The length measurement of yellowfin tuna was performed on all hand line tuna vessels operating by identifying the length of the fish from the forefront of the mouth to the tip of the tail. The data were listed and grouped per trip, and the month of capture was subjected to Microsoft Excel for further analysis of population parameters and displayed in tables and graphs using the Fisat-II software.

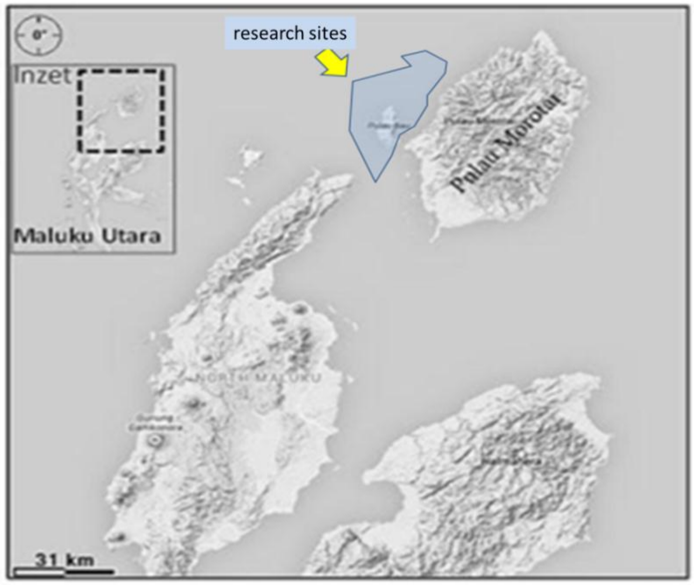

Fig. 1. Map of research data retrieval locations, Morotai Islland, Indonesia

Data Analysis

The population parameters analyzed were:

Identification of age groups, estimation of age groups (cohort), analyzed using the Bhattacharya method of **Sparre and Venema (1999)**, with the following mathematical formula:

$$Fc = \frac{n.dl}{s\sqrt{2\pi}} Exp\left[\frac{-(x-\bar{x})^2}{2s^2}\right]$$

Where: n = number of samples, dl = change in length of fish, s = standard deviation, x= length of yellowfin tuna (i = 1, 2, 3,… n) and $\bar{x}$ = average length of yellowfin tuna.

Growth parameters (L∞, K) and t0 were evaluated; the estimation of growth parameters was carried out using the Ford and Walford method of **Sparre and Venema (1999)**, namely by plotting L (t + Δt) and L (t) with the successive mathematical formula:

$$L(t + \Delta t) = a + b.\ L(t)$$

After getting the regression equation from the two relationships, the linear equation was considered as follows:

$$Y = a + bX, \text{ with } a = L\infty(1-b) \text{ and } b = \exp(-K.\ \Delta t)$$

$$L\infty = \frac{a}{1-b} \quad \text{and} \quad K = \frac{-1}{\Delta t} \text{Ln } b$$

Furthermore, the estimation of the theoretical age was determined. When the length of yellowfin tuna is equal to zero (t_0), the Pauly empirical formula of **Sparre and Venema (1999)** was used, regarding the following mathematical formula:

$$\log(-to) = -0.3922 - 0.2752 \log L\infty - 1.308 \log K$$

Where: Lt = length of fish at age t (unit of time), L_∞ = asymptotic length, K = growth coefficient and t_0 = theoretical age when length equals zero.

For the estimation of natural mortality, the natural mortality rate (M) was estimated using the empirical formula of **Pauly (1983)** as cited in **Sparre and Venema (1999)**, with the following mathematical formula:

$$\ln M = -0.0152 - 0.279 * \ln Ls + 0.6543 * \ln K + 0.463 * \ln T$$

Where: M = natural mortality, L_∞ = asymptotic length, K = growth coefficient and T = mean surface temperature (^oC)

For the estimation of total mortality (Z), it was analyzed using the Baverton and Holt methods of **Sparre and Venema (1999)**, where the mathematical formula used was:

$$Z = K\left[\frac{L\infty - \bar{L}}{\bar{L} - L'}\right]$$

Where: Z = total mortality rate (per year), L∞ = length of yellowfin tuna asymptote (cm), K = growth rate coefficient (per year), $\bar{L}$ = average length of caught yellowfin tuna (mm) and L' = smallest limit of length of fully caught yellowfin tuna (mm).

Estimation of fishing mortality (F) is obtained by the equation:

$$Z = F + M \longrightarrow F = Z - M$$

Exploitation rate (E) is attained using the Beverton and Holt formulas as follows:

$$E = F / Z$$

Where, F is capture mortality value, and Z is total mortality **(Sparre & Venema, 1999)**. The optimum exploitation rate was evaluated using the equation of **Gulland (1971)** as follows:

$$F_{opt} = M \text{ dan } E_{opt} = 0{,}5$$

The conclusions in this study were determined by comparing the results of the population parameter data analysis with the research hypotheses:

H_0 = level of exploitation of yellowfin tuna resources in West Morotai waters is not optimal

H_1 = level of exploitation of yellowfin tuna resources in West Morotai waters is optimal

The criterion for drawing conclusions in this study is if the value of exploitation (E) <0.5, then accept H_0 and reject H_1, and if the value of exploitation (E) ≥ 0.5, accept H_1 and reject H_0.

RESULT AND DISCUSSION

Yellowfin tuna catch

The production of yellowfin tuna catches during October to December 2020 seemed fluctuating, where the lowest production was detected in October, with a total catch weight of 4,463 kg, and the highest production was in November, recording a total catch of 12,669 kg. The average catch during the study was 8,387 kg. Yellowfin tuna production during the study is presented in Fig. (2).

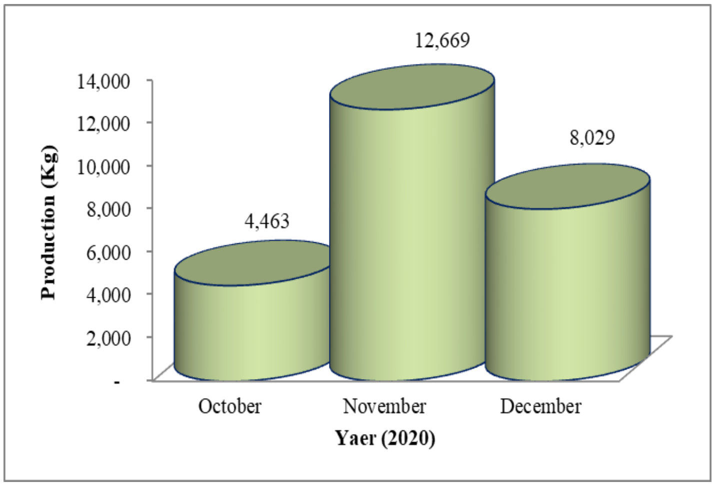

Fig. 2. Yellowfin tuna production from October to December 2020 in West Morotai waters, Morotai Islland, Indonesia

Population parameters of Yellowfin Tuna

Frequency length and age groups

The number of yellowfin tuna samples measured during the study from October to December 2020 was 1,585, with a total length ranging between 110 and182 cm. They were grouped in 11 classes, with a class width of 8 for later frequency analysis according to age groups. Based on the results of Bhattacharya's analysis **(Sparre & Venema, 1999)**, using the results of mapping of the difference between the theoretical natural logarithms and the mean class value, one age group was obtained in October-December 2020, with a fish length range of 110-182 cm, such as shown in Fig. (3).

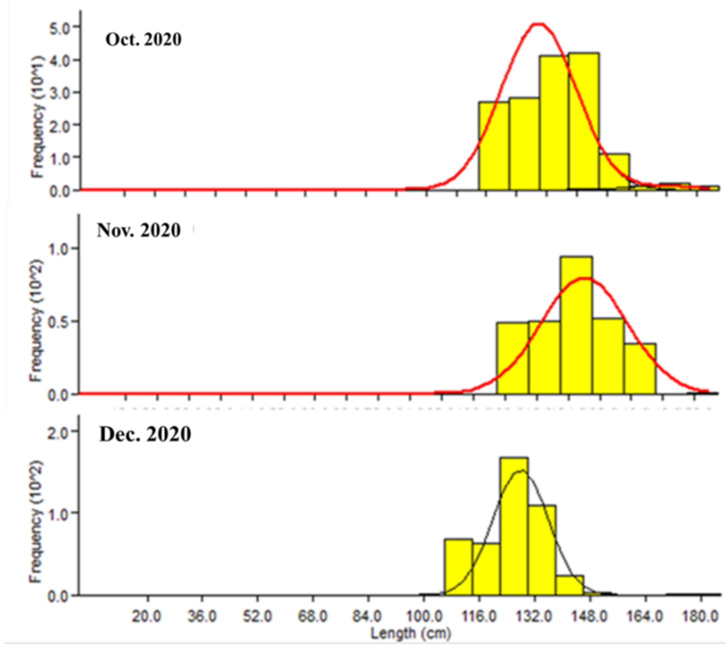

Fig. 3. Histograms showing yellowfin tuna frequency and monthly cohort in West Morotai waters, using FISAT II program during October-December 2020 Morotai Islland, Indonesia

Growth parameters

Estimated values of growth parameters were analyzed using the FISAT program, ELEFAN I subprogram and Routin Response Surface Rn = 0.24. The results of the analysis of the growth parameters estimation of yellowfin tuna in West Morotai waters including maximum length ($L\infty$), growth coefficient (K) and age at birth (t_0) using the growth formula of Von Bertalanfy were $L\infty$ = 242 cm, K = 0.32 per month and t_0 = -0.41, respectively. The results obtained by other researchers are exhibited in Table (1).

Table 1. Estimation of yellowfin tuna growth parameters in several areas

References	Location	Growth Parameters		
		L_∞ (cm)	K	t_0
Present study	West Morotai	242	0.32	-0.41
Ghofar *et al*. (2021)	Indian Ocean	194.25	0.51	-0.1889
Hashemi *et al*. (2020)	Oman Sea	171	0.54	-0.18
Haruna *et al*. (2018)	Banda Sea	215	0.31	-0.311
Susanto and Supyan (2019)	Ternate Island	194.26	0.242	-0.18
Rohit *et al*. (2009)	East Coast of India	197.4	0.30	-0.1157
Lessa and Duarte (2004)	W. Equatorial Atlantic	230.7	0.267	-0.081
Sun *et al*. (2003)	Western pacific	175.0	0.392	0.0031
John (1995)	Andaman and Nicobar, India	171.5	0.316	-0.305

In Table (1), it can be seen that the growth parameters of yellowfin tuna in West Morotai waters are relatively better and are almost the same as the results of **Haruna *et al*. (2018)** in Banda Sea waters. This difference in growth parameters may be due to exploitation pressures and different water environmental conditions. Generally, in West Morotai waters, fishing still uses hand line fishing gear, which is a tool with a simple category. Besides, the number of fleets is still very little compared to other areas including the island of Ternate. In addition, the geographical conditions of Morotai Island, which is in the AIRLINDO area, also strongly support the growth and development of yellowfin tuna species.

Based on the growth parameters of L∞, K and t_0, the growth curve of yellowifn tuna per month is plotted with the growth equation of L_t = 242 [1-exp-0.32 (t - (- 0.41)] as shown in Fig. (4). It was shown that changes in the length of yellowfin tuna from various relative ages per year reach the asymptote length by relating the relative age as the X axis to the length of yellowfin tuna as the Y axis. Yellowfin tuna caught in the waters of West Morotai are around 1.3 - 5.0 years old.

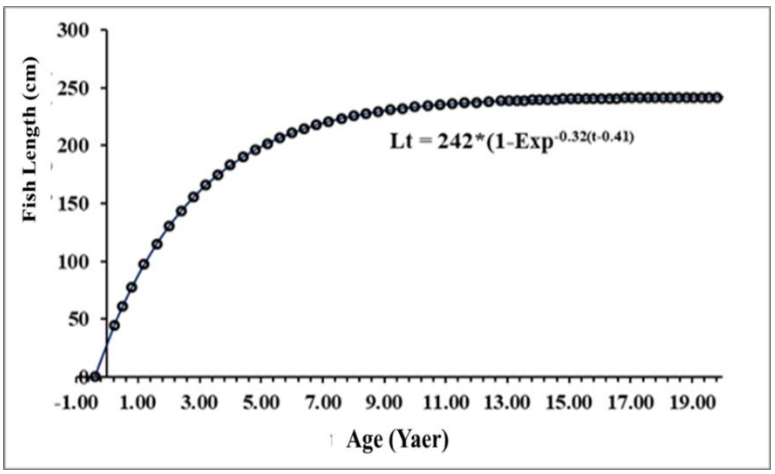

Fig. 4. Graph of yellowfin tuna growth rate in West Morotai waters, Morotai Islland, Indonesia

The estimated growth of yellowfin tuna in Morotai Island waters is shown in Fig. (4) with a specific growth curve, where yellowfin tuna in the early stages of its life experiences fast growth, followed by slow growth in old age. Based on this specific growth curve, the yellowfin tuna growth in West Morotai waters occurs at a young age and slows down with age until reaching its asymptote length, where the yellowfin tuna grows no longer. In addition, fast growth for young fish occurs since the energy obtained from food is mostly used for growth.

Effendie (2002) stated that the fast growth generally takes place when the fish are 3-5 years old, even though the old fish continues to grow, their growth is slow for the energy obtained from food is no longer used for growth, but only to maintain itself. replace damaged cells and movement. **Nikolsky (1969)** in **Nebuchadnezzar (2014)** stated that young fish will have relatively fast growth, while adult fish will be slower to reach their asymptote length or maximum length, then stop when they reach their asymptote length. Furthermore, **Azis (1989)** in **Damora & Baihaqi (2013)** suggested that, the body length over time showed a uniform level with the growth rate at the beginning, then decreases towards the theoretical maximum length or asymptote length.

Based on the growth equation Lt = 242[1-exp$^{-0.32(t-0.41)}$], it can be estimated that the length of yellowfin tuna for each year reaches its asymptote length assuming that this yellowfin tuna has a pattern of recruitment or the addition of new individuals to the population occurs almost along with the highest recruitment, thought to occurr in May and June at 16% and 17% (Fig. 5).

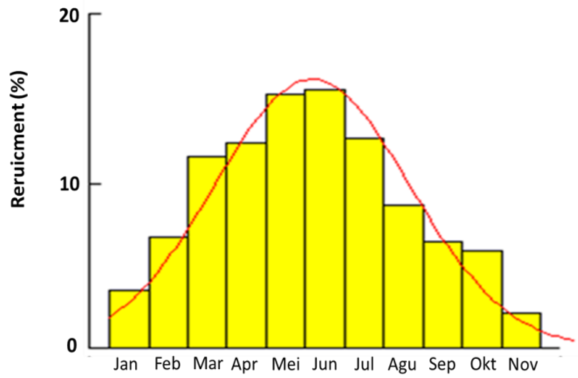

Fig. 5. Histogram showing recruitment patterns for yellowfin tuna in West Morotai waters

Yellowfin tuna mortality

The mortality rate is important in analyzing the dynamics of fish populations, since the mortality rate can provide an overview of the size of the exploitable stock of a population. The analysis of the mortality rate of yellowfin tuna in the waters of West Morotai, using an average sea surface temperature of the study location were 28°C; the total mortality (Z), natural mortality (M) and catch mortality (F) were 0.79, 0.46, and 0.33, respectively (Fig. 6).

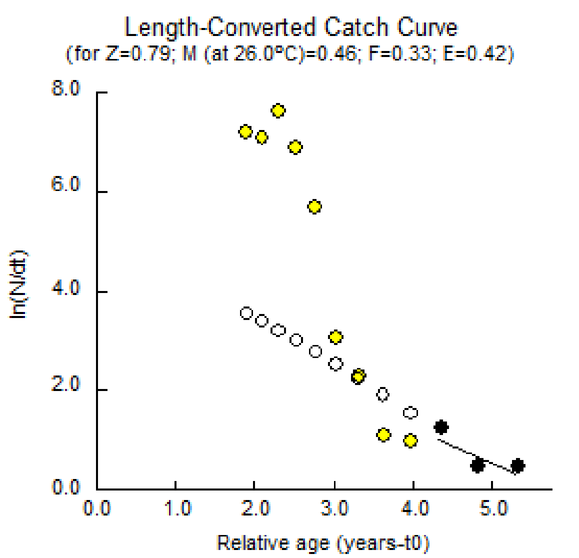

Fig. 6. Histogram showing yellowfin tuna mortality curve in west Morotai waters

The analysis carried out using fishing data for 3 months (October - December 2020) revealed that, the fishing mortality of yellowfin tuna is still low when compared to natural mortality (Fig. 6). This is attributed to the nature of fishing operations, restricted to specific periods throughout the year, and generally they are still traditional, using fishing gear with relatively low mobility (fishing line/hand line). Thus, fishermen are not optimal in exploiting the yellowfin tuna resources in West Morotai waters. In contrast to the current results, several researches conducted in other areas are shown in Table (2).

Table 2. Estimated value of mortality of yallowfin tuna in several other areas

Author/Year	**Location**	**Estimated Value of Population Parameters**		
		Total Mortality (Z)	**Natural Mortality (M)**	**Catch Mortality (F)**
Present study	West Morotai	0.79	0.46	0.33
Hashemi *et al*. (2020)	Oman Sea	2.28	0.71	1.57
Haruna *et al*. (2018)	Banda Sea	1.47	0.49	0.98
Susanto dan Supyan (2019)	Ternate Island	2.017	0.337	1.860

Suman and Boer (2005) postulated that, the mortality rate of fish resources due to fishing (F) operations varies according to the variety of fishing effort each year, where the F value shows how much and how much fishing pressure increases on fish stocks.

Exploitation Rate

The natural mortality value of yellowfin tuna (M = 0.46) per year and fishing mortality (F = 0.33) per year, in addition to the value of the exploitation rate (E = F / Z = 0.42) were obtained. By looking at the exploitation value (E) of 0.42 based on the results of population parameter analysis, it was concluded to reject H0 and accept H1, namely the level of exploitation of yellowfin tuna resources in West Morotai waters has been optimal. The exploitation rate (E) is close to the maximum value (E = 0.50). **Pauly *et al.* (1984)** stated that the value of rational and sustainable exploitation rates in waters is at the value of E <0.5 or the highest at the value of E = 0.5. If it is more than that value, it is categorized as more catch n and more catch recruitment. More biological capture/ growth is the capture of young fish with the potential to be a stock of fishery resources before reaching a suitable size for fishing. Whereas, more catch recruitment is that, if the number of adult fish in stock is exploited to a great extent, the reproduction of young fish decreases **(Pauly, 1983)**.

CONCLUSION

The estimated results of the yellowfin tuna population parameters in West Morotai waters showed that the maximum assumed length of yellowfin tuna (L∞) is 242 cm, with a growth coefficient (K) of 0.32 per year and t_0 = -0.41. In addition, the total mortality rate (Z= 0.79), natural mortality (M= 0.46) and fishing mortality (F= 0.33) were determined as well as the exploitation rate (E) that reached its optimum condition of 0.42.

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