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Analysis of population dynamics for the sustainability of yellowfin tuna (*Thunnus albacares*) resources landed in Pondokdadap Sendangbiru, Malang District, Indonesia

Agus Tumulyadi [1], Hartati Kartikaningsih [2, 3, *], Bambang Semedi [1, 2], Alda Wuldan Dwigita [1] and Abd. Aziz Amin [3]

[1] Department of Utilization of Fisheries and Marine Resources, Faculty of Fisheries and Marine Sciences, Brawijaya University, Malang, Indonesia.
[2] Management of Environmental Resources and Development Study Program, Graduate School of Brawijaya University, Malang, Indonesia.
[3] Department of Fisheries and Marine Resources Management, Faculty of Fisheries and Marine Sciences, Brawijaya University, Malang, Indonesia.

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Abstract

Pondokdadap is a fishing port that has large pelagic fish resources and biodiversity. This fishing port is an effective location for fish landing where it is close to the yellow fin tuna fishing ground. Tuna is one of the important commodities in the national capture fisheries sub-sector. Yellow fin tuna (*Thunnus albacares*) is a fish with economic value and a high level of public consumption, both domestically and abroad. However, it has an impact on the magnitude of market demand which is in line with the high activity of catching tuna in nature. Therefore, the exploitation of yellowfin tuna resources should be controlled. The purpose of this study was to identify, growth rate, mortality rate, exploitation rate and recruitment pattern of yellow fin tuna (*Thunnus albacares*) landed at TPI Pondokdadap. The results of growth parameter values, $L\infty$= 191 cm, K = 0.36 per year, and t0 = -0.27 per year. The mortality rate is Z = 2.81 per year, M = 0.45 per year, F = 2.36 per year and the exploitation rate is E = 0.84 per year, which means that the utilization status of yellowfin tuna (*Thunnus albacares*) was in the overexploited category. The highest value seen from the analysis of recruitment patterns occurred in June with a percentage of 34.83%. This research concludes that advisable to limit the efforts of catching yellow fin tuna (*Thunnus albacares*).

Keywords: *Thunnus albacares*; Pondokdadap; Fishing ground; Population

1 Introduction

Sendang Biru waters is a strategic area as an abundant fishing ground. Sendang Biru has the potential to bring in a wide variety of fish types from open waters, with tuna being one of the important commodities from the national capture fisheries sub-sector. As a result of increasing market demand each year, tuna is the leading export fish with an average catch percentage of 64% per year [1, 2]. Yellow fin tuna (*Thunnus albacares*) is a consumption fish that belongs to the Scombridae family [3]. Yellow fin tuna (*Thunnus albacares*) is a migratory fish species that inhabits the epipelagic zone to a depth of 200 meters below sea level and is commonly found in tropical and subtropical marine waters throughout the world [4]. In general, this fish is caught by fishing gear including hand line, troll line, and longline line. In small-scale fisheries, fishery business actors catch tuna using hand line fishing gear or handlines. The fishermen in Sendang Biru catch yellow fin tuna using a fleet of lifeboats with fishing gear in the form of hand lines which are operated around the Indian Ocean in the waters around deep sea FADs [5]. The average yellowfin tuna (*Thunnus albacares*) caught in the waters of the Indian Ocean in 2016-2020 was 434.235 kg per year, and during that period the status of yellowfin tuna

* Corresponding author: Hartati Kartikaningsih

(*Thunnus albacares*) was at the IOTC (Indian Ocean Tuna Commission) classified as overfishing. The high level of exploitation due to overfishing of yellowfin tuna makes it vulnerable to unsustainable fishing [6].

The dynamics of fish stock populations is very important to study because it is quite closely related to a statement or claim for sustainable fish resources in an area. Studies on the dynamics of fish populations can determine decision making regarding the management of fish resource stocks, and can also provide indications through biological indicators in determining stock status [7]. Population parameters of a type of fish are studied in order to obtain information about stocks so that fishery resources can be used optimally and sustainably [8, 9]. Due to the higher demand for yellowfin tuna on the international market in recent years, this has had an impact on intensive exploitation, as well as on the availability. Therefore, to find out information on the status of yellowfin tuna stocks, it is importat to conduct research on biological aspects including growth rates, mortality rates, exploitation rates, and patterns of recruitment of new individual fish using the fork length variable of yellowfin tuna. It aims to find enough information about the sustainability of yellowfin tuna stocks in the Indian Ocean region now and in the future [10].

Therefore, to find out information on the status of yellowfin tuna stocks, it is necessary to conduct research on biological aspects including growth rates, mortality rates, exploitation rates, and patterns of recruitment of new individual fish using the fork length variable of yellowfin tuna. It aims to find enough information about the sustainability of yellowfin tuna.

2 Material and methods

2.1 Location of Research

The research location is located at UPT PPP Pondokdadap Fish Auction Place, Sendangbiru Hamlet, Tambakrejo Village, Sumbermanjing Wetan District, Malang Regency, East Java Province, Indonesia in 2022. Retrieval of long distribution frequency data of yellowfin tuna was carried out every month with a minimum collection period of 30 days.

2.2 Analysis of Fish Length Frequency Distribution Data

To determine the frequency of fish length, the data used is fork length (FL) data from yellowfin tuna (*Thunnus albacares*). The process of analyzing the long frequency distribution includes determining the desired number of class intervals, determining the class range, determining the class frequency, then entering length measurement data for the same class interval, after that a plot is made on the graph. The purpose of making the graph is to find out the shift in the distribution of long classes in each month during the study. Shifts in the length distribution can indicate the number of existing cohorts (age groups). It can be seen in the graph that the mode of the long class frequency distribution shifts every month, indicating the existence of several cohorts.

2.3 Growth rate

Measurement of growth rate used the bhattacharya method. This method is a method for analyzing the structure of an age group, which uses the separation of the combined distribution into several separate normal distributions that can represent an age group (cohort). In determining the normal distribution starting from the left side of the total distribution. Likewise with the normal distribution that has been determined, it will be separated from the total distribution and then the same steps are repeated as long as it is still possible to do it in separating other normal distributions from the total distribution. The peak of the normal distribution is called the cohort (age group) or the mode of the long frequency each month. The mode value is used to calculate L∞ and K. To estimate the growth parameters from the L∞ (asymptotic width) and K (growth constant) values of a fish stock, the Fisheries Stock Assessment Tools II (FISAT II) application was used.

The L∞ and K values that have been obtained, then for estimating the theoretical age (t0) of fish when the length is equal to 0 (zero) years Pauly's empirical equation is used [11], as follows:

$$\text{Log}(-t_0) = 0{,}3922 - 0{,}2752\ (\text{Log}\ L_\infty) - 1{,}038\ (\text{Log}\ K) \quad \text{..............................(1)}$$

Information

L∞ : maximum length that can be reached by fish if no death occurs (cm)
K : Growth rate coefficient (per year)
T0 : The theoretical age of fish at zero length (per year).

To determine the value of the growth rate of yellowfin tuna (*Thunnus albacares*), the Von Bertalanffy growth model equation is used [11], which is as follows:

$$Lt = L\infty\ (1 - e\ [- K\ (t\text{-}t0)])\ \ldots\ldots(2)$$

Information

Lt : length of fish at age t (cm)
L∞ : Maximum length that fish can reach when no death occurs (cm)
K : Growth rate coefficient (per year)
t0 : The theoretical age of fish at zero length (years)
t =Age of fish (years)

2.4 Mortality Rate

The results of estimating the value of the total mortality rate (Z) and the natural mortality rate (M) can determine the fishing mortality rate (F). to determine the estimated value of total mortality (Z), that is by using analysis in the FISAT II application.

Calculation of the total mortality rate (Z) uses the Beverton and Holt equation formula [11], which is as follows:

$$Z = K\left(\frac{L\infty - L}{L - L'}\right)\ \ldots\ldots(3)$$

Information

K : Growth rate coefficient (per year)
L∞ : Asymptote length of fish (cm)
L : average length of fish caught (cm)
L' : the smallest limit for the length class of fish that has been fully caught

Calculation of the natural mortality rate (M) uses the Pauly empirical method [11], which is as follows:

$$M = 0.8 * \exp(-0.152 - 0.278\ \mathrm{Ln}\ L\infty + 0.6543\ \mathrm{Ln}\ K + 0.4636\ \mathrm{Ln}\ T)\ \ldots\ldots(4)$$

Information

M : Natural mortality rate (years)
L∞ : Asymptote length of fish (cm)
K : Growth rate coefficient (per year)
T : average surface water temperature (°C)

Calculation of fishing mortality rate (F) is determined from the estimation of Z and M values, then the following equation is obtained:

$$Z = F + M \text{ atau } F = Z - M\ \ldots\ldots(5)$$

Information

E : Exploitation rate value
F : Fishing mortality rate value
Z : Total mortality rate value

2.5 Exploitation Rate

Exploitation rate (E) level of utilization of fishery stocks can be determined using the formula:

$$E = \frac{F}{F+M} = \frac{F}{Z}\ \ldots\ldots(6)$$

Information

F : fishing mortality rate

Z : Total mortality rate
M : Natural mortality rate
E : Exploitation rate

The criteria for determining the estimation of the status of fishery resources using the exploitation rate parameter are as follows:

E > 0.5: indicating overexploited fisheries status
E = 0.5: indicates the status of the fishery is classified as optimal/Maximum Sustainable Yield (MSY)
E < 0.5: indicates the status of the fishery underexploited

2.6 Recruitment Pattern

Recruitment pattern analysis can be estimated using FISAT II software using the Recruitment Pattern sub menu. The data needed are the values of L∞, K and t0 which were previously obtained. The results of the analysis are the histogram graphs and the percentage of recruitment patterns every month**.**

3 Results and discussion

3.1 Fish Length Frequency Distribution

Forked length (FL) measurements of yellowfin tuna (*Thunnus albacares*) in Pondokdadap, a total of 4440 samples. From the primary data, it is known that the range of fish length is from 27 to 171 cm using a class interval of 1 cm. Furthermore, the data that has been obtained is processed in the FISAT II application using the Bhattacharya method and several cohorts of fish are obtained in each month starting from Marchl to July 2022. The purpose of knowing the distribution of fish length frequencies is to find out the normal distribution by looking at the number of cohort peaks produced where it can be used to determine the maturity of the fish and the size feasible for catching yellowfin tuna.

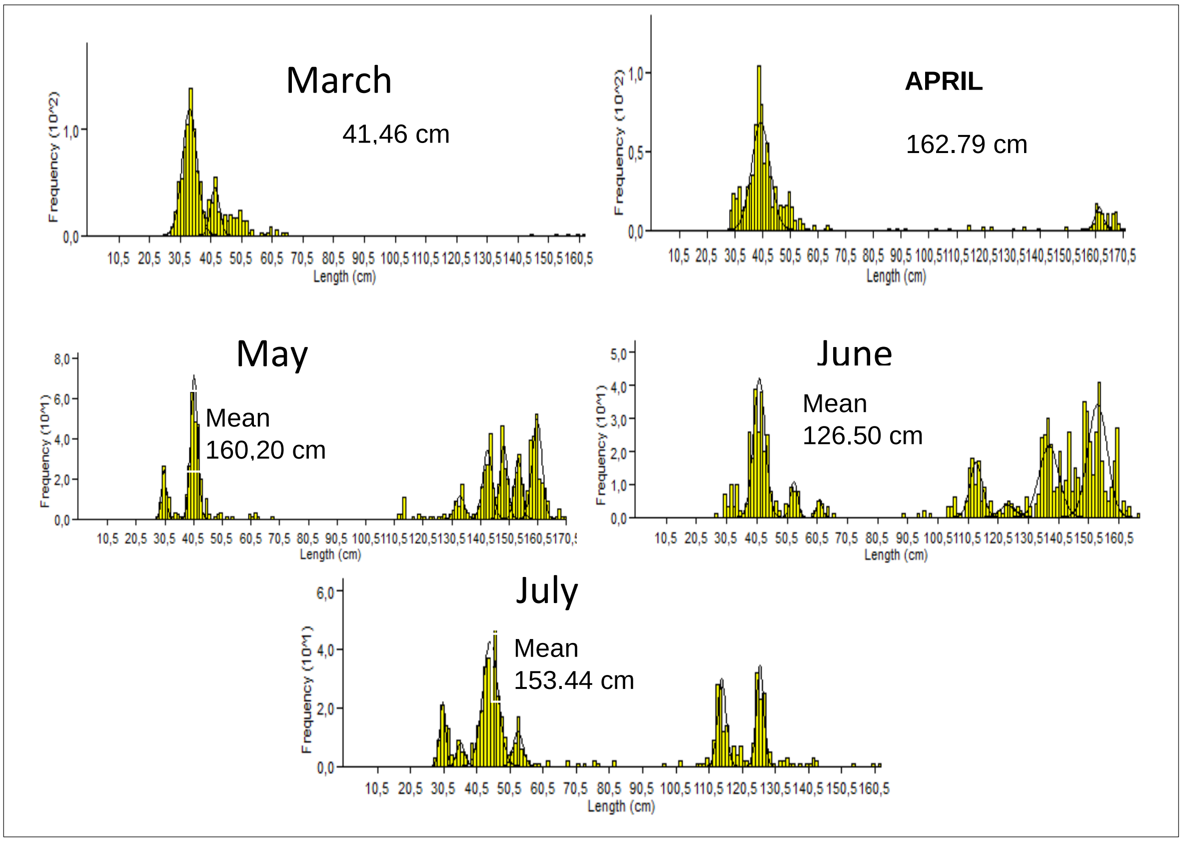

Figure 1 Distribution of March-July 2022 Length Frequency

The distribution of the long frequency of yellowfin tuna (*Thunnus albacares*) shows a graph of the factors that affect the distribution of the long frequency of yellowfin tuna [12]. Yellow fin tuna caught in the surface area of the waters and still around the fishing ground is dominated by small fish (Juvenile) with a percentage of 98%. Based on the presumptive assumptions, yellowfin tuna matured for the first time at 84 cm FL with a length of >84 cm FL classified as an adult fish and <84 cm FL classified as a juvenile [13].

The results of this study were 1040 samples of yellowfin tuna with a fish length range of 28 to 162 cm and based on the graph, there was a tendency to form 2 cohorts. In April 2022, the results obtained from a study of 852 samples of yellowfin tuna with a fish length range of 29 to 171 cm and based on the graph there is a tendency to form 2 cohorts. In May 2022, the results obtained from a study of 960 samples of yellowfin tuna with a fish length range of 28 to 170 cm and based on the graph there is a tendency to form 7 cohorts. In June 2022, the results obtained from a study of 946 samples of yellowfin tuna with a fish length range of 27 to 167 cm and from the graph there is a tendency to form 7 cohorts. In July 2022, the results obtained from a study of 642 samples of yellowfin tuna with a fish length range of 27 to 167 cm and based on the graph there is a tendency to form 6 cohorts.

The results of this analysis indicate that the long frequency distribution of yellowfin tuna in Pondokdadap is dominated by small fish, namely fork lengths of less than 100 cm, but in certain months, such as May and July, medium to large fish with a length of more than 100 cm begin to dominate. The decrease in the frequency of fish length is due to the increase in body length in fish. This illustrates that yellow fin tuna in Pondokdadap dominated by large, medium to small fish.

3.2 Growth Rate Analysis

The results of the observations showed that the maximum length/ asymptote length (L∞) was 191 cm with a growth coefficient (K) of 0.36 per year. Then the value (t0) is the result that has been calculated by Pauly's formula, which is 0.2758 per year. This value indicates that the yellowfin tuna (*Thunnus albacares*) can grow up to 191 cm if there is no death due to fishing. The von Bertalanffy growth function (VBGF) shows that yellowfin tuna (*Thunnus albacares*) can continue to grow up to an asymptotic length of 191 cm if they do not die due to natural factors or fishing factors.

Previous research in 2021 showed an L∞ value of 174.46 cm, a K value of 0.21 per year and a t0 value of 0.4951 per year [15]. It is known that the maximum length (L∞), growth rate (K) and value (t0) of the research in that year were smaller than the results of this study.

This study shows that the yellowfin tuna landed at Pondokdadap in 2022 requires a short time to reach its asymptotic length because it has a higher coefficient value, on the other hand in 2021, yellowfin tuna takes a long time to reach its asymptotic length due to the higher coefficient value. low. The value of the growth rate (K) is highly correlated with the value (L∞) which means the value (K) can indicate the growth rate of the fish until it reaches (L∞). If the value (K) is large, fish generally have a relatively short life span and vice versa (Mamangkey & Nasution, 2014). The growth rate (K) value of yellowfin tuna is slow because it does not reach a value of one, meaning that the use of fishery resources must be approached with the precautionary principle [14].

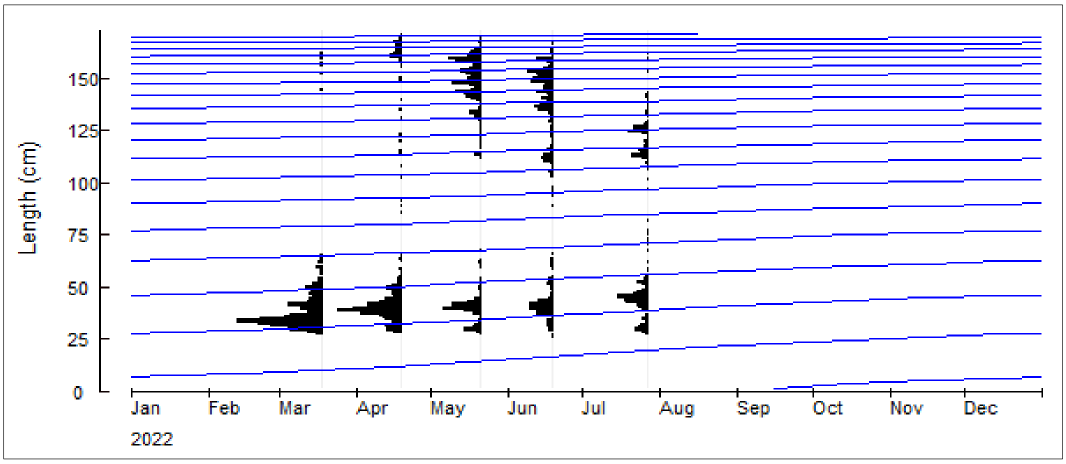

Figure 2 VBGF plots for Yellowfin Tuna (*Thunnus albacares*) in 2022

The values of L∞K and to that have been obtained are then used to determine the optimal growth point for yellowfin tuna (*Thunnus albacares*) using the Von Bertalanffy and Beverton Holt equation. Based on research conducted in 2022, the results obtained were Lt = 191 (1-e-0.36(t+0.2758)). Then for the optimal point of fish growth, the value of tmax = 0.85 years and length of Lmax = 181.45 cm are obtained. In the growth curve in 2022, it is known that when fish are 0-8 years old they experience quite rapid growth, but when they are more than 8 years old the growth of yellowfin tuna (*Thunnus albacares*) becomes slower and tends to be constant according to with a maximum length of fish that is equal to 181.45 cm.

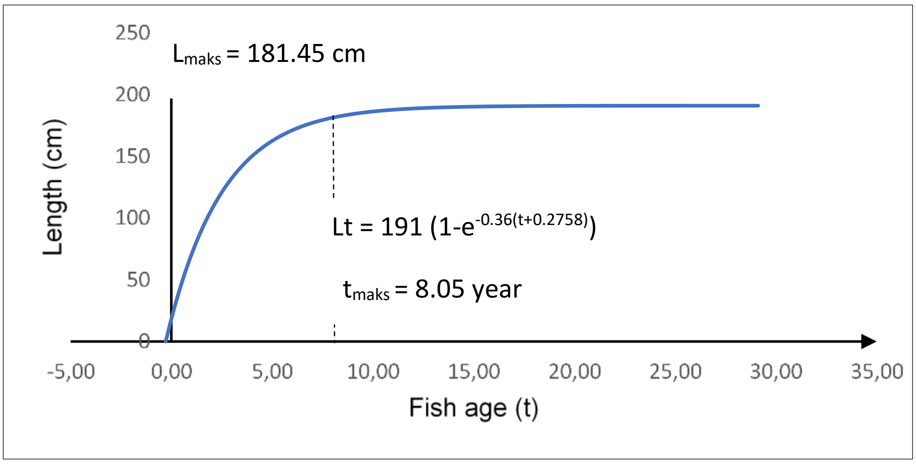

Figure 3 Yellowfin Tuna (*Thunnus albacares*) Growth Rate in 2022

3.3 Mortality Rate

The value of the total mortality rate was obtained by analyzing data using the FISAT II application in the Length-converted Catch Curve sub-program by entering data on known L∞ and K values, so that the value of the total mortality rate (Z) was 2.81 per year-1. The value of natural mortality (M) is calculated using the Pauly formula by entering the values of L∞, K and also T. It is known that the value of T or the average temperature in Sendang Biru waters during the study period from March to July 2022 was 29.18 °C, so that the natural mortality rate (M) is 0.45 per year. The value of the fishing mortality rate (F) is obtained by calculating the formula for the total mortality rate minus the natural mortality rate, so that the fishing mortality rate is 2.36 per year. Based on the results of the analysis, it is known that the value of the fishing mortality rate is greater when compared to the natural mortality rate, which means that more deaths of yellowfin tuna caused by fishing activities than deaths in nature.

3.4 Exploit Rate

Exploitation rate analysis is obtained from the calculation of mortality using the formula for the fishing mortality rate (F) divided by the total mortality rate. Based on calculations, it is known that the value of the exploitation rate for yellowfin tuna (*Thunnus albacares*) landed at Pondokdadap Sendang Biru in 2022 is 0.84 per year. This value has exceeded the optimal limit of the exploitation rate, which is 0.5 per year. This indicates that the status of the yellowfin tuna fishery, especially in WPP-RI 573 that year, was at the overexploited level. Based on the research that was carried out in 2021, the calculation results for the exploitation rate (E) are 0.88 per year. This indicates that the status of fisheries is at the overexploited level [15].

3.5 Recruitment Pattern Analysis

The recruitment pattern shows that the peak of fish recruitment occurred in June with a percentage gain of 34.83%. Conversely, the lowest percentage occurred in December with a percentage value of 0%, this indicates that there was no recruitment at all that month. Recruitment patterns are related to spawning time. It is known that in the study of yellowfin tuna in Pondokdadap in 2021, results showed that the peak of fish recruitment occurred in August with a percentage of 28.63% [15]. This shows a shift in fish spawning times and also differences in the percentage value of recruitment when compared to the results of the analysis of the yellowfin tuna recruitment pattern in 2022. The cause is due to natural factors, namely changes in weather anomalies due to shifts in the onset of the rainy season and dry season due to the influence of El Nino Southern Oscillation (ENSO).

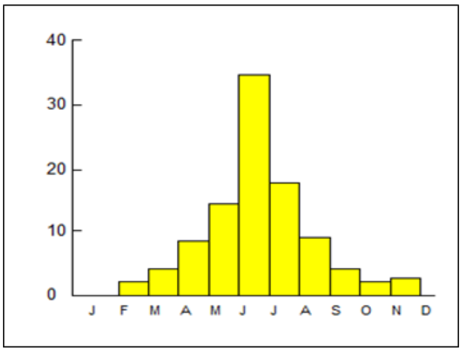

Figure 4 Graph of Yellowfin Tuna (*Thunnus albacares*) Recruitment Pattern in 2022

4 Conclusion

This study concluded that the maximum length value for yellowfin tuna derived from the 2022 Forked Length (March - July) data with L∞ is 191 cm, K is 0.36 per year, and t0 is -0.2758 years. The total mortality rate (Z) for yellowfin tuna was 2.81 per year, the natural mortality rate (M) was 0.45 per year, and the fishing mortality rate (F) was 2.36 per year. Analysis of the rate of exploitation of yellowfin tuna obtained the value of the exploitation rate (E) is 0.84 per year, which means the value of E is more than 0.5. This shows the current utilization status is overexploited. Analysis of the recruitment pattern of yellowfin tuna showed that the peak of recruitment occurred in June with a percentage of 34.83%. and the lowest recruitment value occurred in December with a percentage of 0%.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare that the research was conducted in the absence of any financial relationships that could be construed as a potential conflict of interest.

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