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Evaluation of Yellowfin Tuna Thunnus albacares (Bonnaterre 1788) Stocks in Ternate Waters, North Maluku – Indonesia, Based on Population Dynamics Studies

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ABSTRACT

The tuna fishery resources, particularly yellowfin tuna (YFT), in Ternate waters, North Maluku, Indonesia (fishery management area 715), are currently classified as fully exploited at 0.97% utilization rate of the available potentials, i.e., 31.659 ton/ year. This calls for an attempt to manage the yellowfin tuna in such a way that its existence in the waters can be maintained. Studies on fish population parameters are an effort to obtain scientific information as a recommendation for sustainable fisheries management. This research used experimental fishing by measuring the fish's length. Then, its population was estimated using FISAT II program, and its spawning potential ratio (SPR) was analyzed using length based-spawning potential ratio (LB-SPR) software. It was expected that this would be able to give the yellowfin tuna current status and condition in Ternate waters. Conducted from May through August 2023, and analyzing 4,904 fish, the research managed to determine the population parameters of yellowfin tuna in Ternate waters. Its asymptotic length ($L\infty$), growth coefficient (K) and t_0 were 117.60 cm, 1.4 per year, and 0.17 year, respectively. These were then plotted to obtain a von Bertalanffy growth curve using the formula $Lt = 117{,}60*(1\text{-}Exp^{-1{,}4(t-0{,}17)})$. From the analysis, it was found that the fish total mortality, natural mortality and captive mortality rates were 3.89, 1.55, and 2.34, respectively. Furthermore, it was found that recruitment occurred twice a year, i.e., on March and August at 6.72 and 25.18%, with the Y/R value being 0.039 and B/R value of 0.482. Meanwhile, the spawning potential ratio (SPR) value was 19%, indicating that the utilization rate had been over exploited (SPR< 20%) and it was supported by the fact that the exploitation rate value had been over 0.60 (over fishing) from the E_{max} value (0.421). Therefore, management is needed to ensure the sustainability of yellowfin tuna stocks.

INTRODUCTION

Ternate waters are located in Indonesian through flow (ITF) area and fishery management area (WPP) 715, known for its fairly high fishery potential. Among its assets is the presence of large pelagic fish, i.e., yellowfin tuna **(DKP of North Maluku**

Province, 2022). Yellowfin tuna (*Thunnus albacares*), locally known as madidihang fish, is one economically important large pelagic fish from Scombridae family, living throughout the tropical waters (www.fishbase.org, 2023) . Its length can reach 195 239 cm with fusiform-shaped body (Fig**.** 1). Yellwofin tuna is the highest, non-fuel and gas export commodity from Indonesia after shrimps & prawns and seaweed **(Fishbase.org, 2023)**.

Fig. 1. Yellowfin tuna (*Thunnus albacares*)
(Research data, 2023)

The yellowfin tuna (YFT) in Ternate waters (fishery management area 715) are currently classified as fully exploited at 0.97% utilization rate of the available potentials, i.e., 31.659 ton/ year **(KKP, 2021)**. The utilization rate of yellowfin tuna resources can be discovered by estimating the population parameters to see the changes in age groups, asymptotic length, growth rate and other population parameters **(Lelono *et al*., 2018)**. In an attempt to manage fish resources, knowledge on population parameters can provide information on the number and size of fish caught every year **(Tangke, 2014; Tangke *et al.*, 2018)**. Furthermore, according to **Kartamiharja (2015)**, for the purpose of management, studying population parameters is important, including the fish resources to be exploited optimally. Studies on population parameters provide important information and effective strategy to manage fish resources **(Hoeng & Gruber, 1990)**. Meanwhile, the management itself aims at allowing the fish population as biological resources to recover and be conserved and its exploitation pressure can be limited based on the biological aspects, i.e., the study of stock and estimation of population parameters **(Tangke *et al*., 2021; Tangke *et al*., 2022)**.

Law Number 45 of 2009 concerning Amendment to Law Number 31 of 2004 concerning Fisheries states that fishery management is an integrated attempt to manage the information, analysis, planning, and decisions, as well as the allocation of fish resources and enforcement of law regulations in the field of fishery by the government to sustain the fish resources productivity and to achieve the agreed goals (Law No. 45, 2009). Moreover, according to **Yunanda (2019)**, sustainable fishery management is to maintain the balance of all fishery management aspects, including biological, environmental, economic and social aspects, with the biological aspects being more emphasized to keep the fish resources productivity sustainable.

To keep the yellowfin tuna stocks safe, sustainable tuna fishery management, particularly for the yellowfin tuna (YFT), is needed by studying and evaluating its resources current stocks and utilization rate for consideration in sustainable yellowfin tuna fishery management in Ternate waters.

MATERIALS AND METHODS

The data on the yellowfin tuna were measured from 4,904 tuna obtained from the handline tuna fishermen's catches in Ternate Island, North Maluku - Indonesia (Fig. 2) for 4 months since May through August 2023.

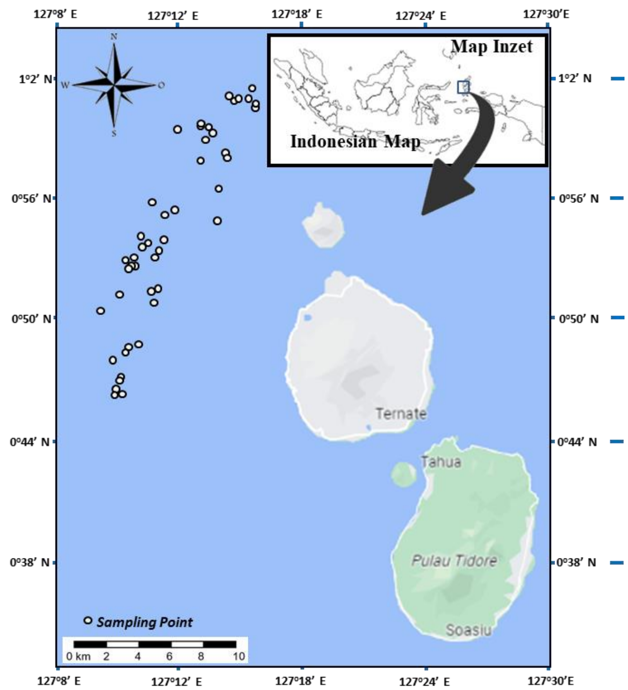


Fig. 2. Research site

The data were then analyzed to achieve the research objective, i.e., evaluating the population dynamics including the growth, mortality, recruitment, exploitation rate and spawning potential ratio (SPR), using the following formula:

a. Growth; the growth of yellowfin tuna including, among other things, its asymptotic length, growth coefficient, and theoretical age were analyzed using electronic length frequency analysis (ELEFAN), based on the von Bertalanffy's growth function **(Sparre & Venema, 1999)**, using the following formula:

$$L_t = L_\infty \left[1 - e^{-K(t-t_0)}\right]$$

Where:

L_t = yellowfin tuna's length at its age t (cm)
L_∞ = yellowfin tuna's maximum length (cm)
k = growth coefficient (per year)
t_0 = theoretical age when yellowfin tuna's length was zero.
Using the theoretical age (t_0), it was estimated using Pauly's empirical equation (1983), namely:

$$Log\ (-t_0 = -0.392 - 0.275 Log\ L\infty - (-1.038 \log k)$$

b. Mortality; the natural, total, captive mortality rate values were estimated using FISAT II software with Pauly's M model and length converted-catch curve **(Pauly, 1984; Gayanilo *et al.*, 2005; Tangke *et al.*, 2014; Tangke *et al.*, 2018)**, using the mathematical model:

M = exp (-0,0152 - 0,279 ln L∞ + 0,6543 ln K + 0,4634

c. Exploitation rate; it is an indicator of utilization rate as analyzed using the formula described by **Pauly (1984)**, **Gayanilo *et al*. (2005)**, **Tangke *et al*. (2021)** and **Tangke *et al.* (2022)**, namely E = F/Z. According to **Sparre and Venema (1999)**, if E> 0.5, then the exploitation rate of fish resources is fairly high, if E= 0.5, then the exploitation rate of fish resources is at the optimum rate, and if E< 0.5, then the exploitation rate of fish resources is still low.

d. Yield per recruitment; with % unit, it is a condition where new generation of fish, as represented in a chart of fish resources, begins to interact with the fisheries, as characterized by the capture of small-sized fish by fishing tools. For the analysis of recruitment pattern, the yield per reucruitment was analyzed using FISAT II in recruitment pattern submenu, utilizing the data on L_∞, K and t_0 values, with Beverton and Holt's formula, as outlined in **Sparre and Venema (1999)**:

$\frac{Y}{R} = \left(1 - \frac{3U}{1+m} + \frac{3U^2}{1+2m} + \frac{U^3}{1+3m}\right)$, with $U = 1 - \frac{L'}{L_\infty}$ and $m = \frac{1-E}{M/K}$

Where, M= natural mortality (per year), L'= is the shortest length limit of yellowfin tuna caught (cm), L∞= asymptotic length of yellowfin tuna (cm), and k is yellowfin tuna's growth coefficient (per year).

Spawning potential ratio (SPR); it is a relative reproduction index to find out the stock condition in the resources that have been exploited. SPR was analyzed using length based-spawning potential ratio (LB-SPR) software developed by **Hordyk *et al*. (2015)** (http://barefootecologist.com.au/lbspr). The SPR reference value according to **Walters and Martel (2004)** is: SPR> 40% means utilization rate is still under exploited; 20%< SPR< 40% means utilization rate has been moderate; and SPR< 20% means utilization rate has been over exploited.

RESULTS AND DISCUSSION

1. Yellowfin tuna catches during the study

The production or catch of yellowfin tuna during the study using 4 units of handline tuna fishing gear during 384 fishing trips is illustrated in Fig. (3). In Fig. (1), it can be observed that the number of catches remained relatively stable throughout the study period (4 months) form May to August 2023. The total catch during the study period was 44,136kg, with an average monthly catches of 11,034kg. The highest number of catches occurred in June, amounting to 14,229kg, while the lowest was recorded in May, with 8,001kg.

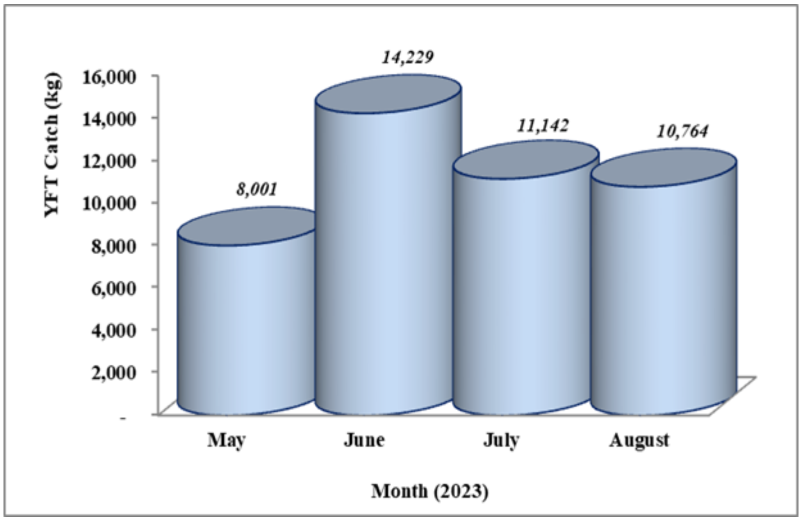


Fig. 3. Number of monthly catches during May - August 2023

The relatively stable number of catches during this research was due to the relatively stable amounts of fishing operation by the handline tuna fleets and fishing trip each month **(DKP Kota Ternate, 2022)**.

2. Dynamics of yellowfin tuna [opulation

2.1. Structure of yellowfin tuna sizes

The analysis on the number of yellowfin tuna catches revealed that 4,904 yellowfin tunas were caught for 4 months, with the monthly average catches being 1.226 fish at 14- 113cm length range. In general, the size distribution showed a single-mode pattern at 70- 80cm sizes, with 72% of them being identified within the L25- L75 length range (Fig. 4).

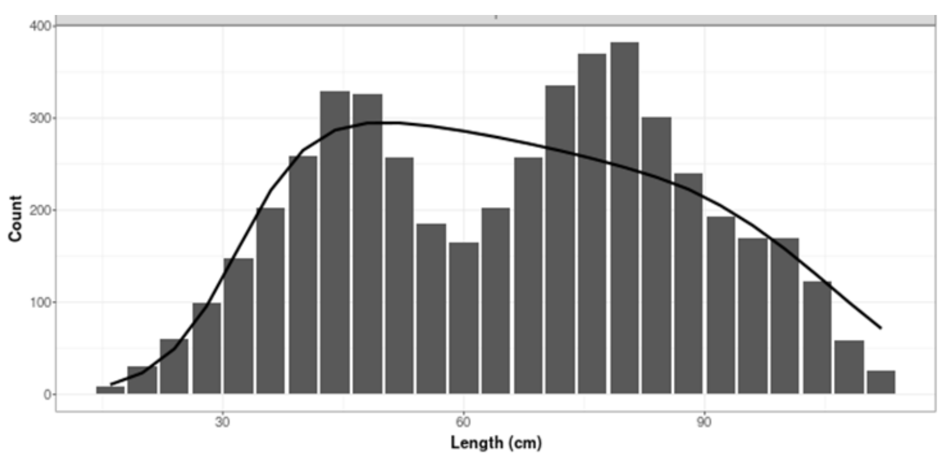


Fig. 4. Monthly cohort of skipjack tuna in Ternate Island waters

2.2. Growth parameter

The growth parameters of yellowfin tuna in Ternate waters were estimated using ELEFAN I in Fisat II program, specifically in scanning the K-values menu. From this estimation, the K and L∞ values were found at 1.4 per year and 117.60cm, respectively

(Fig. 5). Furthermore, using the K and L∞ values estimated using **Pauly's** (**1983**) empirical formula, the t_0 value of yellowfin tuna was found to be 0.17 year.

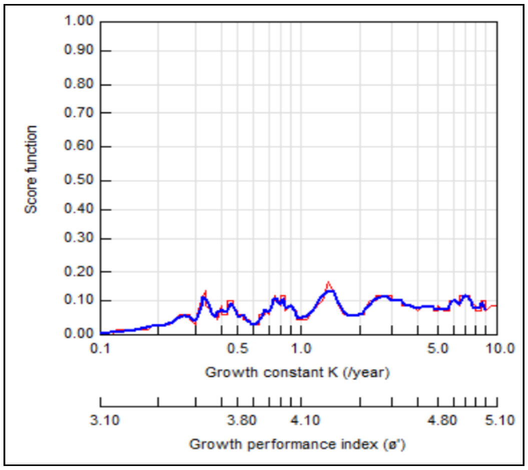


Fig. 5. Curves of L∞ and K values

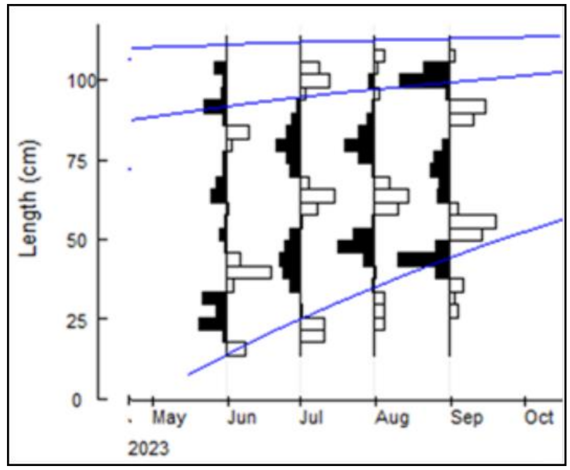


Fig. 6. von Bertalanffy's growth curve of yellowfin tuna (May - August 2023)

Analyzed using Fisat II, the VBGF curve (Fig. 6) shows that the yellowfin tuna could still grow to its asymptotic length, reaching117.60cm. Furthermore, Figs. (5, 6) provide information that the yellowfin tunas caught during the study in Ternate waters had a fast growth pattern with a long age. The values were then plotted to obtain a growth curve using von Bartalanffy's model for yellowfin tuna, i.e., Lt = 117,60*(1-Exp$^{-1,4(t-0,17}$) (Fig. 7).

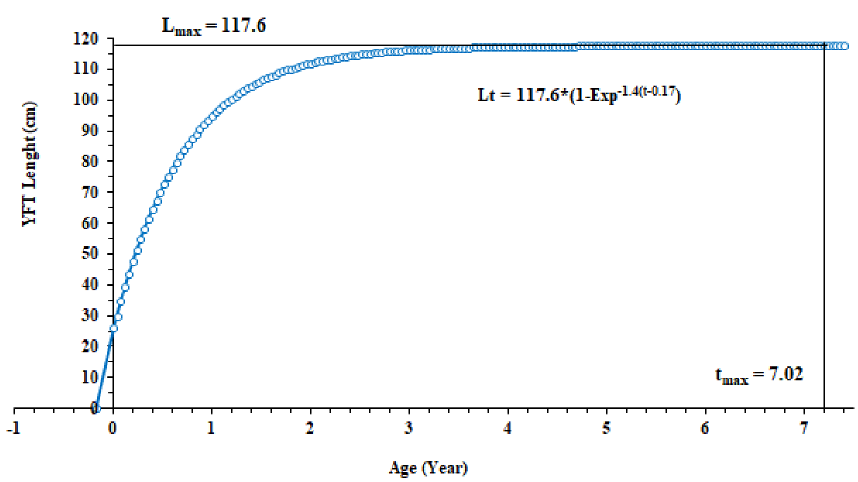


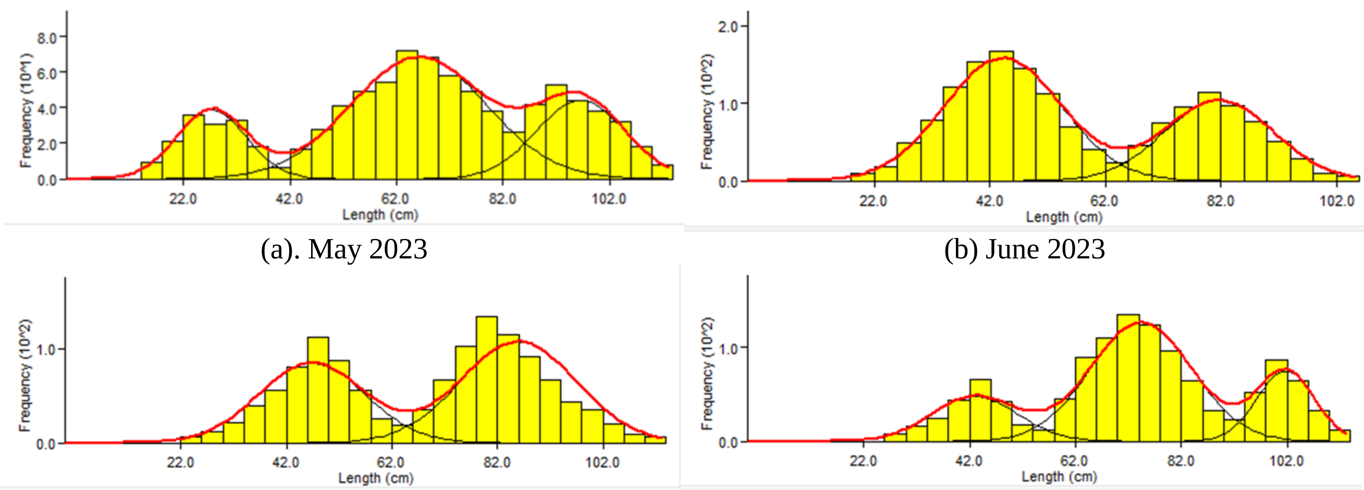
Fig. 7. Growth curve yellowfin tuna (YFT) in Ternate waters

Fig. (7) shows that the yellowfin tuna aged under 3 years old had a rapid growth rate and once they were older than 3 years old, their growth rate decelerated and tended to be constant until they reached their asymptotic length at 117.60 cm, which occurred when they were 7.02 years old. **Welcome (2001)** and **Saranga *et al*. (2018)** suggested that fish body size would increase and upon approaching its asymptotic length, its growth rate would decelerate.

2.3. Cohort

The cohort mapping based on length of fish caught each month gave us 2 cohort models, namely 3 cohorts in May and August 2023 and 2 cohorts in June and July 2023. Figs. (8- 11) show the cohort pattern of yellowfin tuna during the study.

In May 2023 (Fig. 8a), 889 YFTs were measured, at a length range between 14 and 113cm. Analyzing the data for May 2023 gave us 3 cohorts with their average length value of cohorts being 27.27 (S.D. 6.58), 66.16 (S.D. 12.8), and 96.56 cm (S.D.8.32), respectively.



(a). May 2023 (b) June 2023

(c) July 2023 (d) August 2023

Fig. 8. Distribution of yellowfin tuna length frequency in (a) May 2023, (b) June 2023, (c) July 2023, and (d) August 2023

In June 2023 (Fig. 8b), 1,581 YFT samples were measured at a length range between 14 and 104cm. Furthermore, the analysis gave 2 cohorts with their average lengths being 44.20 (S.D. 10.16) and 81.64cm (S.D. 9.47), respectively. In July 2023 (Fig. 8c), 1,238 YFT samples were measured at a length range between 22 and 113cm. The analysis of data from June 2023 gave 2 cohorts with their average values being 46.79 (S.D. 10.08) and 86.00cm (S.D. 11.02). respectively. Finally, in August 2023 (Fig. 8d), 1,196 ekor YFT samples were measured at 26- 113cm length range. The analysis gave 2 cohort with their average fish length being 42.95 (S.D. 8.08), 74.42 (S.D. 9.63), and 101.71cm (S.D. 5.43), respectively. Based on fishbase.org data, the size of gonad mature YFT fish falls within the range of 78- 158cm in length. When considering the average value of the cohort caught during May to August 2023, out of the 4,904 YFT fish caught, it was found that 63%, or 3,089 fish, belonged to a category that is not yet suitable for fishing or are less than 78cm in size.

2.4. Mortality and exploitation rate

Mortality is the death rate resulting in the decreasing stocks in a population. Both natural mortalitiy (M) and captive mortality (F) also affect the exploitation rate, and both are helpful to estimate the fish biomass **(Shephard *et al*., 2015)**. Analyzing the mortality rate at the waters average temperature of 29.3°C, using Fisat II software in length catch curve method **(Sparre & Venema, 1999)**, it was found that the total mortality rate (Z) was 3.89 per year, with the natural mortality (M) being 1.55 per year and fishing mortality being 2.34 per year (Fig. 9).

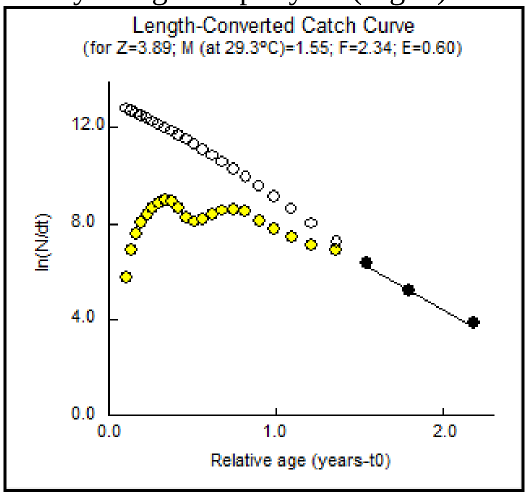


Fig. 9. Length-converted catch curve

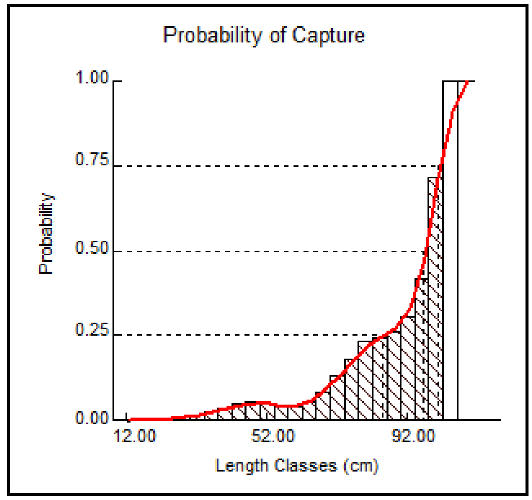


Fig. 10. Probability of capture

Fig. (9) also shows that the exploitation rate (E) of yellowfin tuna was 0.60 per year. This indicates that 60% of yellowfin tuna mortality rates was contributed by capture pressure. Furthermore, Fig. (10) shows the probability of capture, where it can be seen that the yellowfin tuna fish less than 84.64cm long had 25% probability of capture, those at 96.38cm in length had 50% probability of capture, and those greater than 100.83cm long had 75% probability of capture. Furthermore, in Table (1), a comparison of total mortality, natural mortality, fishing mortality and exploitation rates of yellowfin tuna in several locations can be seen, where it can be seen that at the current research site and in the waters of the Banda sea, the exploitation rate has exceeded the maximum value. This is due to the high number of tuna caught, as well as the absence of a management model carried out by the Department of Fisheries and Marine and by local fishermen.

Table 1. Study of mortality rate and exploitation rate in several location

Source/Year	Location	(Z)	(M)	(F)	(E)
Present study (2023)	**Ternate waters**	**3.89**	**1.55**	**2.34**	**0.60**
Haruna *et al.* (2018)	Banda Sea	1.47	0.49	0.98	0.67
Nurdin *et al.* (2016)	Pelabuhan Ratu	1.27	066	0.61	0.48
Kaymaram *et al.* (2014)	Oman Sea	2.04	0.48	1.56	0.76
Damora & Baihaqi (2013)	Banda Sea	2.40	0.68	1.79	0.75
Kantun & Amir (2013)	Strait of Makassar	2.21	0.55	1.69	0.77
Rohit *et al.* (2012)	East Cost of India	0.71	0.48	0.23	0.32

Keterangan : (Z) = Total mortality rate; (M) = Natural mortality rate; (F) = Fishing mortality rate; E = Exploitation rate.

The VPA result (Fig. 11) shows that the yelowfin tunas at 14 - length range, natural mortality was more dominant when they reached lengths between 16 to 37cm. Meanwhile, the yellowfin tuna began to be vulnerable to capture pressure when the proportion of caught fish and fishing mortality (F) values increased. The F value began to increase at 0.03 per year mortality rate when the fish reached 60.0cm in length, with the most vulnerable to capture ranging between 72.0 to 96.0cm long, and when the F value reached its peak at 2.38 per year. At a size greater than 96.0cm, the proportion of survivors compared to the combined population of those caught and suffering from natural mortality began to appear balanced.

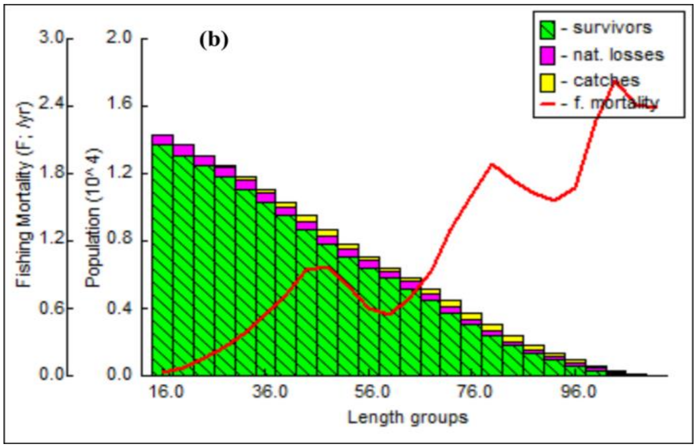


Fig. 11. Analysis of virtual population of yellowfin tuna in Ternate waters

2.5. Recruitment pattern

Recruitment is a method to see the addition of new individuals into a population **(Caley *et al*., 1996; Lelono *et al*., 2018)**. It was determined via using the asymptotic length, growth coefficient, and t0 values obtained from calculating the measurement data during the study. From the recruitment pattern analysis, it was found that, the yellowfin tuna had recruitment nearly every month even if the number was not too big (Fig. 12). Fig. (12) also shows that the first peak of yellowfin tuna recruitment occurred in March at 6.72%, and the second recruitment was the highest recruitment rate occurring in August at 25,18%. These different recruitment patterns usually occurred because of the fish growth rate **(Mawarida *et al*., 2022)**.

2.6. Yield per recruitment (Y/R) and biomass per recruitment (B/R)

SPR is an approach used to estimate fish resources utilization status, where SPR is the relative reproduction index as a point of biological reference to discover the utilization status between selectivity and size of fish caught and the adult fish size in the fisheries being exploited **(Prince *et al*., 2014)**. The estimated yellowfin tuna SPR was at 30% when the F/M ratio was 1.6 and M/K was 1.1 (Table 2 & Fig. 13). This SPR level was also contributed by the average size of the yellowfin tuna caught (SL50), i.e., 78.04cm, which was also the fish size at first maturity, i.e., 78- 158cm **(Fishbase.org, 2023)** .

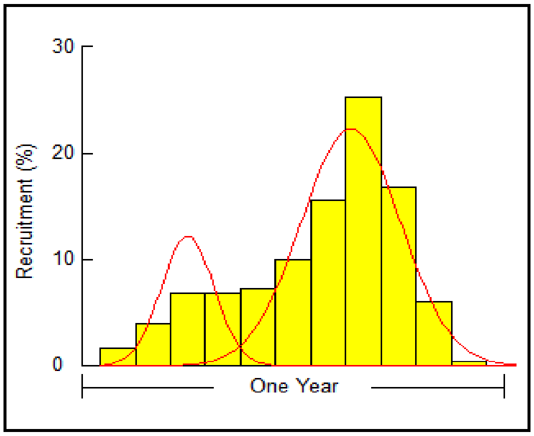


Fig. 12. Recruitment pattern of yellowfin tuna (YFT) in Ternate waters

Table 2. Estimated SPR value of YFTs (*Thunnus albacares*, *Bonnaterre*, 1788) caught in Ternate waters

Species	SPR (%)	SL_{50}	SL_{95}	F/M	MK	L∞
YFT	19	96.38	110.11	1.5	1.1	117.60

Fig. (13) illustrates the visualization of SPR at 19%, indicating that the utilization rate of yellowfin tuna had been over exploited (SPR< 20%). This was supported by the estimated exploitation rate value that had reached E= 0.60, and the result of analysis and observation from the Ministry of Marine Affairs and Fisheries of Indonesia on the utilization rate of yellowfin tuna in Ternate waters (WPP 715) that had been fully exploited. Therefore, this research result could be taken into consideration by fishermen and policymakers to devise an effective management strategy to maintain and conserve the fish resources, especially the yellowfin tunas, by closing down the access to capture areas where smaller fish live and has not spawned yet. Tagging can be used as a strategy to track the specific areas used as spawning areas to protect the fish broodstock when spawning to allow the recruitment of new individuals into the stocks to increase in the future.

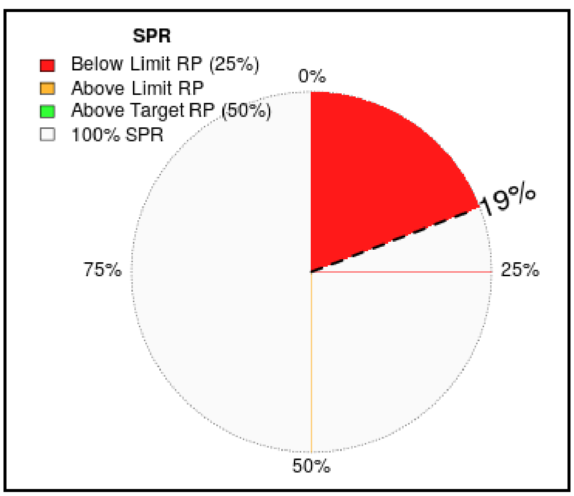


Fig. 13. SPR value of yellowfin tuna (*Thunnus albacares*)

CONCLUSION

Yellowfin tuna is a leading fishery commodity for Ternate Island fishermen which causes high exploitation pressure on these fish resources. The results showed that based on yellowfin tuna population parameters including asymptotic length, growth coefficient to mortality analysis, recruitment pattern and spawning potential ratio (SPR) value, the utilization rate of yellowfin tuna in Ternate Island waters has reached an over exploited condition, which is also supported by the value of the exploitation rate which is already in an over fishing condition. To ensure the sustainable management and conservation of the yellowfin tuna population in Ternate Island waters, it is necessary to conduct further studies to reduce fishing trips, use a larger fishing line size to get a catchable size (ever spawning) and temporarily close areas that have been over exploited and the fishing season when the fish are in a mature gonad condition.

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