Population dynamic of skipjack (*Katsuwonus pelamis*) in Timor Sea, East Nusa Tenggara, Indonesia

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Abstract. Skipjack tuna is one of the potential fishery commodities in the waters of Timor, East Nusa Tenggara. This fish is exploited throughout the year without any management policies. This study aims to analyse population dynamic parameter. Length data were collected at the Oeba Fish Base from April to December 2020. Data analysis, size structure and age group of the Bhattacharya method, the \( L_\infty \) and \( K \) values of the Ford and Walford method, total mortality by length catch converted curve, natural mortality by Pauly method, \( Y/R \) using the Beverton and Holt method. The results showed that the smallest fish was 27 cm FL, the largest was 71 cm FL, the dominant size is 55-58 cm FL and the average length was 48.68 ± 10.67 cm FL, \( L_\infty \) 91.00 cm FL, and \( K \) 0.51 year\(^{-1}\). The population consists of three age groups, the values of \( Z \), \( M \), \( F \) and \( E \) are 2.64 year\(^{-1}\), 0.86 year\(^{-1}\), 1.78 year\(^{-1}\), and 0.68 year\(^{-1}\) respectively. Current \( Y/R \) and optimal \( Y/R \) values are 0.036 and 0.060 grams recruit\(^{-1}\) respectively. The conclusion, the high mortality of skipjack tuna is caused by fishing activities, and the high level of exploitation causes the recruitment process to be not optimal.

1. Introduction
The waters of East Nusa Tenggara are part of the Fisheries Management Area 573 and 713. WPP NRI 573 covers the Indian Ocean south of Java to the south of Nusa Tenggara, the Savu Sea, and the western Timor Sea, as well as WPP NRI 713 which includes the Makassar Strait, Bone Bay, Flores Sea, and the Bali Sea. Capture fisheries production in NTT Province shows fluctuating conditions. Total fishery production in 2013 was 103,825 tons, in 2014 there was an increase of 6.81%, by 111,415 tons, in 2015 it was 118,391 tons (an increase of 5.8%), in 2016 it was 128,931 tons (an increase of 8.17%), in 2017 the total production was 72,226 tons (a decrease of 78%) [1].

One of the large pelagic fish that is important and becomes an export commodity in the waters of the Timor Sea of East Nusa Tenggara is skipjack tuna (*Katsuwonus pelamis*). This fish resource has long been used by fishermen using various fishing gear, including hand line, trolling line, pole and line, purse seine, traditional seine net, and drift gill net [2]. Skipjack tuna production in East Nusa Tenggara Province in 2012 reached 6,328.15 tons, in 2013 it increased by 45.05% with production reaching 11,516.48 tons, in 2014 it increased again by 18.64% so that the total production became 14,155.6 tons while in 2015 production did not change, and in 2016 production decreased by 235.68% with a total production of 4,217 tons [3]. This fluctuating condition is thought to be related to...
population dynamics (growth, mortality, recruitment) and the condition of skipjack tuna stocks in the waters.

The study of fish population dynamics is the key to the future management of skipjack fish resources. Fishing efforts become a strategic economic business in the future, but on the contrary, it will cause problems, if there are no restrictions. To manage skipjack tuna resources, accurate data and information are needed to be related to biological aspects, population dynamics, stock conditions, and several related aspects. Some researchers report that skipjack tuna in Indonesian waters has a high catch rate [4], the use of fishing aids also causes many problems [5], overfishing will result in a decrease in the size and age of fish in the population [6], the stock of a type of fish has decreased characterized by smaller fish size, decreased growth rate, the number of age groups in the population is not much, the size suitable for catching is small [7]. In fact, high exploitation will significantly affect production results [8].

Based on the description above, it is necessary to study the dynamics of the skipjack tuna population in the Timor Sea, East Nusa Tenggara Province. This study aims to analyze the population dynamics parameters (size structure and age group, growth rate, mortality, exploitation rate, and catchable-size) of skipjack tuna in the waters of the Timor Sea, East Nusa Tenggara Province.

2. Research Method

2.1. Time and location of research
This research was conducted from April to December 2020. Sampling and measurement were carried out at the Oeba Fish Landing Base, Kupang, East Nusa Tenggara. The location of the research is presented in Figure 1.

![Figure 1. Location of the research](image)

2.2. Materials and equipment
The materials and types of equipment used in this study included skipjack tuna, cameras, stationery, fish measuring boards, computers, and software to analyze data such as MS excel and FISAT II.
2.3. **Data collection**

Data on skipjack catches, including fish length (cm, FL), were collected directly by following the fishermen who landed their catch at the Fish Landing Base (PPI). Fish samples were taken using the Stratified Random Sampling method by classifying the caught fish based on small (<30 cm), medium (30-50 cm), and large (>50 cm) sizes.

2.4. **Data analysis**

2.4.1. **Structure size.** The size structure of the fish was analysed descriptively by displaying the length class, and fishing frequency presented in the form of a histogram (column diagram).

2.4.2. **Age groups.** Age group estimation was carried out by means of long frequency analysis which was processed using the Bhattacharya method and displayed in a column diagram [9].

2.4.3. **Fish growth.** Fish growth parameters (K & L∞) analysed using the Von Bertalanffy exponential growth equation [10] as follows:

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

Where, \(L_t\) = Length of fish at age \(t\) (cm), \(L_\infty\) = Maximum length that can be reached by fish (cm), \(K\) = Length growth rate coefficient, \(t\) = Age of fish (years), and \(t_0\) = The theoretical age of the fish when the length is equal to zero (years)

The theoretical age (\(t_0\)) is calculated using an empirical equation [11,28] as follows:

\[
\log (-t_0) = -0.3922 - 0.2752 \log (L_\infty) - 1.038 \log (K)
\]

2.4.4. **Total mortality.** The total mortality (Z) rate was obtained from the length conversion catch curve method using FiSAT II.

2.4.5. **Natural mortality.** The natural mortality rate (M) was estimated using the empirical formula [12] as follows:

\[
\log (M) = -0.0066 - 0.279 \log (L_\infty) + 0.6543 \log (K) + 0.4634 \log (T)
\]

Where, \(M\) = Natural mortality (years), \(L_\infty\) = Asymptotic length in the Von Bertalanffy growth equation, \(K\) = coefficient of growth in the Von Bertalanffy growth equation, and \(T\) = Average water surface temperature (°C)

2.4.6. **Fishing mortality.** Fishing mortality rate (F) assumed by using the equation;

\[
F = Z - M
\]

2.4.7. **Exploitation rate.** The exploitation rate (E) of skipjack tuna is determined by comparing the fishing mortality rate (F) with the total mortality rate (Z), namely:

\[
E = F / Z
\]

2.4.8. **Yield Per Recruitment.** Yield Per Recruitment (Y/R), obtained from the equations of Beverton and Holt [10], namely:

\[
(Y/R) = E, U^m \left[1 - \frac{3U}{1+m} + \frac{3U^2}{1+2m} + \frac{U^3}{1+3m}\right]
\]
\[ U = 1 - \frac{L_c}{L_\infty} \]

\[ m = \frac{1 - E}{K} \]

Where, \( L_c \) is the length of the fish at age \( t \) (cm), \( K \) is the coefficient of growth rate (per year), \( Z \) is the total death rate (per year), \( M \) is the death rate due to natural factors, and \( E \) is Exploitation rate (per year).

All parameters above calculated using the help of FISAT II software

2.4.9. Catch-up size presentation. The size suitable for catching using the Mallawa method [13], namely that the fish that enter the catchable-size are skipjack tuna that has spawned, the size of skipjack tuna spawned for the first time > 55 cm The percentage of suitable size for catching is calculated using the following equation:

\[ I_E = \left( \frac{I_S}{I_T} \right) \times 100 \% \]

Where, \( I_E \) is the number of fish worth catching (%), \( I_S \) is the number of fish that have spawned (tail) and \( I_T \) is the total number of fish caught or sample fish (tails)

3. Results and discussion

3.1. Size structure

Skipjack collected during the study period as many as 1229 samples had a length range of 27 - 74 cm FL, the smallest size was 27 cm FL while the largest size was 71 cm FL. The mean length was 48.68 ± 10.67 cm FL. The largest size of skipjack caught was in the length range of 55 – 58, which was 262 (21%), and the length range of 39-42 of 190 fish (15%) (Figure 2).

![Size structure of skipjack in the waters of the Timor Sea](image)

The length of skipjack tuna caught in the study area did not differ much from the length of skipjack in other locations, as reported by the following studies. Skipjack tuna in the Makassar Strait has a length range of 12.5 - 72.5 cm FL[12], in the waters of Barru, Makassar Strait, based on data from fishermen's catches during the East to West season shift, skipjack tuna has a length ranging from 17.5
to 72.5 cm FL [13], in the waters of the Flores Sea has the smallest size, 17.5 cm FL, the largest is 69.5 cm FL with an average length of 37.2 cm FL [2], skipjack tuna caught in Bone Bay in the East monsoon, dominantly has a length of around 45.0 - 54.5 cm FL and the average length of skipjack tuna is 50.73 cm FL [14,15], in Andaman waters reported skipjack lengths of 16.5 to 71.0 cm FL [16], while in Indian waters during the period 2006-2010, skipjack lengths ranged from 12 to 88 cm FL[17]

3.2. Number of age groups (Cohort)
The results of the analysis using the Bhattacharya method in the FISAT II program can be seen that skipjack fish caught in the study area have three age groups with an average individual length of 38.45 ± 3.43 cm for the age group I, 54.46 ± 2.47 cm for age group II and 64.88 ± 2.87 cm for age group III (Figure 3).

![Figure 3. Composition of size and number of skipjack cohort in the waters of the Timor Sea](image)

The figure shows three cohorts with varying average lengths. The smallest size group is thought to be the beginning of recruitment. The results of research in the Makassar Strait waters consist of three age groups [18], in the Flores Sea waters there are two age groups with the average length of individuals per age group differing according to fishing area and fishing technology [2], while in Bone Bay waters there are two age group or come from two different times of birth [14].

The age group in the waters is relative. Age groups (cohorts) in the population are always dynamic as a result of survival numbers, changes in individual length, changes in individual weight, and changes in population biomass [19].

3.3. Population Growth
Growth parameter analysis was carried out using ELEFAN I in the FISAT II program by means of visual response surface analysis and automatic search to obtain the values of K, L∞, and Rn (Goodness of fit), the value of Rn = 0.341. The estimated value of the infinity length growth parameter (L∞), the growth rate coefficient (K) through the von Bertalanffy growth model equation, and the theoretical age value (t0) using the Pauly method can be seen in table 1. The growth curve is presented in Figure 4.

| Parameter                          | Value   |
|-----------------------------------|---------|
| Asymptote Length, L∞ (cm)         | 91.00   |
| Coefficient of growth rate, K (per year) | 0.51    |
| The theoretical age of fish length is equal to zero, (years) | -0.235  |
Based on the parameter values presented in table 1, the Von Bertalanffy exponential growth equation can be written as follows:

\[ L_t = 91.00 \times (1 - e^{-0.51 \times (t + 0.235)}) \]

The relationship between length and age and the estimated length according to the age of skipjack tuna in the waters of the Timor Sea, East Nusa Tenggara province are presented in Figure 5 below.

The value of the coefficient of growth rate (K) of skipjack tuna in the study area is 0.51 per year, this condition explains that the population of skipjack tuna in the waters of the Timor Sea of East Nusa Tenggara is relatively fast (K> 0.5). Fish that have a high coefficient of growth rate (K) means that they have a high growth rate and usually these fish require a short time to reach the maximum length [20]. The higher the growth rate value, the faster the fish reach their asymptote length (L infinity), but most of them are also short-lived. The growth rate of fish does not have an absolute value but is dynamic, always changing along with the development of life, metabolic rate, and environmental conditions [21].

Skipjack tuna has a maximum length that varies, this condition is thought to be due to differences in location, time of the study, number of samples taken at the time of the study, availability of feed and water conditions, and fish stocks. The \( L_\infty \) value is closely related to the maximum length of the observed fish sample (L max) [11]. In the following table 2, previous studies in different locations are presented, which show different values of the von Bertalanffy growth parameters (\( L_\infty \) and K).
Table 2. Estimated growth parameters of skipjack tuna in different locations

| Area                          | L∞(cm) | K(year⁻¹) | Reference                          |
|-------------------------------|--------|-----------|------------------------------------|
| Makassar Strait               | 107.0  | 0.8       | Amir and Mallawa (2015),           |
| Flores Sea                    | 106.0  | 0.5       | Mallawa et al (2014)               |
| South Indian Ocean Java       | 80.85  | 1.1       | Rochman et al (2015)               |
| Southwest Atlantic            | 90.10  | 0.24      | Soares et al (2019)                |
| Andaman waters                | 74.55  | 0.59      | Divakar et al (2017)               |
| Southern Arabian Sea          | 72.5   | 0.48      | Muhsin et al (2020)                |
| Indian waters                 | 92.0   | 0.50      | Koya et al, (2012)                 |
| Tuticorin waters, Tamil Nadu, | 95.70  | 0.40      | Kumar et al (2019)                 |

3.4. Mortality and exploitation

Calculation of total mortality using the “Length converted catch curve” method with the help of FISAT II software (figure 6). The Z, M, F, and E values of skipjack tuna (Katsuwonus pelamis) in the waters of the Timor Sea are presented in table 3 below.

Table 3. Z, M, F and E values of skipjack tuna in the waters of the Timor Sea

| No  | Mortality value | Estimated value (per year) |
|-----|-----------------|----------------------------|
| 1   | Total mortality (Z) | 2.64                       |
| 2   | Natural mortality (M) | 0.86                       |
| 3   | Fishing mortality (F) | 1.78                       |
| 4   | Exploitation rate (E) | 0.68                       |

Based on the results in Table 3, it can be explained that the total mortality rate obtained is in line with the number of age groups of skipjack tuna populations in the waters of the Timor Sea. In theory, the higher the total mortality value (Z) the faster an age group disappears. It was further explained that when Z approaches the value of two per year, the number of age groups in the population ranges from 1-3 age groups, at a value of Z = 1 the number of age groups in the population is 3 to 5 age groups [22].

Figure 6. Length converted catch curve of skipjack in the waters of the Timor Sea
The fishing mortality value is based on the Mallawa classification [13], where \( F < 1 \) = low, \( F = 1.0 - 2.0 \) high and \( F > 2.0 \) very high. The mortality rate of skipjack tuna fishing in the study area is high (1.78 per year), higher than natural mortality. The number of deaths due to catch is thought to be due to the intensified exploitation by fishermen, resulting in an increase in the number of fleets and fishing gear.

Research results in the Indian waters of Tuticorin, obtained the estimated \( Z, M, \) and \( F \) values, respectively, 1.63, 0.73, and 0.90 per year [23], while the results of research off the southeast coast of Brazil, assuming \( M = 0.7 \) and \( K = 0.307 \) per year, increasing fishing mortality rates by 30% and 50% [24]. The same opinion is also expressed by the results of research in the East Pacific Ocean, stating the uncertainty in estimates of monthly fishing mortality by around 40% to 140% per year [25], in the Southwest Atlantic the reported values of \( Z, M, \) and \( F \) are estimated 1.42 year\(^{-1} \), 0.95 year\(^{-1} \), 0.47 year\(^{-1} \) [26], while in the south of the Arabian Sea the number of natural mortality, fishing mortality and total mortality were 0.82, 1.51 and 2.33 [27].

3.5. Yield per recruitment

The exploitation rate is an indicator of the population caught in the sea waters of Timor, East Nusa Tenggara. The results of the FISAT II analysis obtained the value of the exploitation rate (\( E \)) of 0.68 per year, the value of \( Lc/L\infty = 0.050 \) and \( M/K = 1.00 \), while the \( E_{max} \) and \( E_{opt} \) values were 0.421 and 0.355, respectively.

![Figure 7. Model Relative Yield-per-Recruit (Y/R) Beverton & Holt Skipjack in the waters of Timor Sea](image)

The optimal \( Y/R \) value is 0.060 grams per recruit, and the actual \( Y/R \) value is 0.036 grams per recruit, indicating that the \( Y/R \) of skipjack tuna in the waters of the Timor Sea, East Nusa Tenggara is not optimal where the current \( Y/R \) is smaller than the optimal \( Y/R \), it can be interpreted that the recruitment process is not going well. This condition occurs in populations or stocks with a high level of exploitation (\( E > 0.5 \) per year). The value of \( E = 0.68 \) per year indicates the level of exploitation that has passed the MSY value (\( E > 0.50 \)) [29].

3.6. Catch-up size presentation

Of the 1229 research samples in the study area, 48.41% was the size of fish that was suitable to be caught with a length class of 55 -74 cm FL (>55 cm FL), then 51.59% was a fish size that was not suitable to be caught with a length class 27 – 54 cm FL.

The size of skipjack tuna when it first spawns is > 55 cm and those of such size is declared catching size [13]. The results of the research in the study area showed that the size of fish suitable for
catching was quite high (48.41%). From 1229 samples obtained consisted of young to adult fish, and the dominant fish were pre-adult fish and adult fish.

The percentage of a fish size suitable for catching in waters differs according to location, the number of fish samples, stock, and water conditions. The percentage of a fish size suitable for catching (> 55 cm) in the waters of Bone Bay in the East season is 32.0%, in the West season, it is 15.0% [14], while the fish caught in the FAD area of Barru waters, Makassar Strait, which is included in the size of fish fit to be caught is 10.86% [13], the percentage of fit-to-catch size with pole and line through hunting is greater than that of pole and line with FAD [30].

4. Conclusion

Based on the results of the study, several conclusions can be drawn as follows: Skipjack tuna in the waters of the Timor Sea, East Nusa Tenggara has a length ranging from 27-74 cm, skipjack tuna caught a lot in the size of 39-42 cm and 55-58 cm, consisting of young, pre-adult, and adult fish. Consisting of three age groups, Skipjack tuna in the waters of the Timor Sea, East Nusa Tenggara has a fast growth so that it reaches asymptotic length (L∞) faster, a high total mortality rate, the main cause of death due to fishing activities, a high level of exploitation and causes the recruitment process to be not optimal. The actual Y/R is less than the optimal Y/R value. The number of skipjack tuna that is suitable for catching in the catch of fishermen is quite high and higher than in other waters.

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