Population dynamics of skipjack tuna (*Katsuwonus pelamis*) in the northern and western waters of Aceh

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**Abstract.** Skipjack tuna (*Katsuwonus pelamis*) is a pelagic fish species that have important economic value in the northern and western waters of Aceh. Skipjack tuna is one of the dominant catch fish landed at the Fishing Port of Kutaraja, Banda Aceh. The dynamics population of skipjack tuna in the northern and western waters of Aceh need to be done to get information on the status of skipjack tuna in ocean. This research aims to determine the dynamic parameters of the population of skipjack tuna based on the growth parameters, length and weight relationship, length distribution, length at the first capture, mortality, and exploitation rate. The data collection was conducted in February to March 2020, located at the Fishing Port of Kutaraja, Lampulo, Banda Aceh. A total of 166 sample, were measured with stratified random sampling method. The FAO-ICLARM Stock Assessment Tools (FiSAT) program was used by analyze growth parameter, mortality parameters, and exploitation rate. The results showed that has a negative allometric growth pattern, with a length of fork length (FL) ranging from 25-51 cm. The length of first capture was 38.2 cm. The asymptotic length (L∞) of skipjack tuna was 84.78 cm with K value of 0.22/year and. The estimated natural mortality (M), fishing mortality (F), and total mortality (Z) were 0.5/year, 1.55/year, and 2.99/year respectively. The exploitation rate (E) of skipjack tuna was 0.83/year that indicated skipjack tuna in the Northern and Western waters of Aceh over-exploited.

1. Introduction
Fishers that landed their catches in the Fishing Port of Kutaraja mostly catches from northern and western Aceh waters. These waters are directly adjacent to the two most important waters with the Andaman Sea and Malacca Strait in the northern part and the Indian Ocean in the western part. In the Indian Ocean, skipjack tuna (*Katsuwonus pelamis* Linnaeus, 1758) became the most dominant catches [1-3], highly affected by oceanographic factors, sea surface temperature, and chlorophyll-a. Skipjack tuna is also well known for their preference in deep depth, water current, and have a great distance from the coastline, such as in the Indian Ocean and Malacc Strait [4].

Skipjack tuna is one of the primary commodities in the fisheries sub-sectors because of its high economic value, and the Fishing Port of Kutaraja became one of the skipjack tuna suppliers within and outside the area. Skipjack tuna is also the most dominant fish catch landed in the Ocean Fishing Port of Kutaraja, with a total of 6.709.470 kg in 2018 [5].
The exploitation activity of skipjack tuna must include the sustainable principle to protect natural resources. This principle is important because of the environment's fragility; hence the right optimization and management are needed. One of many aspects of analyzing fish stock availability is the biological aspect, the dynamic population aspect [6-10]. The dynamic population parameters used in this study are length-weight relationship, distribution frequency, length at first capture, growth, mortality, and exploitation rate.

2. Material and Methods

2.1. Data Collection
This study was conducted from February to March 2020 in the Fishing Port of Kutaraja, Lampulo, Banda Aceh. A total of 166 sampled fish collected using stratified random sampling, with a catching trip as the stratification factor. The first stratification is the purse seine fishing fleet with the daily trip and the second stratification is the purse seine fleet with the weekly trip. The stratified random sampling was used to collect a sample from each stratification. The primary data collected from each sample were the study of the biological aspects, which are length (cm) and weight (gr). The secondary data used in this study was collected through interviewing fishers on the coordinate of the purse seine fishing fleet, which is the main fishing gear of skipjack tuna.

2.2. Data Analysis
The length-weight relationship can be analyzed using the equation of \( W = a \), with \( W \) is the total fish weight (gram), \( L \) is the fish fork length (cm), while \( a \) and \( b \) is the regression result constant. The constant (b) value shows the fish growth pattern, isometric, or allometric.

The length at first capture (Lc) was calculated through the frequency distribution value of the fish length. This distribution value was then analyzed using the standard equation approach, where the length class that has the highest fork length value (cm) is the length at first capture (Lc) [11]. The mathematical model for the equations are as follow:

\[
\begin{align*}
S_{L_{est}} &= \frac{1}{1 + \exp(S1 - S2 \times L)} \\
\text{Ln} \left| \frac{1}{S_{L_{50\%}}} - 1 \right| &= S1 \cdot S2 \cdot L \\
S_{L_{50\%}} &= \frac{S1}{S2}
\end{align*}
\]

where:
- \( S_L \) = logistic curve
- \( S1 \) = a
- \( S2 \) = b
- \( S1 \) and \( S2 \) = constant of the logistic curve formula

The value of \( t_0 \) was calculated using Pauly’s empirical formula, which calculates the multiple regression relation between theoretical lifespan when the fish length is zero (\( t_0 \)) with fork length (\( L_\infty \)) and growth rate (\( K \)), as follows:

\[
\text{Log} - t_0 = -0.3952 - 0.2752 \text{ Log } L_\infty - 1.038 \text{ Log } k
\]

where:
- \( L_\infty \) = asymptotic fish length (cm)
- \( k \) = von Bertalanffy’s growth rate

Growth parameters (\( K \) and \( L_\infty \)) measured using the ELEFAN I method [12] based on the von Bertalanffy’s equation as follow:

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

where:
- \( L_t \) = fish length at age of \( t \) (cm)
\[ L_\infty = \text{asymptotic fish length (cm)} \]
\[ t_0 = \text{theoretical lifespan of fish at length } 0 \]
\[ K = \text{Von Bertalanffy’s growth rate} \]

The total mortality rate assumption (Z) was calculated using the catch curve method with \( \ln \frac{N}{t} \) as the relative lifespan, referring to Pauly’s formula \[13\] as follow:

\[
\ln \frac{N}{t} = a - Zt \]

where:
\[
N = \text{number of fish at } t \text{ time} \\
t = \text{time needed to grow in certain length class} \\
a = \text{fish length converted from fish catch} \\
Z = \text{total mortality} \\
R = \text{total mortality rate} \\
K = \text{Von Bertalanffy’s growth rate} \\
T = \text{average water temperature (°C)}
\]

Natural mortality assumption (M) was calculated based on Pauly’s empirical formula \[14\] with average sea surface temperature per year in degree Celcius (T). Pauly’s empirical formula is as follow:

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

where:
\[
M = \text{natural mortality coefficient} \\
L_\infty = \text{asymptotic fish length (cm)} \\
K = \text{Von Bertalanffy’s growth rate} \\
T = \text{average water temperature (°C)}
\]

Fishing mortality (F) can be calculated with the formula below:

\[
Z = F + M, \text{ to: } F = \frac{Z}{M}
\]

where:
\[
Z = \text{total mortality rate} \\
F = \text{fishing mortality rate} \\
M = \text{natural mortality rate}
\]

Based on the fishing mortality rate value (F) assumption, the value is divided by the total mortality rate (Z). The assumption is then counted using the exploitation rate (E) using this formula:

\[
E = \frac{F}{Z}
\]

Optimal fish resources have an exploitation rate of 0.5, and natural mortality is equal to fishing mortality. While exploitation value (E) higher than 0.5 indicate over exploitation.

3. Results and Discussion

3.1. Length-weight relationship

The analysis carried out calculated the approximate length of skipjack tuna is between 25-51 cm with a weight of 230-1940 grams. Figure 1 shows the relationship between fish length and weight with equation of \( W = 0.010L^{3.156} \) with determination coefficient \((R^2) = 0.940\% \). This value means that increase in fish weight is 94\% caused by an increase in fish length, while 0.6\% was caused by other factors such as age and environment. Based on the analysis result, \( a = 0.010 \) and \( b = 3.156 \).

The result of \( b \) that was tested with \( t (\alpha = 0.05) \) concluded that fish growth pattern is positive allometric because \( b > 3 \), where fish weight increases faster than fish length. However, a study by \[15\] showed that the skipjack tuna growth pattern is positive allometric, which means that weight growth is more dominant than length growth. Zahid and Simanjuntak \[16\] argued that a fish’s growth pattern might be affected by many factors. The factors such as season, the maturity of the gonads, habitat, health,
food, stomach contents and yearly growth variation, average fish size, number of fish samples, fish conditions, and environmental factors [6-8, 17-25].

Figure 1. The length-weight relationship of skipjack tuna (*Katsuwonus pelamis*).

3.2. Length frequency distribution
Figure 2 shows that the skipjack tuna growth pattern is positive allometric (b = 3.156), where the growth of weight is higher than length. Fish age group analysis was carried out after calculating the total length-frequency distribution at each fish sampling. The frequency analysis was then plotted into Figure 2.

Figure 2 shows the measurement result of 166 fish divided into 14 classes with 2 cm intervals. Fish samples have a maximum fork length (FL) of 51 cm FL and a minimum of 25 cm FL. The mode of length class is 41.5 cm FL, with a total of 42 fish caught. The mode values are the same for distribution frequency in February and March (41.5 cm FL) and were the most fish size caught each month.

Figure 3 also shows the mode length class of 41.5 cm, with approximately 42 fish catch. In February, 104 fish was caught and dominated by the fish with the mode length of 41.5 cm as much as 23 fish. While in March, from 62 fish caught, 19 fish fell into the mode length of 41.5 cm.

3.3. Length at first capture
The length at forst capture (Lc) calculated using frequency data and fish size class. The analysis of the Lc is shown in Figure 3. Figure 3 shows that the length at first capture (Lc) of skipjack tuna is 38.2
cm FL. The difference in fish size caught in each area is based on the fish gear used. Gear selectivity can be one solution to regulate the fish size allowed to be caught [26].

3.4. Growth parameters

Analysis of the parameters was performed to estimate the asymptote length ($L_\infty$), growth rate ($K$), and theoretical age ($t_0$). The results are shown in Table 1.

| Parameter | Value |
|-----------|-------|
| $L_\infty$ (cm) | 84.78 |
| $K$ (/year) | 0.22 |
| $t_0$ (year) | -3.50 |

The analysis carried out resulted in the von Bertalanffy growth function equation for skipjack tuna ($Katsuwonus pelamis$), as shown in Figure 4. The von Bertalanffy growth function of skipjack tuna was $L_t = 84.78 \cdot [1-e^{-0.22(t+3.50)}]$. Skipjack tuna has a low growth rate value ($K$) of less than 0.5 per year, i.e., 0.22 per year. This result is similar to Sparre and Venema [27] mentioned that fish with a high growth rate coefficient value ($K$) has a high growth rate and needs a short time to reach its maximum length. Meanwhile, fish with a low coefficient rate need a longer time to reach its maximum length. The initial parameter condition of the $t_0$ value is negative because of the uncertainty of the initial age of fish birth determination. Based on the skipjack tuna’s growth curve, fish growth is relatively fast toward 20 years and slows down next year and reaches the maximum length.

3.5. Mortality parameters

The catch curve using the Mortality Estimation program integrated into the FAO-ICLARM Fish Stock Assessment Tools (FiSAT II) software program of skipjack tuna ($Katsuwonus pelamis$) fish in northern and western Aceh waters can be seen in Figure 5.

The mortality rate of skipjack tuna was analyzed using the Sparre and Siebren method by including an average water temperature of 29°C into Pauly’s empirical equation. The results are total mortality ($Z$) = 2.96/year, natural mortality rate ($M$) = 0.50/year, and fishing mortality rate ($F$) 2.46/year, as shown in
Figure 6. Fish death is caused by two factors: natural mortality (M) and fishing mortality (F). The result shows that the natural mortality rate (M) of skipjack tuna is lower than the fishing mortality rate (F). A high number in fishing mortality rate (F) of skipjack tuna is assumed caused by continuously catching activity with no regulation on the size of skipjack tuna that is allowed to be caught. These activities can decrease skipjack tuna stock and high total mortality value (M), reaching 2.46/year.

Figure 4. Growth rate curve of skipjack tuna (Katsuwonus pelamis).

Figure 5. The mortality rate of skipjack tuna (Katsuwonus pelamis).

Figure 6 shows the result of total mortality analysis, which is (Z) 2.96/year, natural mortality (M) 0.51/year, fishing mortality (F) 2.46/year, and exploitation rate (E) 0.83. The skipjack exploitation rate calculated in this study is 0.83 (E>0.5). Tangke [28] stated that a resource is exploited in an optimum condition if F = M, i.e., Eopt = 0.5. If E > 0.5, then the fish resources in the waters are in an overfishing condition. Based on the E value calculation (0.83/year) indicate an overexploited activity of skipjack tuna in northern and western Aceh waters, and resulted in a smaller skipjack tuna size caught. An increase in fishing activity may result in threatening fish resources [29].

4. Conclusion
This study concluded that the growth pattern of Katsuwonus pelamis in northern and western Aceh waters is positive allometric (b>3) with the first fish caught size Lc = 38.2 cmFL. Based on the analysis, the growth value L<sub>∞</sub> = 84.78 cmFL (K) 0.22/year and t<sub>0</sub> = -3.50. Total mortality rate (Z) 2.96/year, natural mortality (M) 0.51/year, and fishing mortality (F) 2.46/year. The catch mortality rate of skipjack tuna
(Katsuwonus pelamis) is higher than the natural mortality rate. This value also affects the exploitation rate value of 0.83/year or fully exploited.

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