# Stock assessment of skipjack tuna *Katsuwonus pelamis* in Makassar Strait, Indonesia

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**Abstract**. Skipjack tuna, *Katsuwonus pelamis*, is a sought-after fish commodity and has been long exported. *K. pelamis* fishing activities are common in Makassar Strait. The present study aimed to determine the *K. pelamis* population's biology in Makassar Strait. This study was conducted from April to September 2019. A total of 1,208 fish were caught during the study period. Data was collected on the length asymptote (L∞), growth coefficient (K), total mortality (Z), natural mortality (M), fishing mortality coefficient (F), exploitation rate (E) and the potential yield per relative recruitment (Y'/R). The collected data were processed using FISAT-II software package. The results showed the fork length (ranging from 33.3 to 55.4 cm), the Von Bertalanffy growth (80 cm), the growth coefficient (0.28 year$^{-1}$), the age at hatching (-0.309 years), the total mortality (1.61 year$^{-1}$), the natural mortality (0.64 year$^{-1}$) and the catch mortality (0.97 year$^{-1}$), the exploitation (0.60) and the exploitation rate (0.482x). The value of Y'/R was obtained at 0.042 and B'/R at 0.026. The growth performance index and exploitation ratio were 3.015 and >0.5, respectively. This finding suggests the fishing activities restrictions and buffer zone for the study area.
**Key Words**: exploitation rate, fisheries, population's biology, FISAT-II, natural morality.

**Introduction**. The production of skipjack tuna, *Katsuwonus pelamis*, in Makassar Strait reached 69,948 tons, with several types of fishing gears used, including the trawl technology, trolling rods and handling line. The Makassar Strait is included in the Fisheries Region Management of eastern Indonesia (WPP RI 713 region). The tuna fishing ground consists of 6 main areas around Makassar Strait, particularly West Sulawesi with a productivity of 12,093 tons (KKP 2018). However, the production of *K. pelamis* tends to decline due to the high exploitation rate.

Studies on *K. pelamis*, particularly in Eastern Indonesia, have not been carried out comprehensively. The majority of the previous studies focused on the biological aspects of *K. pelamis*, such as a study that was conducted in Bone Bay by Jamal et al (2011), Mallawa et al (2010, 2012), and Amir & Mallawa (2014) that was conducted in Barru waters. Besides, there is also a study related to *K. pelamis* reproductive biology in the Indian Ocean (Rochman et al 2015), migration and feeding habits of *K. pelamis* (Andrade & Garcia 1999; Nihira et al 1996; Arai et al 2005), the survival rate of *K. pelamis* concerning water quality changes and weather pattern (Mugo et al 2010). All these studies were intended on *K. pelamis* management, so that those studies can encourage the sustainability of *K. pelamis*.

According to Daris et al (2019), various problems can arise in the management of coastal areas, such as conflicts between the catchment areas' users. Daris et al (2020) noticed that unresolved conflicts would be the main threat to the sustainability of the coastal and marine resources, being a potential cause of the fishermen poverty, according to Demmallino et al (2020). Danial et al (2020) stated that the catch fisheries management must be carried out in an integrated manner for the fishery resources and catches productivity optimization, including the port infrastructure. El Fajri et al (2020) remarked that management becomes crucial for the sustainability of the fisheries resources in a multi-aspect and multi actors context.

Although the stock assessment of *K. pelamis* has already been carried out in several areas, none was carried out in Makassar Strait. This study also distinguishes between the types of fishing gear used, as referred to by the Western and Central Pacific Fisheries Commission (WCPFC), while providing information about the population parameters of *K. pelamis* caught in Makassar Strait. The findings can be used as a reference in formulating an appropriate management methodology of *K. pelamis* fishing sustainability in the WPP RI 713 region.

## Material and Method

***Sampling***. The present study was conducted from April to September 2019 in the Makassar Strait, Mamuju Waters. The sampling was performed twice a month, using a trolling rod as fishing gear. The fish specimens' fork length (±1 mm) was measured. The sampling was performed randomly, based on the fish size class: <30 cm (small), 30-50 cm (moderate) and >50 cm (large), according to Amir & Mallawa (2014).

***Length frequency class***. Data from the measurement of sample fish lengths were tabulated into length classes by intervals of 1 cm using the Microsoft Excel program. The FAO-ICLARM Stock Assessment Tools-II (FiSAT-II) program was applied to analyze the catch frequency by length class, according to Gayanilo et al (2005).

***Growth and mortality assessment***. The length asymptote (L∞) and growth coefficient (K) of the von Bertalanffy growth equation (Sparre et al 1989) were estimated using the Electronic Length Frequency Analysis - I (ELEFAN I) method (FiSAT-II program), as described by Gayanilo et al (2005). The L∞ and K values were calculated with the Response Surface routine, which is projecting a number of possible combinations of L∞ and K to obtain the highest conformity index of aqua surface response (Rn) values (Pauly & David 1981). The stock assessment value of "$t_0$" was calculated according to Pauly's empirical formula (1979). The estimated values of the growth parameters (L∞, K, and $t_0$) were then depicted by von Bertalanffy's growth equation, namely:

$$Lt = L\infty\ (1 - e^{-K(t - t0)})$$

Where:
Lt - fork length during the study period t;
L∞ - length asymptote;
K - growth coefficient;
$t_0$ - age if the fork length is zero.

The mortality parameters were estimated using the FiSAT-II program. The total mortality rate (Z) was estimated using the analysis of the length-converted catch curves (Sparre et al 1989). The natural mortality rate (M) was estimated using an empirical relationship (Pauly 1980):

$$\text{Log } M = -0.0066 - 0.279 \text{ Log } L\infty + 0.6543 \text{ Log } K + 0.4634 \text{ Log } T$$

Where:
L∞ - length asymptote;
K - growth parameter;
T - temperature (°C).

Fishing mortality rate (F) was determined using the relationship of mortality parameters (Z = M + F). The exploitation rate (E) was calculated using the Beverton and Holt equation, E = F / Z (Sparre et al 1989).

***The relative yield per recruitment model***. The catch probability was estimated from the capture curve converted to length, using the moving average technique to determine the length capture (Lc). The relative yield per recruitment (Y'/R), as a function of E, was estimated using the FISAT-II program by entering the values M/K and Lc/L∞ (Pauly & Soriano 1986).

**Results and Discussion**

***Distribution of fish length***. The number of *K. pelamis* specimens collected during the study period was 1,208, with a size distribution ranging from 33.5 to 55.5 cm (40.87±0.131 cm). The dominant size class was in the range of 40.0-41.0 cm in length, with 109 specimens (9.02%) and the lowest distribution was found in the size class of 55.0-56.0 cm, with 2 specimens (0.17%) (Figure 1).

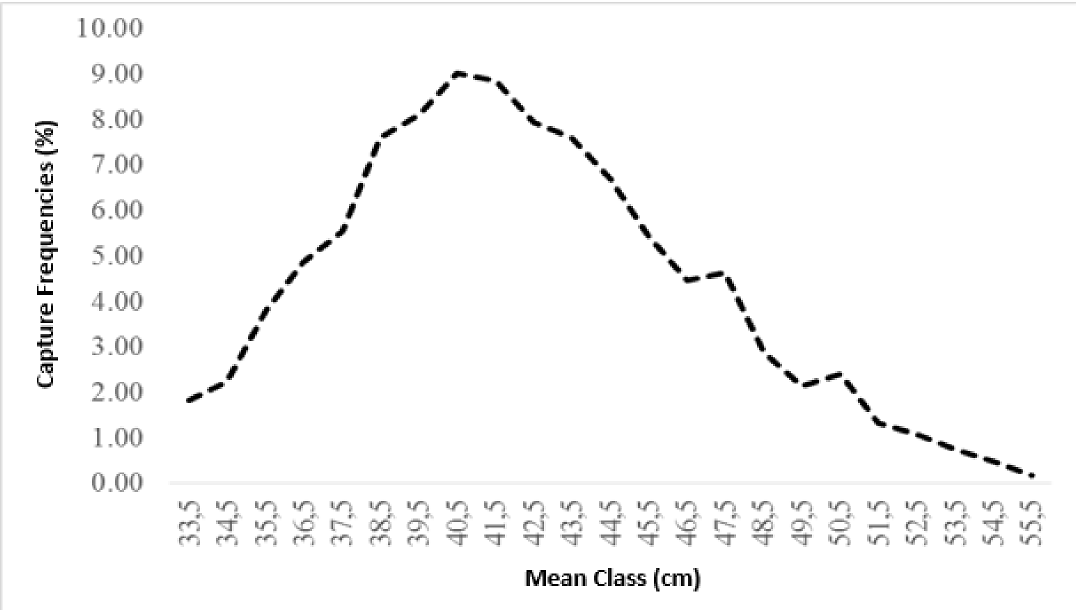


Figure 1. Fork length distribution of *Katsuwonus pelamis*.

The present study's results had smaller size distributions compared to previous studies. The size distribution is related to the size of the fishing line used and to the status of the resources: *K. pelamis* are mostly caught in the areas around the small size Fish Aggregating Devices (FADs), characterized by a high fishing intensity and effort, a diversity of fishing gear types not environmentally friendly and no seasonality or fishing quotas for *K. pelamis*. Dempster & Taquet (2004, 2005), Hallier & Gartner (2006) and Deepti et al (2017) stated that, due to the FADs, *K. pelamis* and mackerel tuna catches can disrupt fish migration patterns, change dietary patterns, growth and survival, and size patterns.

The calculation of the *K. pelamis* specimens' length at their first capture resulted in a value of 40.87 cm. Rochman et al (2015), in the South Indian Ocean Java, obtained an Lc of 38.73 cm. The value obtained in this study was still below the Lc of the specimens at their first mature gonad (Lm 50), which reached 43 cm in the western and southern waters of North Maluku (Karman et al 2013), 49.30 cm in North Sulawesi Bitung waters (Nugraha & Rahmat 2008) and 48.09 cm in Flores East Nusa Tenggara waters (Mallawa et al 2014). This finding confirms that *K. pelamis* caught with trolling rod in the waters of the Makassar Strait of Mamuju has not yet reached the mature gonads.

***Growth of fish***. The growth analysis using the Response Surface method generated the estimated values for the von Bertalanffy's growth model applied to *K. pelamis*: the length asymptote (L∞) was of 60.75 cm and the growth rate coefficient (K) was of 0.28 year$^{-1}$, at a Rn value (goodness of fit) of 0.167, with the $t_0$ of -0.3092 years. The resulting equation was: Lt = 60.75 [1 – exp-0.28(t + 0.3092)]. Similar studies from different areas are shown in Table 2.

Table 2

Stock assessment of *Katsuwonus pelamis* from previous studies

| *Study sites* | *Growth parameters* | | | | *Method* | *References* |
|---|---|---|---|---|---|---|
| | *L∞* | *K* | *$T_0$* | *Θ* | | |
| Bone Bay | 75.9 | 0.19 | | | Length frequency | Jamal (2011) |
| Barru and Majene | 107 | 0.8 | | | Length frequency | Amir & Mallawa (2014) |
| Brazil | 66.9 | 0.24 | -3.8 | | Dorsal fin | Garbin & Castello (2014) |
| Samudra Hindia | 80.85 | 1.1 | -0.110 | | Length frequency | Rochman et al (2015) |
| Samudra Hindia | 73.0 | 0.4 | | | Length frequency | Fontenau & Gascuel (2008) |
| Mamuju | 60.75 | 0.28 | -0.309 | 3.014 | Length frequency | Present study |

L∞- length asymptote; K-growth coefficient; $T_0$-age if the fork length is zero; Θ-performance of growth.

Table 2 shows the differences between the L∞ value of *K. pelamis* in this study and the previous research data. These could be caused by different and ever-changing environmental conditions of the waters and food availability, differences in the maximum length of fish samples, and number of captured specimens, different stocks and recruitment, and capture location, methods and technology. The growth performance of *K. pelamis* caught in the Makassar Strait of Mamuju waters amounted to 3,014 and was classified as still good, despite being overfished. This further confirms that low growth performance is rather caused by the less selective capture technology, than by environmental factors.

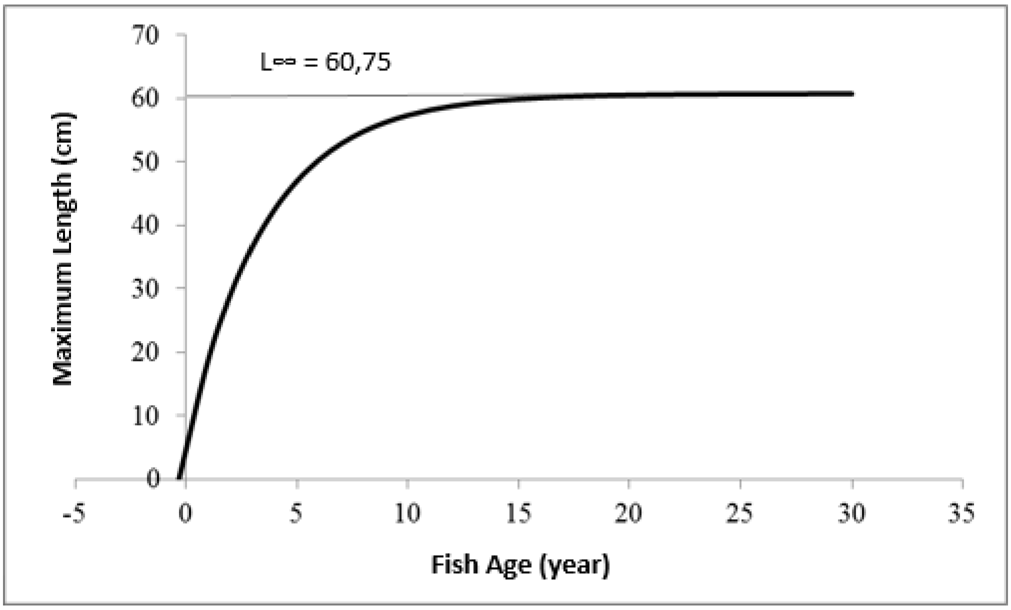


Figure 2. Growth curves of *Katsuwonus pelamis* caught in the Makassar Strait of Mamuju waters, using trolling rod.

Figure 2 illustrates that the growth coefficient (K) value reached 0.28 (28% $year^{-1}$), which is quite high. The predicted maximum length (L∞) of *K. pelamis* was 60.75 cm, according to the results of this study, but the measured length results suggested that the fish caught reached only a maximum size of 55.5 cm, below the maximum size of the fish caught (L∞).

K-value is an indicator of the growth rate of fish: the greater the K value, the faster the L∞ value is reached or the shorter the fish's age lifespan. The value of K in specimens captured from different regions shows fluctuating values caused by the environmental conditions (especially by the temperature and food availability). Sparre et al (1989) stated that the growth rate does not have absolute and dynamic values related to the developmental stage of life, metabolic rate and environmental conditions. Similarly, Anderson & Gutreuter (1983) stated that fish continue to experience the increase of length, even in conditions of poor environmental conditions.

The value of $t_0$ in the population estimation is important for the fisheries management, because the value of $t_0$ is used to predict the development of the final oocyte follicle level until oviposition and spawning. The success of spawning determines the strength of the recruitment of new individuals into the stock (Rochman et al 2015).

***Mortality and exploitation rate***. The estimated total mortality rate (Z) of 1.60 year$^{-1}$ was obtained using a curve of capture converted to length model. The estimated value of M was 0.64 year$^{-1}$ and the estimated value of F was 0.96 year$^{-1}$. The exploitation rate (E) of *K. pelamis* in Makassar Strait waters was 0.60 year$^{-1}$. According to Rochman et al (2015), in the Java South Indian Ocean, the mortality rate (Z) obtained was of 2.99 year$^{-1}$, the M value was of 1.44 year$^{-1}$ and F value was of 1.55 years, with an exploitation rate of 0.52 year$^{-1}$.

The mortality rate of *K. pelamis* in the Makassar Strait of Mamuju waters was dominated by the mortality caused by fishing activity factors (compared to natural factors), due to an intensification of the exploitation carried out by the local fishermen. The Exploitation Rate (E) of 0.60 (E>0.50) indicates a very high level of exploitation and has passed the MSY value. The capture mortality in the present study was higher than the natural mortality, which indicates that the rate of exploitation exceeds the optimum limit which is 0.50 (Gulland 1971). E value of 0.60 year$^{-1}$, showed the pressure of *K. pelamis* exploitation in the waters of the Makassar Straits in over-fishing conditions. Fontenau (2003) argues that *K. pelamis* is a special type of fish with limited migration movements. Research using the tagging method shows that *K. pelamis* has an area of migration of less than 1,500 mil$^2$ (or 2,778 km$^2$), suggesting that the over-fishing of *K. pelamis* occurred locally, causing a decline in the size (length and weight) of fish and a decrease in the number of catches per unit of effort.

***The relative yield per recruitment***. The yield per relative recruitment (Y'/R), with an E value of 0.6 year$^{-1}$, or 24.1%, was higher than the optimum value ($E_{max}$ = 0.359), producing a maximum catch of 0.008 g recruit$^{-1}$. Amir & Mallawa (2014) obtained an Y/R value of 0.058 g 146 recruit$^{-1}$, with an E value of 0.75 year$^{-1}$ or 26% higher than their optimum E ($E_{max}$ = 0.492 year$^{-1}$) in the waters of Barru and Majene. The recruitment pattern can be caused by the reproductive behavior of *K. pelamis* that do spawning gradually. The results of Fontenau's (2003) study found that *K. pelamis* spawn in a range of 40-45 cm in length, at an age of approximately one year. The spawning process occurs at temperatures over 24°C. Moreover, Stequert & Ramcharrun (1996) stated that *K. pelamis* in the Indian Ocean have permanent spawning activities with two peaks during the spawning season, namely during the northwestern monsoon (November-March) and the southeast monsoon (June-August). This spawning results in a continuous recruitment. The difference in the monthly percentage of recruitment was considered. Its values fluctuate due to shifts in the transition season and to the climate change or weather anomalies. Referring to the fluctuation of recruitment, it is necessary to regulate the fishing mortality, by restricting the installation of FADs in certain areas, through a moratorium on the overfishing.

**Conclusions**. Based on the results of the Y'/R analysis that there has been a decline in the *K. pelamis* catches in of the waters of the southern Makassar Strait of Mamuju. This situation urges to improve the catches management by decreasing the number of fishing effort units, by working on the standards regulating the size of fish that can be caught and by regulating and controlling the vessel and fishing gear used.

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**Conflict of interests**. The authors declare no conflict of interest.

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