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Growth Pattern of Skipjack Tuna (*Katsuwonus pelamis Linnaeus*, 1758) Caught with Hand Lines in Majene Waters, West Sulawesi, Indonesia

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Majene, a coastal area in Indonesia, is rich in fish resources – specifically skipjack tuna (*Katsuwonus pelamis*). Most fishermen in the area often use a tool called hand lines to catch skipjack tuna, which reduces the number of catches. Therefore, this research aimed to determine the growth pattern of skipjack tuna in Majene waters. Sampling was carried out monthly from July–September 2023 at the fish landing site in Majene City, West Sulawesi, among local fishermen who normally use hand lines to catch fish. The sample specimen was analyzed in the Fish Laboratory of Sulawesi Barat University. The total length of skipjack tuna used as the sample was measured with a digital caliper having an accuracy of 0.01 mm. Furthermore, the body weight of the sample was determined using a digital scale with an accuracy of 0.01 g. The results showed that the equation for the relationship between the fish length and weight based on sampling time was $W = 0.0019L^{3.5954}$ and $W = 0.0023L^{3.5308}$ in July and August. The analysis indicated that the equation for the relationship between the fish length and weight based on sex was $W = 0.0027L^{3.4783}$, $W = 0.0012L^{3.7569}$, and $W = 0.0019L^{3.5981}$ for males, females, and the combined sample. In conclusion, skipjack tuna in Majene waters were classified as having a positive allometric growth pattern ($b > 3$), where body weight tended to increase faster than body length. This suggests that the fish may be adapting to the selective pressures imposed by fishing practices. Therefore, the findings underscore the importance of considering fishing pressure, as it can significantly influence their biological characteristics and adaptive strategies.

Keywords: hand lines, length-weight, Majene waters, skipjack tuna, West Sulawesi

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INTRODUCTION

Skipjack tuna (*Katsuwonus pelamis*) is a species that has the potential to live on the surface of the sea and as a pelagic fish (Hidayat *et al.* 2019, 2021; Hermawan *et al.* 2023). The fish species have a high economic value which brings about its exportation to numerous countries (Genti *et al.* 2016). Therefore, skipjack tuna become the main target for fishermen during fishing activities (Sala *et al.* 2023). It was recorded that almost all skipjack tuna production in the world is caught in both tropical and subtropical waters – particularly the Pacific, Atlantic, and Indian Oceans. According to Jin *et al*. (2015), there are more than 70% of tuna caught in the western and central Pacific Ocean.

The skipjack tuna, which belongs to the Scombridae family, is particularly sensitive to long-distance transportation and has a high mortality rate when subjected to such conditions (Dacunha-Neto *et al*. 2022). Generally, they form large groups and are usually associated with similar-sized tuna, particularly yellowfin and bigeye tuna (Holland *et al.* 1989). Fromentin and Fonteneau (2001) explained that skipjack tuna tend to have high productivity, as well as a lifespan of under 4.5 years. The fish does not migrate to spawn or search for food, but its movement is significantly impacted by several environmental conditions, specifically prey availability and temperature with dissolved oxygen (Bintoro *et al*. 2021).

Skipjack tuna is a fish with quite large fecundity, with estimates ranging from 100,828–627,325 oocytes (Grande *et al*. 2014), 450,570–1,707,390 eggs (Chodrijah *et al.* 2020), and 203,377–739,820 eggs (Nur *et al.* 2024). This fish spawning can also occur throughout the year, with more intensive reproductive activity during the northeast season (November–March) and the Southwest season (June–July) in the western Indian Ocean (Grande *et al*. 2014); April and September in Toli-Toli waters, Central Sulawesi, Indonesia (Chodrijah *et al.* 2020); and November–February in Majene waters, West Sulawesi, Indonesia (Nur *et al.* 2024).

A significant skipjack tuna-producing area in Indonesia is Majene waters, which is located in West Sulawesi (Mallawa *et al.* 2016). Globally, these fish are caught near the sea surface by using purse seines, poles, and lines, and to a lesser extent with gill nets, troll lines, and longlines (Kumar *et al*. 2019). In Majene waters, skipjack tuna (Figure 1) is mostly carried out using hand lines. The behavior of such fish allows them to be caught in large quantities, thereby becoming vulnerable to over-exploitation. Although skipjack tuna is classified as a renewable resource, its recovery rate is unbalanced with the usage (Putri *et al*. 2018). Therefore, given the high catches of skipjack tuna and their vulnerability, it is essential to conduct research on their biological aspects – particularly their growth patterns – to ensure sustainable management practices.

Growth is referred to as a change in a fish's total weight or length within a certain time. It can be positive or negative and even occur within a temporary or long-term duration (Segun *et al*. 2022). The information concerning growth is evident from the length-weight relationship of skipjack tuna. The length-weight relationship, which is also known as the growth index, is needed during the estimation of the total length and weight of fish. Based on the flexibility of data for the length-weight, many fish biologists tend to convert the equation meant for length growth to weight growth in stock assessment models (Ahmed *et al*. 2011). The growth of fish, defined as a change in total weight or length over a specific period, can be influenced significantly by fishing pressure. High fishing pressure often leads to increased mortality rates and alters the population structure of fish species, potentially impacting growth patterns (Ara *et al.* 2021). When fishing pressure is elevated, larger and older individuals are often removed from the population, leading to a phenomenon known as growth overfishing. This can result in younger fish reaching maturity at smaller sizes and younger ages, which may ultimately reduce the overall size and weight of the population (Catalano and Allen 2010).

Figure 1. Skipjack tuna (TL 55 cm) caught with hand lines in Majene waters, West Sulawesi, Indonesia.

The length-weight relationship can impact the understanding of fisheries aspects, particularly in the assessment of fish stocks as well as the population dynamics. It allows for the estimation of the weight of the species more easily if the total length with condition factors and fish biomass through length frequency are known (Getso *et al*. 2017; Usman *et al.* 2016). Length and weight of fish, when associated with fish age data can provide metadata on fish stock, maturity age, lifespan, mortality, growth, and reproduction (Getso *et al*. 2017). Equally, for effective population control in fish species, metrics such as the length-weight relationship must be reviewed (Adaka *et al*. 2015). The unprotected relationship between the length and the weight in biological characteristics is essential for sustainable fish resources management (Panggabean *et al*. 2020). By syntheses of the fish length and weight, which are suggested by Courtney *et al*. (2014), it can be manifest as a biological index of the aquatic ecosystem condition. As regards, the general focus of this research is to analyze the growth pattern of skipjack tuna, which is caught by using hand lines. The analysis is beneficial by providing basic data on efforts to sustainably manage skipjack tuna in Majene waters in West Sulawesi.

MATERIALS AND METHODS

Time and Location

This research was conducted from July–September 2023 at the fish landing site (TPI) in Majene City, West Sulawesi, Indonesia, where fish samples were taken monthly.

Tools and Material

The research tools and materials were a digital caliper with an accuracy of 0.01 mm to measure the length of the fish and a digital scale with an accuracy of 0.01 g to calculate the weight of the fish. Apart from that, surgical equipment was used to dissect and detect the skipjack tuna sex. The sex of the fish was identified by dissecting the fish and observing the morphological characteristics of its reproductive organs.

Research Procedures

Fish samples were taken from TPI Majene and then continued with confirmation of the type of fish caught through communication with traditional fishermen who use hand lines. The samples were further taken to the Fisheries Laboratory of Sulawesi Barat University to have standards measured such as the total and standard length and body weight. The values obtained from observations were recorded in a tabular form for further analysis using Microsoft Excel.

Data Collection Methods

Fish sampling was assisted by traditional fishermen using handline fishing gear in a fishing area in Majene District. The sample was then taken to the laboratory to be observed and examined to determine the total and standard length in millimeters (mm) using a measuring board. The total length was measured from the front of skipjack tuna's snout to the back of the longest tail fin. The weight was assessed in grams (g) using a digital scale.

Data Analysis

For data analysis, this research adopted the formula provided by (Le Cren 1951a).

$$W = aL^b \quad (1)$$

where W is the fish body weight (g), L is the total length of fish (mm), a is the intercept, and b is the slope.

The b value was obtained from the isometric or allometric growth pattern equation. When the b value was 3, the growth of skipjack tuna became balanced (isometric). When the b value was less than 3, the allometric growth became negative, and when the b value was greater than 3, the growth was positive. Furthermore, the t-test analysis was adopted to examine whether the b value was = 3 or ≠ 3.

RESULTS

A total of 202 skipjack tuna, with 62 females and 140 males, caught in Majene waters were selected as research samples. The range of total length fish caught during the study was 18.20–70.8 for males and 19.40–33.5 for females. The complete analysis of the length-weight relationship is detailed in Table 1.

According to Table 1, all the equations derived were $W = 0.002L^{3.5829}$, $W = 0.0013L^{3.729}$, and $W = 0.002L^{3.5829}$ for males, females, and the combined skipjack tuna, respectively. Furthermore, the t-test result showed that the b values of 3.5829 for males, 3.7292 for females, and 3.5829 for combined fish, were greater than the t-value. The analysis indicated that skipjack tuna increased in length faster than body weight since it had positive (minor) allometric growth (b > 3). Similar results were reported by Santoso *et al*. (2023) at the Kendari Ocean Fishery Harbor, where skipjack tuna followed an equation of $W = 0.000002L^{3.3998}$, with an r^2 value of 98.33%. The t-test value was obtained when the t-count was smaller than the t-table (–37.6301 < –1.9619). Therefore, the observed growth pattern of sampled fish was in line with the positive allometric growth.

Figure 2 shows the length-weight relationship for skipjack tuna based on sampling time.

Table 1. Body length-weight relationship of skipjack tuna in Majene waters.

Parameter	Males	Females	Combined
Number of skipjack tuna	140	62	202
Total length (cm)	18.20–70.8	19.40–33.5	18.20–34
Mean ± SD	23.31 ± 3.22	23.66 ± 2.3	23.42 ± 2.97
Body weight (g)	70.80–645.49	86.1–623.9	70.80–645.40
Mean ± SD	170.79 ± 105.09	176.7 ± 86.92	172.63 ± 99.69
Log a	–2.6575	–2.9008	–2.7065
A	0.002	0.0009	0.002
Coef. regression (b)	3.5829	3.7292	3.5829
Coef. correlation (r)	0.9653	0.9659	0.9653
Regression equation	$W = 0.002L^{3.5829}$	$W = 0.0013L^{3.729}$	$W = 0.002L^{3.5829}$
T-test	$t_{count} > t_{table}$	$t_{count} > t_{table}$	$t_{count} > t_{table}$
Growth type	Positive allometric	Positive allometric	Positive allometric

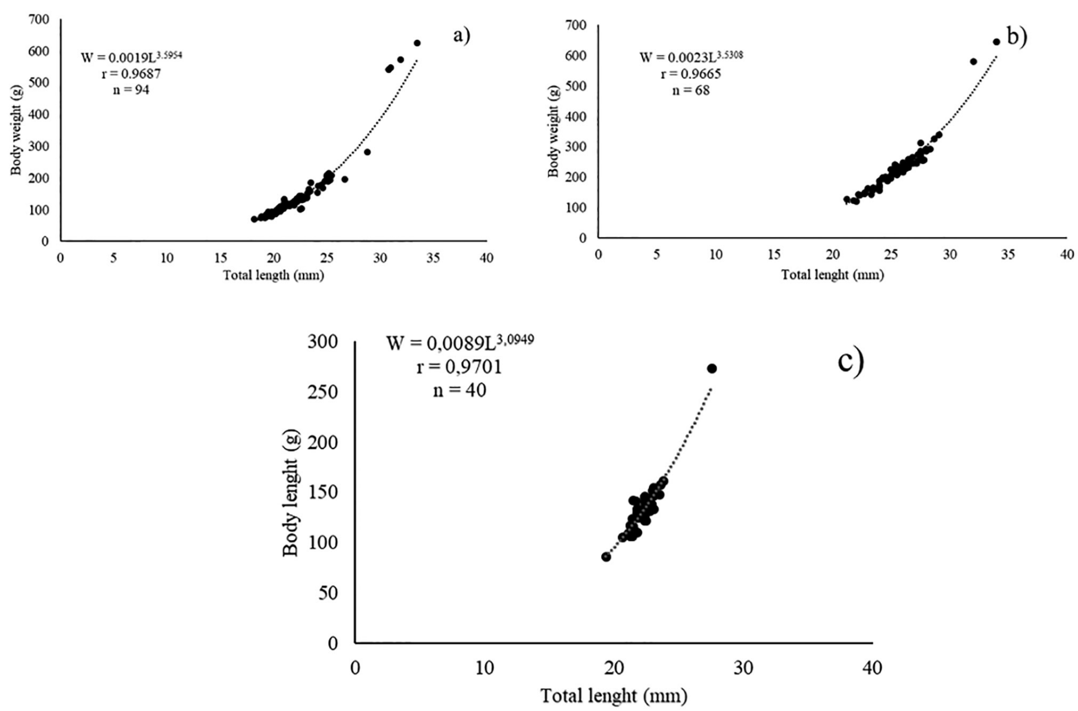

Figure 2. Length-weight relationship for skipjack tuna: [a] July; [b] August; [c] September.

According to Figure 2 generated above, it emerged that the b values obtained in each month were of several kinds. For instance, the values obtained in July, August, and September were of the order of 3.3954, 3.5308, and 3.0984, respectively. The t-test results showed a significant value of the calculated t-table where it exceeded the t-table. The assessment indicated that the skipjack tuna caught using hand lines in all three months had a positive allometric growth pattern.

DISCUSSION

The length-weight relationship was crucial for the effective adoption of fish stock assessment and management and it provided means for the estimation of fish biomass from length data, ecological modeling, and growth estimation (Froese 2006). The information regarding the analysis of the differences in the length-weight relationship among pelagic fish species such as tuna, mackerel, and skipjack tuna belonging to the Scombridae family (Battaglia *et al.* 2010) was still scarce. As important pelagic and migratory species, there was a need to investigate the biological and fishery-related parameters of the migration route with the aim of providing a framework for proper management (Kumar *et al*. 2019).

In this research, the absolute growth of different sexes in skipjack tuna showed a positive allometric growth condition, which signified body weight increased in greater proportion than body length. The observation carried out by Mazumder *et al*. (2016) and Santoso *et al*. (2023) stated the fact that, in the natural habitat, all the skipjack tuna showed good proportions at the growth stage. This was because of changes that occurred in body structure and proportions in growth and in enlargements of more developed animals. The same growth pattern of skipjack tuna is also found in the waters of Prigi, Trenggalek, East Java, Indonesia, which has a positive allometric growth pattern (Bintoro *et al*. 2020), as well as in the waters of Bone Bay (Wahana *et al*. 2021) and also found in the Sadeng Fishery Harbor, where it had positive allometric growth performance and a slightly flattened body (Anggraeni *et al*. 2015). On the other hand, based on the study by Nugraha *et al*. (2020), the growth pattern of skipjack tuna in the Maluku Sea was a negative allometric pattern, whereas those that landed in PPI Kedongan Bali had negative allometric growth (Wardeni *et al.* 2019).

As stated by Le Cren (1951b), the relationship between the length and weight of fish could differ from the ideal value of 3.0 due to the effect of some environmental conditions or fish conditions in the production vessel. Therefore, the slope b value for each of the fish species might be much greater or less than the ideal value, suggesting an allometric growth rate. This research supported the results because the skipjack tuna had allometric growth, which signified that it had different changes in body shape. It then developed into an even clearer picture showing that there were several growth rates for skipjack tuna in each region due to environmental factors and overexploitation of fish stocks. According to the review, natural food was often consumed in huge proportions by the fish and had the energy required to support metabolic activities in the fish body (Santoso *et al.* 2023).

There were some factors that could alter the growth pattern of skipjack tuna and they included temperature, salinity of water, availability of food, hereditary factors, sexual differentiation between male and female fish, age of fish, and population density (Faghani-Langroudi *et al*. 2014). The investigation conducted by Nontji (2005) and Shabrina *et al*. (2017) hypothesized that the increase in the size of fish was related to the amount of food available and the conditions in their surrounding environment. They could also differ because of the degree of gonad maturity, seasonal fluctuations, and specifics of fishing activity in an area, influencing the fish population growth similar to such high levels of fishing pressure (Ya *et al*. 2015). Ya *et al*. (2015) presented different factors that contributed to the b value over the life cycle of fish. A higher b value also incorporated a number of factors explaining the general condition of fish's appetite and gonad content (Lohani and Ram 2018). In the same regard, the b value was affected by some of the biological and environmental factors such as conditions of the geographical location, time factors, and the method of sample collection (Goel *et al*. 2011). From the investigation conducted by Muchlisin (2014), it was found that fish behavior such as the rate of change in swimming speed as evidenced in skipjack tuna could influence the b value, whereby fish with speed were likely to have a lower b value as compared to lower swimming speedy fish. For fast-swimming species like skipjack tuna, the increased energy demands for constant high-speed swimming could limit the amount of energy available for growth, leading to a lower b value. According to the dynamic energy budget theory (Sousa *et al.* 2010), organisms allocate energy toward maintenance (*e.g.* movement), growth, reproduction, and storage. In skipjack tuna, a fast-swimming species, more energy is directed towards sustaining movement rather than building biomass, resulting in relatively slower weight gain compared to their length. Additionally, Arrafi *et al*. (2016) provided a similar opinion that such differences in b values were related to the specific physiological growth conditions.

Correlation coefficient (r) values between 0.90–0.96 indicate a positive relationship between the total length and specific gravity of fish. A very strong correlation indicates that there is a strong linear association between total length and specific gravity, where larger fish tend to have consistently higher specific gravity, and the variability around this trend is small. Subsequently, the coefficient of determination (R^2) was used to test the suitability of the regression model, with the resulting model being that the higher the R^2, the more appropriate the relationship became.

The length and weight measurements in waters had different scores due to interference from internal and external factors. Some internal factors included parasites and diseases that inhibit fish growth. In the early stages of development, when the fish's digestive organs were attacked by disease, the capacity to digest food would be reduced, thereby slowing growth. Meanwhile, external factors including food availability, nutritional content, and environmental conditions – specifically the physical and chemical properties of water that did not support habitat – could inhibit the fish growth process (Bintoro *et al*. 2020). Furthermore, Goel *et al*. (2011) explained that the changes observed in the length and weight across different habitats and in catch stocks might be attributed to several factors such as ecology, body size, the conditions of habitat, the life cycle phase, environmental conditions, nutrition status, length of the specimen, and maturity level. These differences were influenced by synchronization with the inherited body shape and the status/health of each fish (Lohani and Ram 2018).

On the other hand, fishing pressure significantly affects the length-weight relationship and growth patterns of fish. High fishing pressure – particularly size-selective harvesting of larger fish – leads to smaller average fish sizes, altered energy allocation, and shifts in growth patterns (Li *et al.* 2023). Wang *et al.* (2021) explained that this pressure can result in fish maturing at smaller sizes, slower growth rates, and changes in the length-weight ratio (lower b value). Fish may also allocate more energy toward early reproduction rather than growth. In contrast, low fishing pressure allows more natural growth and reproduction, maintaining typical growth patterns. Thus, fishing pressure is a key factor in understanding fish population dynamics and growth in your research.

The basic information regarding the relationship between fish length and weight was essential in fisheries biology. In fisheries biology research, fish size was generally considered more important than age due to various physiological and ecological factors influencing size changes over time. Therefore, the weight-length relationship played a significant role in fisheries management by allowing the estimation of average weight through the establishment of mathematical relationships among relative conditions of fish. This application proved essential in fish stock assessment for improving management strategies, conservation efforts, and cultivation methods.

CONCLUSION

In conclusion, skipjack tuna caught using hand lines in Majene waters had a positive allometric growth pattern, indicating that the body weight was increasing more than what would be expected from body length. This suggests that the fish may be adapting to the selective pressures imposed by fishing practices. This adaptation could be a response to high fishing pressure, where the removal of larger fish leads to changes in growth strategies among the remaining population. Therefore, the findings underscore the importance of considering fishing pressure when analyzing growth patterns in fish populations, as it can significantly influence their biological characteristics and adaptive strategies. Furthermore, various strategies are needed in order to realize the sustainability of skipjack tuna in Majene waters – including the regulation of skipjack tuna allowed to be caught referring to the size of the first mature gonad of skipjack tuna in Majene waters (males skipjack tuna first mature at 400.2 mm, ranging from 396.6–462.3 mm), the closed fishing at the peak spawning period of skipjack tuna (November–January), regulating the allocation of skipjack resource utilization, encouraging the information availability regarding skipjack-tuna fisheries in an integrated database, and improving the institutional system in West Sulawesi Province.

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