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Size Structure and Biological Aspects of Yellowfin Tuna (Thunnus Albacares) in the Makassar Strait, Indonesia

Syamsinar
Magister Program in Fisheries Science, Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar, South Sulawesi, 90245, Indonesia. Email: faisalamir_unhas@yahoo.com

Faisal Amir
Department of Fisheries, Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar, South Sulawesi, 90245, Indonesia

Budimawan
Department of Marine Science, Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar, South Sulawesi, 90245, Indonesia

Abstract

Yellowfin tuna (Thunnus albacares) is a valuable food fish commodity and a main fishery target in West Sulawesi Province, Indonesia. However, the large number of juvenile yellowfin tuna caught by purse seiners, which have shifted from small pelagic fish towards large pelagic fish, could threaten yellowfin tuna populations and thus the sustainability of the fishery. The aim of this research was to analyse size structure and biological aspects of yellowfin tuna caught in the Makassar Strait (by hand line and purse seine fishers) and landed in Majene and Polewali Mandar regencies, West Sulawesi. Yellowfin tuna (N = 2,391) were collected twice a week from August to November 2022 in each regency from intermediate traders; samples were selected randomly. Fork length (FL) and weight were recorded. Gonad maturity level was determined based on gonad morphology. The size range was 11-164 cm, mean ± SD = 60.5 ± 33.9 cm). The length-weight relationship was W = 0.00002*FL2.9461 for male yellowfin tuna and W = 0.00004*FL2.8449 for females, with an isometric growth pattern for both sexes. Condition factor was 14.94 for males and 15.00 for females with a size at first maturity of 106.4 cm for males and 96.8 cm for females. The study results show that many juvenile yellowfin tuna are caught, length and weight increase proportionally, yellowfin tuna were in good condition, and females matured earlier than males.

Keywords: *Yellowfin Tuna, Length-Weight Relationship, Condition Factor, Size at First Maturity.*

INTRODUCTION

Yellowfin tuna, a valuable fisheries commodity, is a cosmopolitan marine pelagic fish, widespread in tropical and sub-tropical waters (Kantun, 2018). Yellowfin tuna is one of the five top species in terms of global production volume (FAO, 2022). Considered over-exploited, this fish is commonly found in the Atlantic, Pacific, and Indian oceans (ISSF, 2021). Consumer demand for tuna continues to rise, driving increases in fishing effort, with negative impacts on stocks, including the catch of small (undersized/immature) fish (Kantun & Amir, 2013). Indonesian yellowfin tuna are important for assessing stocks on the Indian and Pacific oceans (Hutubessy et al., 2021).

Fishers from West Sulawesi catch yellowfin tuna in the central and southern Makassar Strait. Most fishers operating from West Sulawesi Province land their yellowfin and other tuna catch in Majene Regency or Polewali Mandar Regency. Over the period 2015-2020 yellowfin tuna production volume in West Sulawesi was 24,125 tons (DKP Sulbar, 2020). One problem reported from the yellowfin tuna fisheries in the Makassar Strait is the large number of larvae and juveniles caught by hand line and purse seine fishing vessels. Catching mostly juvenile fish will have a negative impact on fish stock abundance in the exploited area (Kemhay et al., 2019) and can lead to overfishing.

Knowledge regarding reproductive biology and growth patterns is very important for responsible tuna fisheries management (Sabri & Ebru, 2020; Schaefer, 2001). The length-weight relationship and condition factor are basic characteristics widely used in fisheries biology, ecology, and management (Guisse et al., 2021), including stock assessment (Ergüden, 2020). Information on size structure is also important in fisheries management (Gobel et al., 2017).

Previous research on the reproductive biology of yellowfin tuna has yielded varied results. Zhu et al. (2008) report a length at first maturity of yellowfin tuna, in the western and central Indian Ocean of 113.77 cm for females and 120.20 cm for males, while in the western Indian Ocean Zudaire et al. (2013) report a length at first maturity of 75 cm. In the eastern Atlantic Ocean, Diaha et al. (2015) found that female yellowfin tuna can reproduce at 72.8-166 cm and males at 72.8-170.9 cm, while female yellowfin tuna matured at 77.2 cm in the Oman Sea (Hosseini and Kaymaram, 2016). In a proposed marine protected area around Ascension Island (tropical Atlantic), Richardson et al. (2018) did not find any females with mature ovaries, although as small proportion were spent, indicating that this is not a spawning ground for the species. In the Bay of Mexico, Pacicco et al. (2023) found that gonad maturity occurred at lengths between 100.2 cm and a maximum of 107.1 cm.

There are also contrasting reports on the length-weight relationship and condition factor of yellowfin tuna. Allometric negative growth patterns are reported for yellowfin tuna in Dilasag Bay, Philippines (Reyes et al. 2021) as well as in the Indo-Pacific and Atlantic oceans (Zhu et al., 2010). In the eastern Pacific Ocean, Thierry et al. (2021) also report allometric negative growth patterns; however, Zhu et al. (2010) report allometric positive growth patterns in this region. A study in the coastal waters off south-eastern India found allometric growth patterns for both sexes, while the condition factor was 0.97 for males and 1.60 for female yellowfin tuna (Yosuva et al., 2018).

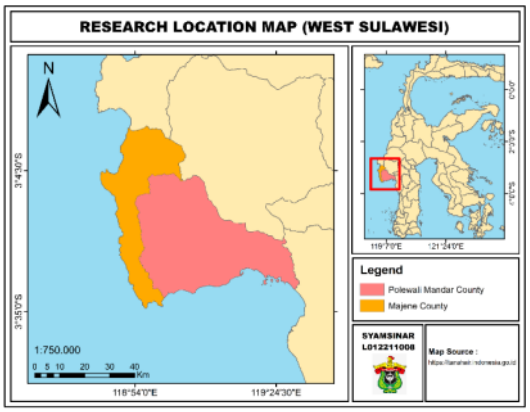
Although Thierry et al. (2021) found an allometric negative growth pattern in the eastern Pacific Ocean, in the Makassar Strait, Kantun et al. (2011) report mean lengths at first maturity of 118.61 cm for females and 119.27 for male yellowfin tuna. Subsequent studies using data on tuna caught using hand line gear in the Makassar Strait reported allometric negative growth patterns (Kantun & Yahya, 2013), and a size range of 25-130 cm for fish caught in the mornings and 25-180 cm for fish caught in the evenings (Kantun et al., 2014a). Two gear types, hand lines and purse seines, are widely used by fishermen from West Sulawesi and thought to be responsible for the majority of small-sized yellowfin caught in the Makassar Strait. The aim of this study was to analyse the size structure and some biological aspects (length-weight relationship, condition factor dan mean length at first maturity) of the yellowfin tuna caught using hand line or purse seine gears in the Makassar Strait and landed in Majene Regency and Polewali Mandar Regency, West

Sulawesi Province, Indonesia. The results are expected to inform the sustainable management of yellowfin tuna fisheries in West Sulawesi Province.

Materials and Methods

This study was conducted in Majene Regency and Polewali Mandar Regency, West Sulawesi Province, Indonesia (Figure 1). The research took place from August to November 2022.

Figure 1. Map of the study area in the Makassar Strait, Indonesia



Data were collected in the field using a survey method. Tuna samples were collected from two traders in Majene Regency (Supasaro and Dwifortuna) and one trader in Polewali Mandar Regency (Air Mancur). Samples were collected twice a week in each regency. Samples from both hand line and purse seine catches were measured to obtain size structure data. Samples for the length-weight relationship, condition factor and gonad maturity analyses were only collected from the hand line catch. Samples were selected randomly, and the fork length was measured using a tape measure (precision 0.1 cm) from the tip of the snout to the middle of the tail fork. Fish were weighed using HENHERR digital scales with a capacity of 150 kg and precision of 10 g. The fish selected for gonad maturity analysis were then dissected to observe the gut contents, specifically the gonads. The gonad maturity stage (GMS) was assessed based on morphological characteristics (Table 1).

Table 1. Gonad maturity stage (GMS) of female and male yellowfin tuna based on morphological traits (Kantun et al., 2014b)

Maturity Stage (I-V)	Female	Male
I Immature	Thin and hollow tubular gonad with diameter 3-4µm.	Thin and hollow tubular gonad with diameter 3-4µm, transparent or white in colour.
II Developing	Oocytes visible on the inner wall of the ovary. Pale reddish or orange colour.	The testicular tube has expanded and blood vessels are visible. Pale white or reddish colour
III Maturing	Ovaries and oocytes developing, oocytes oval, not round, and firmly attached. Blood vessels less apparent than in the previous stage. Pale orange in colour.	Testicular tube still developing, blood vessels less visible than in the previous stage. Sperm abundant in cysts and lobular lumens but not in ducts. Gonads are reddish.
IV Mature	Ovaries continue to develop. Oocytes emerge from the ovary wall and are contained in transparent oval tubes. Colour pale orange or yellow.	Gonads full of sperm, mature sperm present in lobules and ducts. Colour white or reddish.
V Spawning/Spent	The ovaries are generally soft, flat and flaccid. Remnants of oocytes present in the ovaries. Dark orange or yellow colour.	The gonads are soft, deflated and flaccid. Gonads are dark or white in colour.

The size structure of the yellowfin tuna sampled was analysed descriptively using histograms (Kantun et al., 2014a). The data were then tested for normality using the one-sample Kolmogorov-Smirnov test before analysing the difference in size structure between months using the Kruskal-Wallis test, followed by post-hoc pair-wise tests, implemented in SPSS version 20.

The length-weight relationship was determined using the equation in Effendie (1997):

$$W = aL^{b} \quad \text{..(1)}$$

where: W = weight (kg); L = fork length (cm); a = intercept; b = regression coefficient (slope).

The student's t-test was applied (at the 95% confidence level) to determine the growth pattern based on the value of b as follows:

$t > t_{table}$ = reject the null hypothesis (H_0) $b \neq 3$ (allometric growth pattern)

$t < t_{table}$ = null hypothesis not rejected, b=3 (isometric growth pattern)

The condition factor was analysed based on size classes. Condition factor was calculated based on the length-weight relationship for isometric growth (Effendie, 2002):

$$K = \frac{W}{L^3} \times 10^5 \quad \text{..(2)}$$

where: K = condition factor;

W = weight; L = fork length.

The mean length at first maturity was calculated using the Spearman-Karber equation (Udupa, 1986):

$$m = xk + \frac{x}{2} - (x\Sigma pi) \quad \text{........................(3)}$$

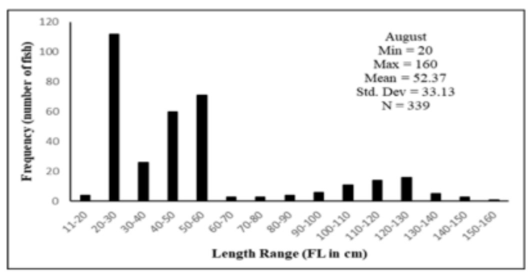
where: m = logarithm of the mean length at first maturity; xk = logarithm of the mean value of the smallest size class where 100% of fish had mature gonads (the k^{th} class); x = logarithm of the size increment (class width); pi = is the proportion of fish with mature gonads in the i^{th} size class (i = 1 to k-1).

Results and Discussion

Size Structure

The fork length of 2,391 yellowfin tuna caught using hand line or purse seine gears between August and November 2022 ranged from 11-164 cm with a mean of 60.5 cm and standard deviation (SD) of 33.9 cm. Overall, the most abundant size class was 50-60 cm, however the dominant size class varied between months (Figure 2). In August (n = 339) and November (n = 367), the most abundant size class was 20-30 cm; in September (n = 821), the dominant size class was 50-60 cm, while in October (n = 864) the dominant size class was 40-50 cm. Overall, the size and the number of tuna caught were higher in September and October than in August and November. The Kruskal-Wallis test showed a significant difference between months and the post-hoc test (Figure 3) showed that size-structure was similar in August and November, but September and October each differed from the other three months.

Figure 2. Size structure of yellowfin tuna in the Makassar Strait during four months in 2022



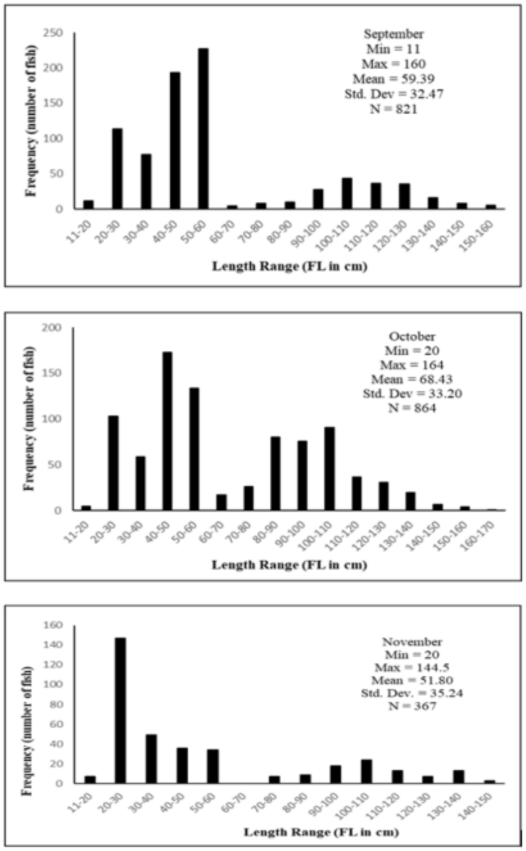
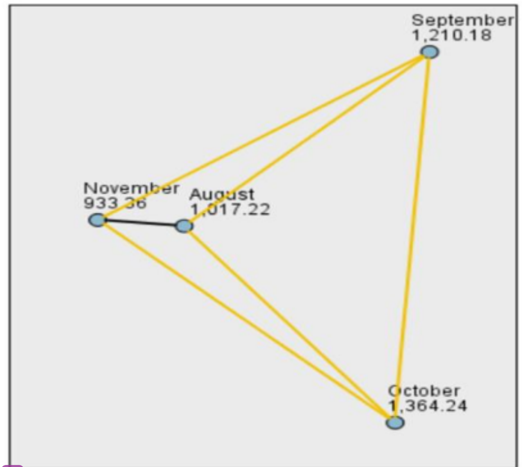


Figure 3. Kruskal-Wallis post-hoc test results for pairwise comparisons between months



The size range of the yellowfin tuna caught can be influenced by the fishing gear used as well as the fishing ground (Wudji et al., 2015) and stock condition. A comparison with other studies on yellowfin tuna in several parts of the world using various gears (Table 2) shows that the size range, dominant size class and mean size fall within the values reported from other regions and from previous studies in the same region.

Table 2. Size structure of yellowfin tuna from this study and previous studies around the world

Location	Gear/remarks	Size range (cm)	Dominant class/ mean size (cm)	Reference
Makassar Strait	Hand line and Purse seine	11-164	50-60 Mean 60.5	This study
Kenya		11-205	66-76	Kimakwa *et al.* (2021)
Indian Ocean		78-185	140-155	Ghofar *et al.* (2021)
Prigi, East Java Barat		21-172	36-45 Mean 68.64	Agustina *et al.* (2021)
Bitung, North Sulawesi	Hand line Pole and line Purse seine	89-150 23-67 35-61	Mean 120 Mean 41 Mean 46	(Darondo *et al.*, 2020)
Makassar Strait	Hand line/ Morning Hand line/ Afternoon	25-130 25-180	Mean 94.5 Mean 113.5	Kantun *et al.* (2014a)

Bearing in mind the seasonal differences found between the four months of this study, overall the size range is quite similar to those reported from other studies in Indonesia (Agustina et al., 2021; Darondo et al., 2020; Kantun et al. 2014a). However, the maximum and dominant sizes are smaller than for Kenya and the Indian Ocean (Kimakwa et al., 2021; Ghofar et al., 2021). One likely reason for this is that Indonesian archipelagic waters, including the waters around Sulawesi and in particular the Makassar Strait, are an important habitat for juvenile yellowfin tuna (Bailey et al., 2012). The influence of fishing ground is highlighted by Kantun et al. (2014a) who found that fork length was generally smaller when fishing around fish aggregating devices (FADs) in shallow water than deepwater FADs. This accords with the findings of Lan et al. (2012) that larval and juvenile phase yellowfin tuna tend to swim around 0-50 m below the sea surface while adults are more often found at depths of 50-200 m. Young yellowfin tuna tend to use coastal waters as feeding grounds, while adults tend to seek prey and reproduce in offshore or oceanic waters (Kantun, 2018). In this study, the size of the fish caught was dominated by juvenile yellowfin tuna to a greater extent than in the study by Kantun, et al. (2014a). They reported that tuna caught in the morning tended to be smaller than those caught in the afternoon, but the average size at both times was higher than in this study. From a temporal perspective, although the maximum size is similar to that reported by Kantun et al. (2014a) in the Makassar Strait, the minimum size is lower (11 cm compared to 25 cm) and the mean size is much lower ($\approx$ 60 cm compared to 95 or 114 cm). While the inclusion of fish caught using purse seine gear could contribute to this difference, it could also indicate a downward trend in the size of individuals within the population.

Length-Weight Relationship

The length-weight relationship obtained for male yellowfin tuna was W = 0.00002*FL2.9461, R2 = 0.9458 (Figure 4) and that obtained for females was W = 0.00004*FL2.8449, R2 = 0.7761 (Figure 5). The t-test results (tmale = -0.66, ttable = 1.97; tfemale = 0.09, ttable = 1.98) indicate that the exponent b is not significantly different from 3 for either sex, and therefore both male and female yellowfin tuna have isometric growth patterns.

Figure 4. Length-Weight Relationship of Male Yellowfin Tuna in West Sulawesi Waters

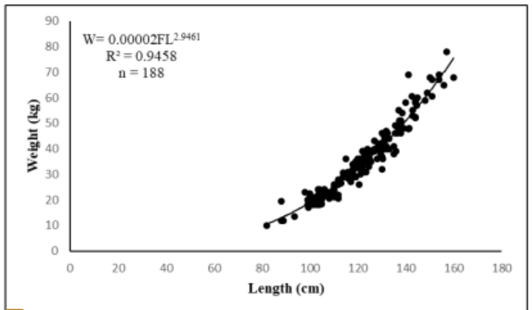
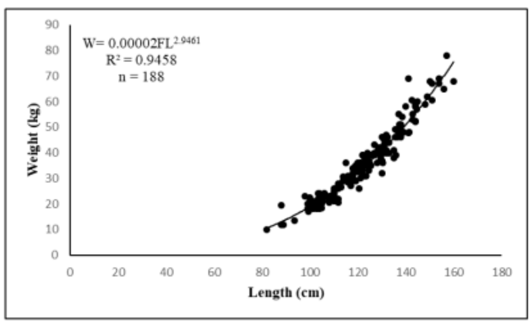


Figure 5. Length-weight relationship of female yellowfin tuna in West Sulawesi waters



The isometric growth pattern found in this study contrasts with several studies reporting allometric growth patterns, including another study in the Makassar Strait (Kantun and Yahya, 2013) which reported allometric negative growth for both sexes. However, Safitri et al. (2019) also report isometric growth in yellowfin tuna landed in Benoa Port, Bali, with a length-weight relationship of W=0.00005*FL2,92222. Other studies reporting allometric negative growth patterns include Agustina et al. (2021) with the equation W= 3×10-5*FL2.8355 in Prigi, East Java; Nugroho et al. (2018) in the eastern Indian Ocean; Ghofar et al. (2021) in the Indian Ocean; Kaymaram et al. (2014) in the Sea of Oman (both sexes); Perera and Weerasiri (2020) in Sri Lanka; and Yosuva et al. (2018) in south-eastern India. Fish growth patterns can be influenced by environmental factors and internal factors, including food (prey) availability, temperature, dissolved oxygen concentration, age, sex, and gonad maturity stage, (Kantun and Mallawa, 2016) so that the length-weight relationship can change over time (e.g. between seasons or years) and between areas, as well as between species, sex, and even the fishing gear used to obtain the samples on which the calculations are based (Ward and Ramerez, 1992).

Condition factor

The condition factor for male yellowfin tuna was Kn = 14.94. Males in the 140-150 cm size class had the highest condition factor (1.94) and those in the 80-90 cm size class had the lowest (1.74). The condition factor for female yellowfin tuna was Kn = 15.00. Females in the 150-160 cm had the highest condition factor (2.19) and those in the 100-110 cm size class had the lowest (1.76).

Condition factor can also vary, with influencing factors including the abundance of the organism, individual condition/health, food availability, and environmental conditions such as water quality (Effendi, 1997; Marzuki et al., 2018). In this study, the condition factor of both male and female yellowfin tuna was generally greater than one, meaning that the fish caught were mostly in good condition (Jisr et al., 2018). This most likely indicates that prey were quite abundant and that other environmental conditions in the Makassar Strait were suitable for yellowfin tuna during the study period. Nugroho et al. (2018) reported a condition factor of 0.978 for yellowfin tuna in the eastern Indian Ocean; Azizi et al. (2020) report condition factor values in the range 0.97-1.25 with a mean value of 1.03 in the Indian Ocean; Pataṅda et al. (2022) report condition factor values for yellowfin tuna landed at the Pelabuhan Ratu fishing port between 0.70-1.54 (mean 1.01). Condition factor can also vary between sexes, for example male yellowfin tuna caught in south-east India had a lower condition factor (0.97) than females (1.60) (Yosuva et al., 2018).

Mean length at first maturity

The sample of hand line caught yellowfin tuna used to estimate length at first maturity comprised 104 females and 188 males. Gonad maturity stage of the female yellowfin tuna was: 66 (63.46%) in GMS IV; 24 (23.08%) in GMS III; 13 (12.50%) in GMS V; and 1 (0.96%) in GMS II. Gonad maturity stage of the male yellowfin tuna was: 78 (41.49%) in GMS IV; 69 (36.70%) in GMS V; 36 (19.15%) in GMS III; and 5 (2.66%) in GMS II. Mean length at first maturity was 96.8 cm for females and 106.4 cm for males.

The size at first maturity can be influenced by environmental factors as well as fishing pressure (Kantun and Mallawa, 2016). In this study, female yellowfin tuna tended to mature earlier than males. Both sexes tended to mature at relatively small sizes compared to the values reported for this species from other areas, although one study in the Indian Ocean (Arnenda et al., 2018) found a mean length at first maturity of 94.6 cm, lower than this study. Other studies also report that males mature later and at longer lengths than females (Pratasik et al., 2022); for example, Shi et al. (2022) found that female yellowfin tuna in the western and central Pacific Ocean had a smaller mean length at first maturity (111,96 cm) compared to males (119,64 cm). Mean length at first maturity for yellowfin tuna caught in the Makassar Strait varied between shallow-water FADs (105.41 cm) and deep-water FADs (114.80 cm) (Kantun et al., 2018). Haruna et al. (2018) report a mean length at first maturity of 115.2 cm FL in the Banda Sea. The mean length at first maturity in this study was also smaller than that reported by Kantun et al. (2011) for yellowfin tuna in the Makassar Strait, which was 119.79 cm for males and 118.61 cm for females, indicating that fish may be maturing earlier, at smaller sizes than in the past.

Conclusion

Size structure analysis of the yellowfin tuna landed in Majene Regency and Polewali Mandar Regency, West Sulawesi Province, Indonesia yielded a size range of 11-164 cm FL with a mean of 60.5 cm. The catch was predominantly composed of 50-60 cm FL juvenile fish. The growth pattern of both male and female yellowfin tuna was isometric, meaning that increases in length and weight were proportional. The condition factor of male and female yellowfin tuna was categorised a good, as it was greater than one. The mean length at first maturity was 96.8 cm for female yellowfin tuna and 106.4 cm for males, meaning that female yellowfin tuna matured earlier than males.

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