Biological Aspects of Yellowfin Tuna in Bone Gulf Waters, Indonesia

Jalil [1*], *Achmar* Mallawa[2], *Faisal* Amir[2], *Safruddin*[2], *Donwill* Pangabean[1]

[1]Universitas Terbuka, Fisheries Management Department, 15437 South Tangerang, Banten, Indonesia
[2]Universitas Hasanuddin, Fisheries Science Department, 90245 Makassar, South Sulawesi, Indonesia

Abstract. The aim of this study was to examine the composition, growth patterns and condition factors of yellowfin tuna caught in Bone Gulf waters. Sample collection was carried out in July – November 2018 at two stations, i.e., station 1 in Cimpu Luwu Regency and station 2 at the Lonrae Fish Landing Site, Bone Regency. At station 1, 10,366 individuals were caught, with an average size of 81.19 cm in length and of 14.43 kg in weight. Station 2 had a larger average size, i.e., 97.14 cm in length and 27.79 kg in weight. The results of the analysis of tuna growth patterns at station 1 and station 2 showed a value of $b < 3$, indicating negative allometric growth. This means that the weight gain of the species was slower than its length gain. The average value of the condition factor was 1.03±0.25 for station 1 and 1.07±43 for station 2. These values varied according to temporal variation and fish size.

1 Introduction

Tuna, Mackarel tuna and skipjack tuna (TTC) are groups that have an important role in increasing the value of Indonesian fisheries exports. This group contributes second only to shrimp, which is 13% of the total value of Indonesian fisheries production. This can be seen from the trend of American market demand which has increased from year to year [1]. One of the most prominent fish in this group is yellowfin tuna (*Thunnus albacares*). However, the Central Bureau of Statistics reported that yellowfin tuna production in the last three years experienced fluctuations; 324,884 tons in 2019, 300,803 tons in 2020, and 359,143 in 2022.

The study of biological aspects is very important in fisheries resource management [2]–[4]. Biological studies tap into length-weight relationship and condition factors, fecundity, length of gonads at first maturity, and eating habits. Length-weight relationship and condition factors give an idea of the growth patterns in fish. This is paramount to providing an overview of environmental conditions, species' well-being, ecological conditions, diseases, and the comparison of fish conditions between one region and another [5]–[8].

The length of gonads at first maturity and fecundity are the object of fish reproductive biology studies. Gonadal maturity length (lm) and fecundity describe the condition of fish populations. While the length of the fish is a description of the lifespan of the fish, the length of gonads at first maturity indicates of the condition of the fish population. Fecundity does

*Corresponding author: jalil@ecampus.ut.ac.id

this similarly. Therefore, the study of the length of gonads at first maturity and fecundity is a key aspect in fisheries biology. Understanding this aspect is closely tied to the fishery resources management for commercial yellowfin tuna, particularly within the waters of Bone Gulf [9]–[11] . Insights into the changes in fecundity, growth of adult fish, and maturation that affect reproductive outcomes are essential to understanding marine fisheries recruitment models [3]. The description above suggests the rationale of conducting fisheries biology studies in a fishery area. However, this subject has generated little scholarly attention, which further emphasizes the importance of examining the biological aspects of yellowfin tuna (*Thunnus albacares*) in the waters of Bone Gulf.

2 Materials and methods

2.1 Research period and location

The study was carried out from July 2018 to June 2020 in Bone Gulf. The sampling research location was divided into two stations, i.e., Station 1 in Luwu Regency in the north and Station 2 in Lonrae, Tanete Riattang Timur District, Bone Regency, in the southern part of Bone Gulf waters.

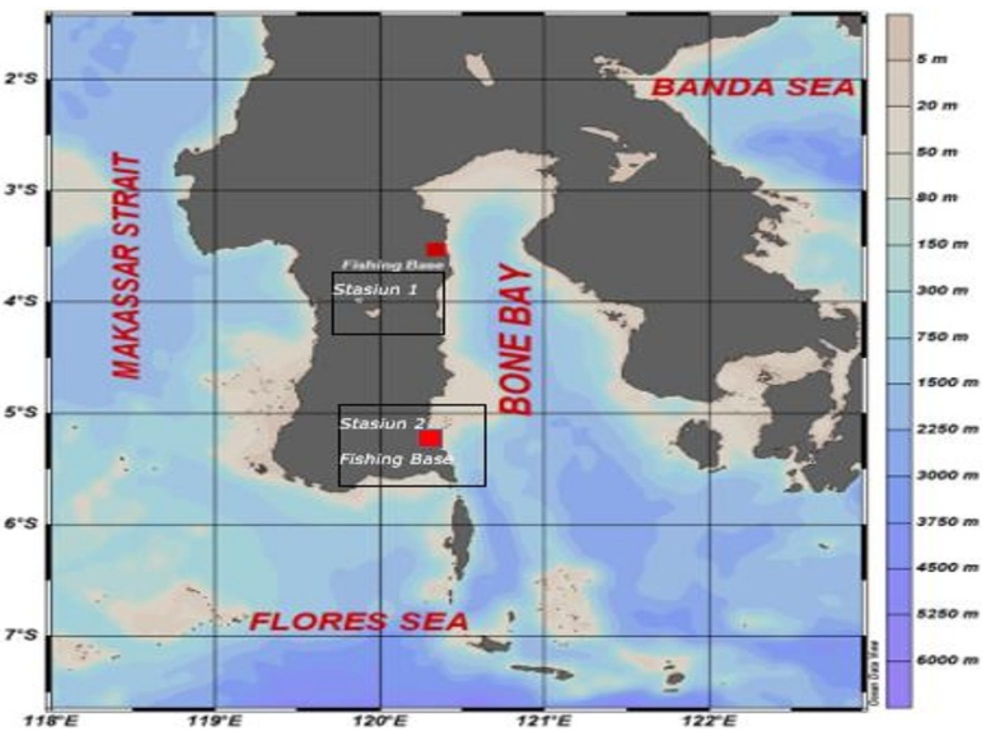


Fig. 1. Research locations and sampling stations in the waters of Bone Gulf [12]

2.2 Tools and materials

Observations were carried out using a variety of tools and materials both in the field and in the laboratory. Among the items include; 1) electric scales with an accuracy of 0.01 grams, 2) meter with an accuracy of 1 cm, 3) ice box made of Styrofoam, 4) stainless steel knives,

5) 60 ml plastic sampling containers, 6) plastic jars, 7) electric microscope, 8) glass preparation, 9) gonadal surgical tools, 10) tissue baskets, 11) microtone knives, and 12) floating bags, dish warmers and staining racks. The essential materials used for the biological observations of yellowfin tuna are: 1) yellowfin tuna caught by fishermen. 2) gonads of yellowfin tuna, 3) intestines of yellowfin tuna. 4) 10% formalin solution, 5) aquade, and 6) xylene, chloroform, talue, ethanol, sodium bicarbonate, magnesium sulfate, Paraffin wax (Paraplast plain/ MEDOS) and Mayer's Hematoxylin-Eosin used during the preparation and observation of gonad samples.

2.3 Sample Measurement

2.3.1 Sample length and weight measurement

The samples in this study were fish caught by fishermen in the waters of Bone Gulf using a handlining technique in one trip. Catches directly landed at each sample measurement station, i.e. Station 1a at the Fish Landing Base (PPI) of Cimpu Village, Suli District and Station 1b in Bonepute Village, South Larompong District, Luwu Regency and Station 2 at PPI Lonrae, Tanete Riattang Timur District, Bone Regency. Sample measurements at both stations were made at the time of landing and/or at the time of distribution to the market or cold storage. The sample fish was first weighed using an electric scale by 0.01 kg accuracy. Subsequent to the body weight data, fork length (FL) data was measured using a specially modified meter to measure large fish. Sampling at Station 2 was assisted by an enumerator of the Indonesian Society and Fisheries Foundation (MDPI) from July to November 2018 and data from collectors from February to June 2019. Data from measuring FL and fish weight were grouped per station for further analysis.

2.3.2 Gonadal Sampling

The maturity levels of yellowfin tuna gonads in Bone Gulf were assumed to be uniform; therefore, sampling was conducted only at Station 1. The gonads were collected once the yellowfin tuna caught by fishermen from the waters of North Bone Gulf landed at Station 1. Gonad sampling was carried out in stages. First, the fish caught by fishermen using handline fishing gear in one trip were stored in a Styrofoam ice box for 5-10 days. The catches were transported to the landing site and subsequently put in a holding box. Before being put into the shelter box, 2-3 fish samples were selected and dissected to collect gonads and intestines as samples. The fork length (FL) used for gonad samples ranged between 65 and 120 cm. These results are based on several research results that report that the length of gonads at first maturity ranges from 80 to 120 cm. However, samples were taken with a FL of 65 cm. The selected fish were measured in length using a meter by 1 cm accuracy and weighed using a digital scale by 0.01 kg accuracy. The samples were then dissected on the abdomen using a knife to take the gonads and intestines. The gonads and intestines were separated, and the gonads were weighed with digital scales by 0.1 g accuracy. Each sample was put into a 100 ml sample pot and preserved using 10% concentration formalin prior to histological GML (Gonad Maturity Level) analysis at the Maros Veterinary Center (BBV) Laboratory. The rest of the gonads were put into plastic jars for fecundity analysis and preserved using formalin of 10% concentration. The size of gonads at first maturity ranged between 65 and 120 cm. Samples were grouped in terms of their FL range, i.e., 60 – 69 cm, 70 – 79 cm, 80 – 89 cm, 90 – 99 cm, 100 – 109 cm, and 110 – 120 cm. One individual from each group was taken to predict the length of gonad at first maturity. The sampled fish intestines were put into jars and preserved using a 10% concentration of formalin for observation. Food habits was observed at the Fish Pests and Diseases Laboratory, Department of Fisheries, and FIKP Unhas.

2.3.3 Sample size composition

Analysis of the size of FL and body weight of yellowfin tuna caught at Station 1 and Station 2 fit into descriptive statistical analysis in SPSS 23. To analyze the FL and body weight of yellowfin tuna at the two stations, an independent-sample t test was performed with the help of SPSS 23.

2.3.4 Length-Weight relationship and condition factors

The analysis of length-weight relationship was carried out using the cubic equation assuming that the fish weight (W) is in proportion to the cube of its length (L) [5] is:

$$W = a\,L^b \text{ or } \log W = \log a + b \log L \quad (1)$$

The intercept is the intersection in which the regression line, the y (a) axis, and the regression coefficient of the slope angle of the line (b) pass through. Based on this equation, the criteria for the growth pattern of yellowfin tuna is based on the value of b. B=3 suggests an isometric growth pattern; B>3 indicates a positive allometry; and B<3 is negative allometry. The analysis of condition factor values is based on growth patterns obtained from length-weight relationship analysis [5].

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

or:

$$Kn = \frac{W}{aFL^b} \quad (3)$$

The equation represents relative condition factor as Kn, the observed weight as W (in gram), and the fork length as FL (in cm). An isometric growth pattern (b = 3) requires the calculation of the condition factor value in the equation 2. When the result of the calculation of the length-weight relationship is allometric (b≠3), the calculated condition factor value constitutes that of the relative condition factor or the Fulton's condition factor [13] using the equation 3.

2.3.5 The Length of gonads at first maturity

The length of gonads at first maturity (Lm) is defined using the formula:

$$P = 1/(1 + \text{Exp}[-r(L - LM]) \quad (4)$$

where proportion is identified as P, FL as L (cm), and the average length of mature gonads as LM (cm).

2.3.6 Gonadal maturity level

Analysis of the levels of gonadal maturity was performed by observing 20 eggs. Observations were carried out using histological microscopy at the Maros Veterinary Center Laboratory and Maros Veterinary Clinic. Development of gonadal identification was based on Itano's analysis [14]. The levels of gonad maturity were broken into Immature, Mature, Reproductively active, Spawning, and Reproductive in active.

2.3.7 Fecundity

The fecundity of yellowfin tuna is calculated using the equation [5] .

$$F = \frac{Q}{q} x\, n \tag{5}$$

where fecundity (grain) is represented as F; the observed weight of the gonads as Q (in gram); the weight of the sub-sample gonads as q (in gram); and the number of eggs in the sub-sample gonads (grains) as n. The relationship between FL and fecundity is defined by equation [6]:

$$\mathrm{F} = a\, FL^{b} \tag{6}$$

or in the form of a linear equation:

$$\mathrm{Log\ F} = \log a + b \log \mathrm{FL} \tag{7}$$

Where Fecundity is represented as F, Fork Length as FL (in cm), constant values as a and b.

3 Result and Discussion

3.1 Result

3.1.1 The Composition of sample size

The samples measured at the station during the study from July 2018 to June 2019 were 12,936 individuals. They ranged in size from 20 and 192 cm FL (84.36 cm in average), and in weight from 0.35 to 99.1 kg (17.08 kg in average). The most samples were obtained in September 2018, and the least samples were obtained in July 2018. The smallest size in average length was collected in August 2018, and the largest was in March 2019. As for the average weight, the smallest was obtained in October 2018 and the highest in May 2019.

Samples measured at Station 2 (in the southern part) were 2,570 individuals that had FL between 60 and 162 cm (97.4 cm in average). Based on weight, the samples ranged between 5.61 and 97.35 kg (27.79 kg in average). The most samples were captured in May 2019, while the fewest samples were captured in December 2018. The average length of the fish was largest in November 2018 and smallest in March 2019. The average weight of the largest fish was in June and the smallest in September 2018. The composition of the FL captured at both stations is presented in Figure 2 and 3. There was no dominant length of the fish caught in the waters of North Bone Gulf (Figure 2). However, the most common size was 85-cm sample group, which encompassed 710 individuals (6.85%).

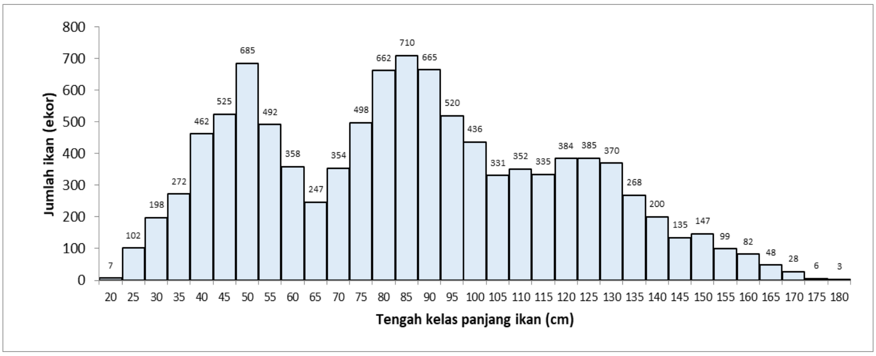


Fig. 2. Number of *Thunnus albacares* samples caught in the Northern Bone Gulf

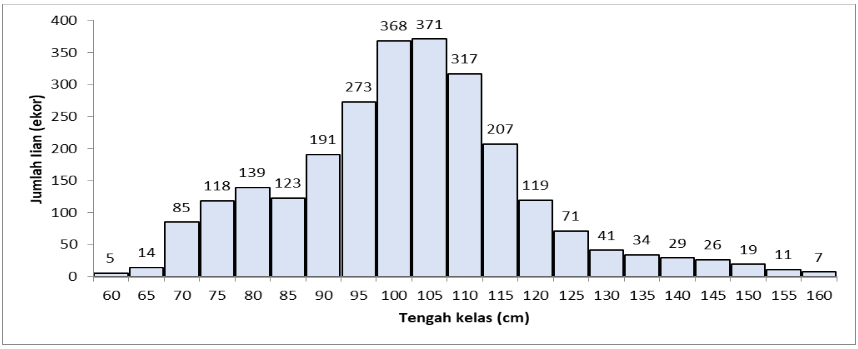


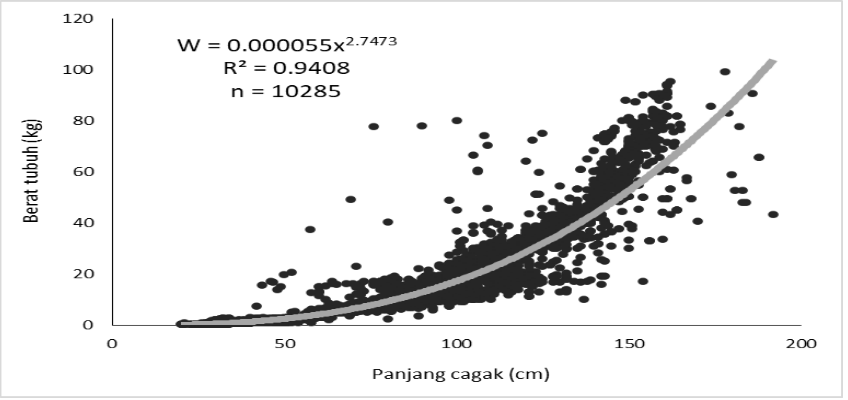
Fig. 3. Size compositions of *Thunnus albacares* caught in the Southern Bone Gulf

Figure 3 shows the same pattern; there was no dominant size among the yellowfin tuna caught in the Southern Bone Gulf. The highest length was found in 100- and 105-cm groups, i.e., 368 individuals (14.32%) and 371 individuals (14.45%), respectively. The smallest size was found among those with a FL of 60 cm, i.e., 6 individuals (0.19%). The total samples of yellowfin tuna caught in the Southern Bone Gulf were 2,570 individuals.

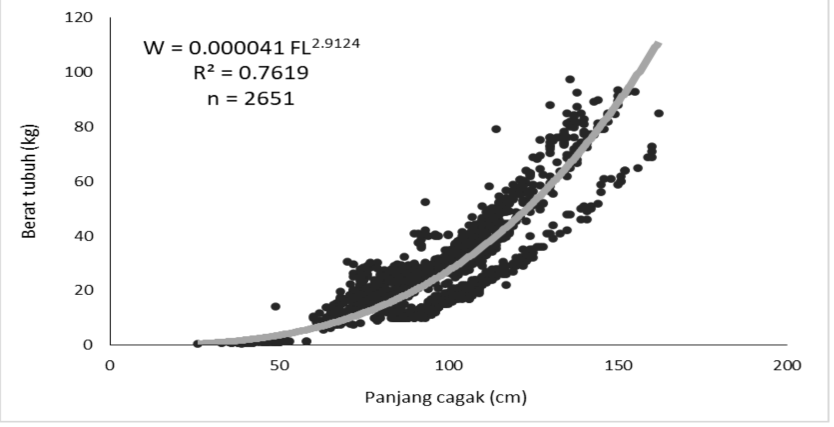
The length-weight compositions of the fish samples in the Northern Bone Gulf were different from those in the Southern part. This is in accordance with the results of different tests on samples obtained at both stations with a significance value of 0.000.

3.1.2 Length-weight relationship

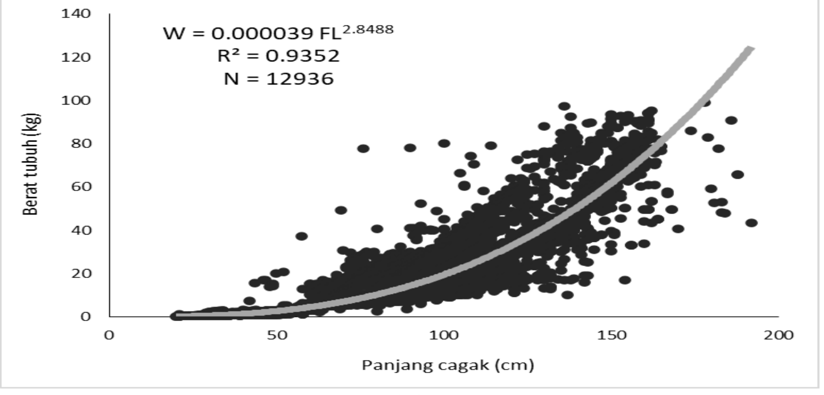
The length-weight relationship analysis of yellowfin tuna in Bone Gulf is presented in graphs as Figure 4 shows below.



(A)



(B)



(C)

Fig. 4. Regression of length-weight relationship of *Thunnus albacares* in Bone Gulf: (a) the North, (b) the South, (c) both North and South

Figure 4 shows the correlation coefficient (R) for the length-weight relationship was 0.982 in the Northern and 0.873 in the Southern Bone Gulf. R value for both stations was found to be 0.967. The a values that indicated the independent variable (fork length) was heavily associated with the weight gain of yellowfin tuna as the table shows below.

Table 1. Regression value of the length-weight relationship of yellowfin tuna in Bone Gulf

Area	a	b	R	LWRs
Northern	0,000055	2,7473	0,982[a]	$W = 0{,}000055FL^{2{,}7473}$
Southern	0,000041	2,9124	0,873[a]	$W = 0{,}000041FL^{2{,}9124}$
Northern & Southern	0,000039	2,8488	0,967[a]	$W = 0{,}000039FL^{2{,}8488}$

T-test for one sample was performed and indicated that the significance value (two-tailed) corresponded to 0.076>0.05 with t-table higher than t-count value, i.e., 4.30625 > 3.408. This output suggests that b values obtained from the analysis of the length-weight relationship are not equal to 3 (b<3), indicating that the yellowfin tuna samples in the Northern part (Station 1), and Southern part (Station 2), both individually and collectively, had negative allometric growth.

3.1.3 Condition factors

The condition factors in the yellowfin tuna samples in Bone Gulf varied by month. In the Northern Bone Gulf, the range of the condition factors was between 0.1 and 4.7 with an average of 1.03 ±0.25. The average condition factor value occurred in April at 0.9, and the highest occurred in September peaking at 1.09. In the waters of the Southern Bone Gulf, the condition factor values ranged from 0.24 to 4.26 with an average of 1.07±0.43. The highest average condition factor values of fish caught in the waters of Southern Bone Gulf were lowest and highest in December and July at 0.60 and 1.74, respectively. The value of condition factors by month during the study at each station is presented in Table 2.

Table 2. Relative condition factors of *Thunnus albacares* in the Northern Bone Gulf and Southern Bone Gulf during the study.

Period	Northern Part			Southern Part		
	N	**Range**	**Average±SD**	**N**	**Range**	**Average±SD**
July 2018	168	0,10 – 2 ,40	1,06 ± 0,23	166	0,88 – 4,26	1,74 ± 0,42
Aug 2018	1554	0,15 – 2,28	1,08 ± 0,21	157	1,15 – 2,21	1,72 ± 0,18
Sep 2018	2722	0,13 – 3,64	1,09 ± 0,28	146	0,80 – 3,52	1,65 ± 0,67
Okt 2018	1185	0,20 – 3,43	1,05 ± 0,28	178	1,34 – 1,79	1,52 ± 0,08
Nov 2018	1070	0,28 – 2,31	0,99 ± 0,19	131	1,19 – 1,90	1,54 ± 0,09
Dec 2018	486	0,28 – 1,93	0,99 ± 0,24	51	0,42 – 0,82	0,60 ± 0.07
Mar 2019	647	0,70 – 1,64	0,95 ± 0,10	238	0,32 – 1,18	0,68 ± 0,19
Apr 2019	375	0,27 – 4,07	0,90 ± 0,37	395	0,24 – 1,18	0,86 ± 0,16
May 2019	988	0,17 – 2,46	0,99 ± 0,26	817	0,44 – 1,49	0,87 ± 0.09
Jun 2019	1.090	0,47 – 2,40	0,94 ± 0,15	372	0,42 – 1,38	0,88 ± 0,08
Total	10285	0,10 – 4,07	1,03 ± 0,25	2651	0,24 – 4,26	1.07±0,43

3.1.4 Gonadal maturity level

The gonadal samples observed in this study were obtained at Station I. The number of samples used was 33 individuals of yellowfin tuna. The fork lengths used for the observations of gonadal maturity levels ranged between 66 cm and 146 cm. The results of these observations are presented in Figures 5 and 6.

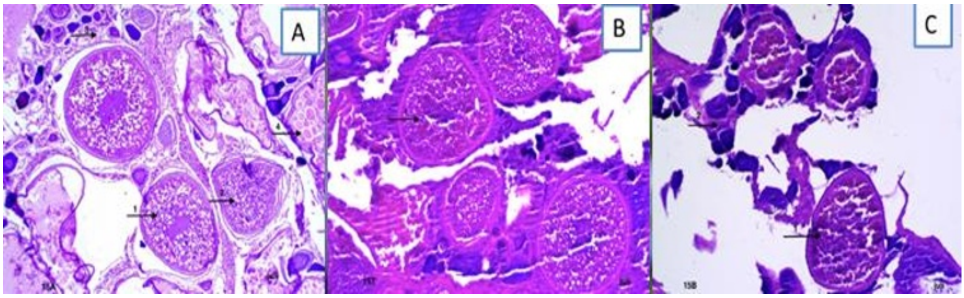


Fig.5. Gonadal sample with 66 cm FL. (a) anterior, (b) middle, (c). posterior. (20X magnification, Mayer's hematoxylin staining)

In (a) anterior, the yolk appears and the nucleus is still visible but only partially. In (b) middle, yolk is not yet visible. In (c) posteriorly, there is no apparent egg yolk either. The gonadal maturity level is therefore classified as active reproductive.

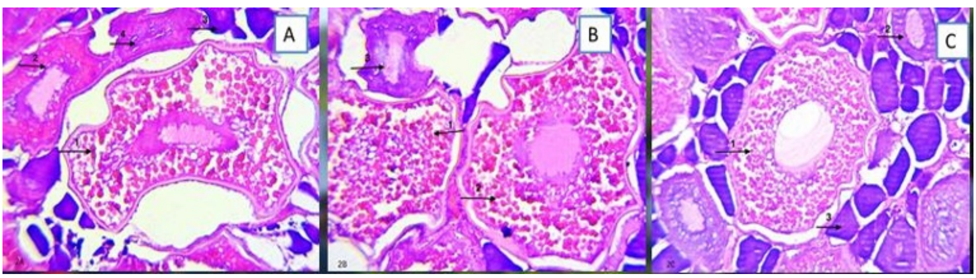


Fig. 6. Gonadal sample with 146 cm FL. (a) anterior, (b) middle, (c). posterior (20X magnification Mayer's hematocxylin-eosin stains)

In both (a) (anterior) and (b) (middle), there is gonadal development on the anterior side, and it appears that the gonads contain egg yolk but not fullly (partially yolked) on the fully yolked oocyte. In (c) posterior, the yolk appears and the nucleus is still visible, but only partially. Based on Figure 6, the level of gonad maturity in fish with a length of 146 cm is early vitellogenic. The results of observations such as those in Appendix 8 show that there has not been found any gonadal mature *Thunnus albacares* in Bone Gulf during the observation.

3.1.5 Length of gonads at first maturity

The length of gonads at first maturity (Lm) indicates the size of maturity of the fish species. A graph of the size of the first mature gonads can be seen in Figure 7.

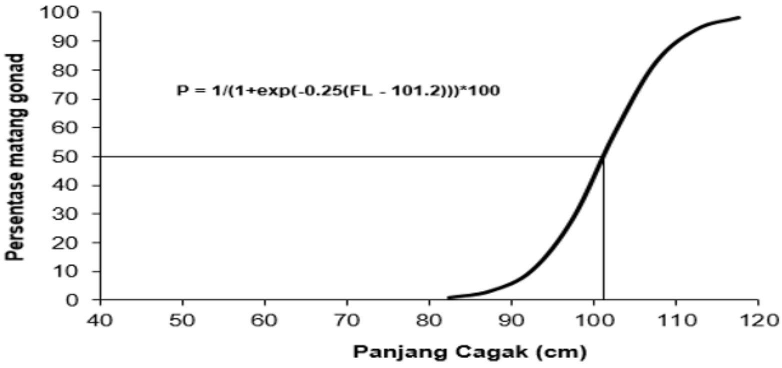


Fig. 7. Logistic curve of the estimation of the length of gonads at first maturity among *Thunnus albacares* in Bone Gulf

Figure 7 demonstrates that the length of gonads at first maturity among yellowfin tuna in Bone Gulf was 101.18 cm FL.

3.1.6 Fecundity

Fecundity analysis was carried out on 33 samples of yellowfin tuna with FL ranging from 66.00 to 148.00 cm and body weight ranging from 5.10 to 31.48 kg. The range of fecundity was from 46,685 to 316,681 eggs, with egg diameters ranging between 0.2000 and 1.1353 mm. The fecundity and diameter of the gonads based on FL and body weight are presented in Figure 7.

The results of the regression calculation of the relationship between FL and fecundity are shown in Appendix 10. If the value of a and the value of b are included in the equation F = aFLb, then the regression equation of the relationship between FL and fecundity is F = 4.414 FL1.654, with a significance level of 0.003. This means that the fork length of is related to the increase in fecundity of yellowfin tuna species in Bone Gulf.

The extent to which FL and fecundity are associated can be seen in the Summary Model based on the results of regression analysis in Appendix 10A. The correlation coefficient R = 0.705, and the determinant coefficient R2 = 0.496. The diameter of yellowfin tuna eggs ranged from 0.2000 to 1.1353 mm, each peaking at the highest frequency in the diameter range of 0.4100 – 0.5000 mm (41.72%) and the lowest frequency in the range of 1.1000 – 1.2000 (0.61%).

3.2 Discussion

3.2.1 Sample composition

An independent-sample t test was performed to see the difference between the fork length and the body weight of the samples at Station 1 and Station 2. The resulting statistical evidence points out that they were significantly different ($p < 0.05$). Comparison of the fork length of yellowfin tuna in several locations according to previous studies is presented in Table 3. In Bone Gulf, the size composition of yellowfin tuna ranges from 20 to 192 cm (an average of 84.35± 31.41 cm). The fork length ranges from 20 to 192 cm (86.252 ± 0.2894 cm in average) in the Northern Bone Gulf, and ranges from 60 to 162 cm (97.14 cm in average) in the Southern Bone Gulf. These results are found to be lower than those of the studies on yellowfin tuna captured in Benoa port, Bali, and Makassar Strait [15] [16].

Differences in size can be influenced by the depth of the waters in which fishing gears take place [17]. In addition, the length of the fishing line can also affect the size of the tuna caught. Yellowfin tunas live to a depth of 200 m or above the thermocline layer. On the other hand, the fishermen in Bone Gulf, particularly in Cimpu and Bonepute, that perform fishing work in Bone Gulf generally use 50 m fishing line. This confirms the previous studies that claimed that the size of fish caught at a depth of ≥ 50 m is greater than tuna caught at a depth of ≤ 50 meters [18]–[21]. Differences in the length-weight relationship may also be subject to internal and external factors [22] [23].

Table 3. Comparison of the fork lengths of *Thunnus albacares* in Bone Gulf and in other waters

Location	FL Range (cm)	FL Average (cm)	Reference
Indian Ocean	81 – 171	129,28	[24]
Indian Ocean	43 – 178(M) 30 – 170(F)	135,3 130,8	[25]
Indian Ocean	78 – 185		[22]
Benoa, Bali	75 – 179	133,71	[26]
Banda Sea	25 – 178	94,0	[27]
Banda Sea	55 – 215	-	[21]
Simeulue Island, Aceh	45,5 – 111,5	-	[28]
East Coast of India	20 – 185	101,9	[29]
Bone Gulf	40 – 160	NA	[16]
Bone Gulf	20 – 192	84,35	This study

3.2.2 Length-Weight Relationship

The analysis of the length-weight relationship of yellowfin tuna points to a close relationship with negative allometric growth pattern, indicating that the length of yellowfin tuna grows faster than the weight does. This study has similarities to other studies in different waters (Table 4).

Tabel 4. Length-weight relationship of *Thunnus albacares* in several locations

Location	A	b	Correlation		Growth Pattern	Reference
			R	R^2		
Makassar Strait	0,000 (♀) 0,000(♂)	2,565 (♀) 2,623 (♂)	-	0,941(♀) 0,944(♂)	Allometry - Allometry -	[30]
South China Sea	0,0096	2,5480	-	0,9243	Allometry -	[31]
Andaman & Nicobar Islands	0,00002(♀) 0,00001(♂)	2,92(♀) 3,12(♂)	0,95 (♀) 0,98 (♂)		Allometry - Allometry +	[32]
Benoa Bali	$3x10^{-5}$	2,911	0,967		Allometry -	[26]
Banda Sea	0,0005	2,919	0,597		Allometry -	[33]

Molucca Sea	0,0172 (♀) 0,0223(♂)	2,983(♀) 2,928(♂)	0,968(♀) 0,983(♂)		Allometry + Allometry -	[34]
Gulf Bone: North South Gulf Bone as a whole	 0,00006 0,00004 0,00004	 2,747 2,912 2,849			 Allometry - Allometry - Allometry -	This study

Compared to several studies in Table 4, the value of the length-weight relationship in this study is within the normal and reasonable range. This becomes obvious from the value of b obtained in the range of previous studies, generally resulting in negative allometry [26], [30], [32]–[35]. Positive allometric and isometric growth are only found in one body of water [15] [36]. The difference in growth patterns is influenced by the nature of yellowfin tuna which has a habit of migrating across very wide ocean waters, so most of the energy obtained from food is used to migrate. Other factors that can be influential are the location of the waters, and the timing of the study, gonadal development and sample distribution [20].

3.2.3 Condition factors

Condition factors vary according to the time of capture (Table 2). The relative condition factor value of yellowfin tuna in the northern part of Bone Gulf ranged from 0.10 to 4.07 (1.03 in average). In contrast, fish caught in the southern waters ranged from 0.24 to 4.26 (1.07 in average). Overall, the samples caught in the waters of Bone Gulf had a condition factor value ranging from 0.11 to 4.72 with an average of 1.05.

Condition factors (Kn) in young fish are higher and decrease as the fish get older. Kn variations are attributed to both internal and external factors. Internal factors may be associated with age, sex, gonadal maturation, species' well-being and food availability [37]. External factors deal with the extent to which food is available and the circumstances of water environments in which the fish inhabit [38] (Jatmiko et al., 2014). Condition factors related to length and weight are a description of food availability and fish health. In general, changes in condition factors based on seasonal cycles are related to gonadal maturity levels [39], [40]. The value of yellowfin tuna's condition factor is directly proportional to its fork length (Azizi et al., 2020). The conditions of gonadal maturity also affect the value of the condition factor up to the time when the fish is about to spawn. Different results were found by a previous study [36] that claimed fish with smaller FL also had smaller condition factor values.

3.2.4 Length of gonads at first maturity

According to the aforesaid result, the observed length of gonads at first maturity in yellowfin tuna ((Lm50%) in Bone Gulf was 101.18 cm. Table 5 summarizes the comparison of yellowfin tuna in several waters in terms of the length of gonads at first maturity.

Table 5. Comparison of the length of gonads at first maturity among *Thunnus albacares* in several waters

No.	Location	Lm_{50} (cm)	Method	Reference
1.	Banda Sea	106	Histology	[33]
2.	Tomini Bay	94,8	Histology and GSI	[41]

3.	West-Central India Ocean	113,77(♀) 120,20(♂)	Morphology	[42]
4.	Western Indian Ocean	102	Histology	[43]
5.	Indonesian & Philippine Waters	98,13	Histology	[44]
6.	ZEE India	57,6	Morphology	[45]
8	Bone Gulf	107,98(♀) 109,75(♂)	Morphology	[46]
9.	Bone Gulf	101.77	Morphology	This study

Description: Lm50 = Length at first maturity

In Table 5, the length at first maturity ($Lm_{50\%}$) in the majority of locations was greater than that in Bone Gulf where this study took place [4], [33], [42], [47]. However, it is important to note that the present result is greater than the previous results in the Exclusive Economic Zone of Indian waters and Tomini Bay [41]. Further, the result of the present study shares similarities to that of the previous work in ocean waters and bay waters. In general, fish caught in ocean waters have a larger gonad maturity size compared to those in coastal waters. Yellowfin tuna faster reaches gonad maturity in areas close to land compared to fish in ocean areas [45].

When compared to the result of a previous work by Kantun & Amir in the same location [16], the present result showed smaller length of mature gonads. In general, a decrease in the length of gonads at first maturity is subject to overfishing. A more in-depth study is needed on the determination of overfishing based on the $Lm_{50\%}$ value to generate findings that correspond to the actual conditions.

The difference in the $Lm_{50\%}$% size can be led by several factors, including fishing gear, the number of observed samples, and geographic location, among others (Itano, 2000). In general, gonadal maturity is faster among the tropical fish than the subtropical fish [48]. The decrease in the length of first maturity can also result from population pressure due to capture [49]. The difference in the size of the first gonad maturity in reproductive biology research, particularly among yellowfin tuna, can be caused by the differences in observation methods and gonad maturity criteria used [43]. The difference in the length of gonads at first maturity in the present study was likely due to the number of gonad samples observed.

3.2.5 Levels of gonadal maturation

The degree to which gonads undergo maturity is heavily associated with environment changes particularly spawning season. Gonad maturity level (GML) can be found to be uniform in certain types of fish and varied in others at the same time. GML analysis serves as a basis for identifying the size of gonads at first maturity ($Lm_{50\%}$). Results of GML observations in the present study indicate that yellowfin tuna spawn more than once throughout the year. This is consistent with several previous studies at various locations [46][47][39]. An important finding in this study was that there was a decrease in the length of gonads at first maturity compared to a previous study, i.e., from FL 119.20 [48] to 101.8 cm. The decline in the size of gonads at first maturity is one indication of the rising exploitation of fishery resources [49]. Wise and proper policy and management are therefore crucial to pursuing the sustainability objectives for yellowfin tuna resources in Bone Gulf in particular and WPP-NRI (Fisheries Management Area of Republic of Indonesia) in general for reducing threats to the species that lead to endangerment.

3.2.6 Fecundity

The fecundity values of yellowfin tuna found in Bone Gulf in this study varied between 46,065 and 316,681 grains. The finding is significantly different when compared to previous studies, such as Itano [44] in the Western Pacific Ocean that peaked between 978,899 and 4061,460 grains for fish with FL between 87 and 149 cm and a study in Hawaiian waters that ranged between 425,354 and 10,611,913 grains with FL of 116 – 154 cm. Different results of various researchers are presented in Table 6. The fecundity values in the present study were smaller than other studies. This is likely due to different sample sizes. In other studies, the smallest sample is generally >100 cm, except for Itano's work [43] that used the smallest sample of 87 cm. The smallest sample in the present study was FL 20 cm.

The common premise is that the increase of fecundity aligns with that of body size. Larger fish have higher fecundity values, and vice versa; smaller fish have lower fecundity values [10]. This corroborates the analysis results of FL and fecundity relationship at 0.000 significance and 0.705 correlation coefficient, with the remaining accounting for other variables led by internal and external factors. External factors may include the condition of the water environment. Different water environment conditions have different impacts on the fecundity of yellowfin tuna, individually or collectively. In addition, sampling time and fishing season may also be determinant factors [50].

Table 6. Fecundity of Thunnus albacares in several aquatic locations

Location	Length (cm)	Fecundity (grain)	Diameter (µm)	Reference
Banda Sea	111 – 145	14.595.000 – 45.720.000	34,60 – 50 ,97	[33]
Benoa, Bali	137 – 153	2.715.515 – 6.744.001	-	[51]
Western Pacific Ocean	87 – 149	549.865 – 4.061.420	-	[44]
Hawaiian Waters	116 - 154	425.354 – 10.611.913	-	(40)
Bone Gulf	66 – 148	46.685 – 316.68	246,17 – 1.026,15	This study

4 Conclusion

The conclusion identifies key insights for attention and is based on the study findings. The size composition of fish caught in Bone Gulf varied between 20 and 192.7 cm (86.26 ± 0.2893 cm in average). The growth pattern of yellowfin tuna (*Thunnus albacares*) in Bone Gulf was negative allometry. The gonadal maturity rate showed variations that indicated fish spawning patterns more than once each year. The length of gonads at first maturity was 101.18 cm, with fecundity values ranging from 46,685 to 316.68 grains.

Acknowledgements

We express our highest gratitude to the Rector of Universitas Terbuka and the Dean of the Faculty of Science and Technology of Universitas Terbuka for the opportunity given to us to carry out the task of studying. We would like to acknowledge warm thanks to the Head of the Fisheries Service of Luwu Regency, the Head of the Fisheries Service of Bone Regency, and South Sulawesi Province for the permission given to the author to carry out the research. Our deepest appreciation also goes to MDPI Foundation for the assistance provided to the authors for Station 2.

References

1. T. Rudi Hartanto, S. Suharno, and B. Burhanuddin, "*Export Competitiveness of Indonesian Tuna-Skipjack-Tongkol in the United States Market"* Indonesian Journal of Fisheries Product Processing vol. 24, no. 2, pp. 227–235, 2021, doi: 10.17844/jphpi.v24i2.36075.(In:Indonesia)
2. T. J. Quinn, "Population DynamicsBased in part on the article 'Population dynamics' by Terrance J. Quinn II, which appeared in the *Encyclopedia of Environmetrics* .," *Encycl. Environmetrics*, no. December, 2013, doi: 10.1002/9780470057339.vap028.pub2.
3. T. Jakobsen, M. J. Forgaty, B. A. Megrey, and E. Moksness, *Fish reproductive biology _ implications for assessment and management*, Second Edi. Willey-Blackwell, 2016.
4. I. Zudaire *et al.*, "Fecundity regulation strategy of the yellowfin tuna (Thunnus albacares) in the Western Indian Ocean," *Fish. Res.*, vol. 138, pp. 80–88, 2013, doi: 10.1016/j.fishres.2012.07.022.
5. M. I. Effendie, *Biologi Perikanan*, Yogyakarta: Yayasan Pustaka Nusantara, 2002.
6. S. Kuriakose, "Estimation of length weight relationship in fishes," in *Summer School on Advanced Mathods for Fish Stock Assessment and Fisheries Management*, no. L, ICA- Central Marine Fisheries Research Institute, 2014, pp. 215–220.
7. Z. A. Muchlisin and I. Dewiyanti, "Length-weight relation of condition factors of three fish species found in Gigieng estuary of Aceh Besar, Aceh Province," *Depik J.*, vol. 1, no. 1, pp. 1–9, 2012, doi: 10.13170/depik.1.1.21.(In: Indonesia)
8. N. Jisr, G. Younes, C. Sukhn, and M. H. El-Dakdouki, "Length-weight relationships and relative condition factor of fish inhabiting the marine area of the Eastern Mediterranean city, Tripoli-Lebanon," *Egypt. J. Aquat. Res.*, vol. 44, no. 4, 2018, doi: 10.1016/j.ejar.2018.11.004.
9. _II Terrance J. Quiinn and R. B. Deriso, *Quantitative Fish Dynamics*. New York: Oxford University Press, 1991.
10. M. Rochet, "Effects of Fishing on the Population," in *Fish Reproductive Biology: Implications for Assessment and Management*, T. Jakobsen, M. Fogarty, B. A. Megrey, and E. Moksness, Eds. Iowa, USA: Wiley-Blackwell, 2009, pp. 172–204.
11. I. Zudaire *et al.*, "Reproductive biology of yellowfin tuna (Thunnus albacares) in the Western and Central Indian Ocean," 2010. 10.14710/ik.ijms.23.4.145-155
12. Safruddin *et al.*, "The fishing ground potential zones of large pelagic fish in the Gulf of Bone," in *Proceedings of the VI National Symposium on Marine Affairs and Fisheries Hasanuddin University, Makassar, 21 Juni 2019*, 2019, no. November, pp. 331–340.(In: Indonesia)
13. P. J. B. Hart and J. D. Reynolds, *Handbook of Fish Biology and Fisheries*, vol. 1. Blackwell Publishing, 2002.
14. D. G. Itano and K. N. Holland, "Movement and vulnerability of bigeye (Thunnus obesus) and yellowfin tuna (Thunnus albacares) in relation to FADs and natural aggregation points," *Aquat. Living Resour.*, vol. 13, pp. 213–223, 2000.
15. I. Jatmiko, H. Hartaty, and B. Nugraha, "Weight-weight, Length-weight Rekationships And Condition Factor Of Yeloowfin Tuna (Thunnus albacares) In Eastern Indian Ocean," 2014.

16. W. Kantun and M. F. Amir, Biological Aspects and Composition of Fishing Rod Catches in the Waters of Bone Bay Balikdiwa Journal vol. 7, no. 1, pp. 24–32, 2016. (In: Indonesia)
17. A. Barata, D. Novianto, and A. Bahtiar, *Distribution of Tuna by Temperature and Depth in the Indian Ocean ILMU Kelaut. Indones. J. Mar. Sci.*, vol. 16, no. 3, pp. 165–170, 2012, doi: 10.14710/ IK.IJMS.16.3.165-170. (In: Indonesia)
18. W. Kantun, A. Mallawa, and A. Tuwo, "Reproductive pattern of yellowfin tuna Thunnus albacares in deep and shallow sea FAD in Makassar Strait Reproductive pattern of yellowfin tuna Thunnus albacares in deep and shallow sea FAD in Makassar Strait," *AACL Bioflux*, vol. 11, no. 3, pp. 884–893, 2018, [Online]. Available: http://www.bioflux.com.ro/aacl
19. W. Kantun, L. Darris, and W. S. Arsana, "Species Composition and Size of Fish Caught in FADs using Hand-line in Makassar Strait" *Mar. Fish. J. Mar. Fish. Technol. Manag.,* 2018, doi: 10.29244/jmf.9.2.157-167.(In: Indonesia)
20. W. Kantun, A. Mallawa, and N. L. Rapi, "Comparison of The Structure Size Yellowfin Tuna (Thunnus albacares) Between Caught at FAD Deep Sea And Shallow Waters at Makassar Strait," vol. 1, no. 2, pp. 112–128, 2014.
21. E. Nurdin, M. F. A. Sondita, R. Yusfiandayani, and M. S. Baskoro, "Growth and mortality parameters of yellowfin tuna (Thunnus albacares) in Palabuhanratu waters, west Java (eastern Indian Ocean)," *AACL Bioflux*, vol. 9, no. 3, pp. 741–747, 2016.
22. A. Ghofar, S. W. Saputra, A. Sabdono, A. Solichin, W. T. Taufani, and S. Febrianto, "Population Dynamics of Yellowfin Tuna Thunnus albacares (BONNATERRE , 1788) in the Fisheries Management Area 573 Of The Indian Ocean," *Croat. J. Fishries*, vol. 0586, no. 79, pp. 53–60, 2021, doi: 10.2478/cjf-2021-0006.(In: Indonesia)
23. A. Nelwan, U. Hasanuddin, S. Sudirman, and U. Hasanuddin, "Fishing Productivity Of Pelagic Fishes In The Waters Of Sinjai Regency On East-West Monsoon Transition" noXVII (1). March, pp. 17–25, 2015.(In; Indonesia)
24. N. Muhammad and A. Barata, "Size Structure Of Yellowfin Tuna (Thunnus albacares) Caught By Handline In Around of Fish Agregation Devices the Indian Ocean of South Bali and Lombok.," *BAWAL Vol. 4 Desember 2012 161-167*, vol. 4, no. 3, pp. 161–167, 2012.
25. A. Wujdi, B. Setyadji, and B. Nugraha, "Length Distributionand Sex Ratio Of Yellowfin Tuna (Thunnus Albacares) In The Easternindianocean" *BAWAL Widya Ris. Perikan. Tangkap*, vol. 7, no. 3, p. 175, 2015, doi: 10.15578/bawal.7.3.2015.175-182.(in:Indonesia)
26. H. Hartaty and K. Sulistyaningsih, "Estimation Of Population Parameter And Exploitation Rate Of Yellowfin Tuna (Thunnus albacares) Landed At Benoa, Bali," *J. Lit. Perikan. Indones.*, vol. 20, no. 2, pp. 97–103, 2014.(In: Indonesia)
27. Haruna, A. Mallawa, Musbir, and M. Zainuddin, "Population Dynamic Indicator of the Yellowfin Tuna Thunnus albacares and Its Stock Condition in The Banda Sea, Indonesia," *AACL Bioflux*, vol. 11, no. 4, pp. 1323–1333, 2018, [Online]. Available: http://www.bioflux.com.ro/docs/2018.1323-1333.pdf
28. Z. Burhanis; Jaliadi; Radmi, "Structure and growth pattern of yellowfin tuna Thunnus albacores (Bonnatere , 1788) in the waters of Simeulue Islands , Aceh," *Int. J. Fish. Aquat. Stud.*, vol. 5, no. 6, pp. 264–268, 2017.
29. P. Rohit, G. S. Rao, and K. Rammohan, "Age , growth and population structure of the yellowfin tuna Thunnus albacares (Bonnaterre , 1788) exploited along the east coast of India," vol. 59, no. 1, pp. 1–6, 2012. akses 17 Jan 2024

30. W. Kantun and A. Yahya, *The Relationship of Long Weight of Madidihang Thunnus albacares Tuna from Majene Waters, Makassar Strait, West Sulawesi J. Balik Diwa*, vol. 4, no. 2, pp. 39–43, 2013.(In: Indonesia)
31. Z. Ma, G. Yu, Q. Wu, S. Ma, S. Wu, and X. Chen, "Length-weight relationships of Yellowfin Tuna Thunnus Albacares, Skipjack Tuna Katsuwonus Pelamis, Yaito Tuna Euthynnus Yaito, and Blue Round Scad Decapterus Maruadsi from Mischief Reef, South China Sea," *Int. J. Innov. Stud. Aquat. Biol. Fish.*, vol. 2, no. 4, pp. 27–30, 2016, doi: http://dx.doi.org/10.20431/2454-7670.0204005.
32. A. B. Kar, L. Ramalingam, K. Govindaraj, and G. V. A. Prasad, "Study of the Growth and Populatio'n Parameters of Yellowfin Tuna (Thunnus albacares) in the Andaman and Nicobar Waters Based on the Length Frequency Data," IOTC-2012-WPTT14-30 Rev_1, 2012.
33. U. Chodrijah, "Some aspects of reproductive biology of madidihang fish (Thunnus albacares) from the waters of the Banda Sea," 2011, no. 1983, pp. 401–409.
34. B. Wahono and L. J. . Lumingas, "Size-frequency and allometric growth of the yellowfin tuna, Thunnus albacares (Bonnaterre, 1788), caught in the Molluca Sea, Indonesia," *Aquat. Sci. Manag.*, vol. 1, no. 2, p. 124, 2013, doi: 10.35800/jasm.1.2.2013.7274.
35. M. Yosuva, D. Jeyapragash, V. Manigandan, M. Machendiranathan, and A. Saravanakumar, "Length-weight relationship and relative condition factor of yellowfin tuna (Thunnus albacares) from Parangipettai coast, southeast coast of India," *Zool. Ecol.*, vol. 8005, no. 2, pp. 1–6, 2018, doi: 10.1080/21658005.2018.1455319.
36. N. A. Azizi, S. W. Saputra, and A. Ghofar, "Length - Weight Relationship, Condition Factors and Legth of The First Time Caught of Yellowfin Tuna (Thunnus albacares) in Cilacap Ocean Fishing Port," *Manag. Aquat. Resour. J.*, vol. 9, no. 2, pp. 90–96, 2020, doi: 10.14710/marj.v9i2.27764.(in: Indonesia)
37. M. King, *Fisheries biology, assessment and management: Second edition*, Secong Edi. Blackwell Publishing Ltd, 2007. doi: 10.1002/9781118688038.
38. A. Wujdi *et al.*, "Distribution and Biological Aspect Of Yellowfin Tuna (Thunnus albacares) Caought By Indonesian Tuna Longline In The Eastern Indian Ocean," 2014.
39. M. Y. Hossain, "Length-weight, length-length relationships and condition factors of three schibid catfishes from the Padma River, Northwestern Bangladesh.," *Asian Fish. Sci.*, vol. 23, no. 3, pp. 329–339, 2010.doi: 10.33997/j.afs.2010.23.3.005
40. M. Jobling, "Environmental Factors and Rates of Development and Growth," in *Handbook of Fish Biology and Fisheries, Volume 1*, 1st ed., P. J. B. Hart and J. D. Reynolds, Eds. Blackwell Publishing Ltd, 2004, pp. 97–122. doi: 10.1002/9780470693803.ch5.
41. S. Mardlijah and M. P. Patria, "Reproductive biology of yellowfin tuna (thunnus albacares bonnatere 1788) attominibay," *Bawal*, vol. 4, no. April, pp. 27–34, 2012.(in: Indonesia)
42. G. Zhu, L. Xu, Y. Zhou, and L. Song, "Reproductive biology of yellowfin tuna T. albacares in the west-central Indian Ocean," *J. Ocean Univ. China*, vol. 7, no. 3, pp. 327–332, 2008, DOI: 10.1007/s11802-008-0327-3.
43. I. Zudaire, H. Murua, M. Grande, and N. Bodin, "Reproductive Ecology of the Yellowfin Tuna (Thunnus albacares) in the western Indian ocean," vol. 111, no. 3, p. 189, 2014, doi:10.7755/FB.111.3.4.

44. D. G. Itano, *The Reproductive Biology of Yellowfin Tuna (Thunnus albacares) in Hawaiian Waters and the Western Tropical Pacific Ocean : Project Summary*. Hawaii: University of Hawaii, Joint Institute for Marine and Atmospheric Research, 2000.
45. E. M. Abdussamad *et al.*, "Fishery of yellowfin tuna Thunnus albacares (Bonnaterre, 1788) in the Indian EEZ with special reference to their biology and population characteristics," *Indian J. Fish.*, vol. 59, no. 3, pp. 43–51, 2012.
46. W. Kantun and F. Amir, *Age Structure, Growth Patterns and Mortality of Madidihang Thunnus albacares Tuna (Bonnatere, 1788) in Makassar Strait J. Balik Diwa*, vol. 4, pp. 8–14, 2013.(in:Indonesia)
47. C. Sun, W. Wang, and S. Yeh, "Reproductive biology of yellowfin tuna in the central and western Pacific Ocean," 2005. doi: 10.3390/fishes7040162
48. C. L. Sun, N. J. Su, and S. Z. Yeh, "Estimation of growth parameters and age composition for yellowfin tuna, Thunnus albacares, in the Western Pacific using the length-based MULTIFAN method," *Journal-Fisheries Society of Taiwan*, *30*(2), 171-184.2003.
49. M. Rochet, V. M. Trenkel, A. Carpentier, F. Coppin, and L. G. De Sola, "Archimer Do changes in environmental and fishing pressures impact marine," *J. Appl. Ecol.*, vol. 47, no. 4, pp. 741–750, 2010, doi: doi.org/10.1111/j.1365-2664.2010.01841.x.
50. J. H. Farley, N. P. Clear, B. Leroy, T. L. O. Davis, and G. Mcpherson, "Age , growth and preliminary estimates of maturity of bigeye tuna , Thunnus obesus , in the Australian region," *Mar. Freswater Res.*, vol. 57, pp. 713–724, 2006 doi: 10.1071/MF05255
51. R. Andamari, J. H. Hutapea, and B. I. Prisantoso, "Reproduction aspects of the yellowfin tuna)," *Journal of Tropical Marine Science and Technology.*, vol. 4, no. 1, pp. 89–96, 2012.(in: Indonesia)