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Reproductive Biology of Frigate Tuna (*Auxis thazard* Lacepède, 1800) Caught by Fishermen in West Sumatra Waters

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Abstract: The frigate tuna (*Auxis thazard*) is important to the fishing industry in West Sumatra. The increasing demand for frigate tuna causes this fish to continue to be exploited. Exploitation carried out continuously can reduce frigate tuna production, so research needs to be done. The research was conducted to: (1) Know the growth pattern and factor condition of frigate tuna (*A. thazard*) in West Sumatra waters; (2) Know the reproductive biology of frigate tuna (*A. thazard*). Samples were collected from fishermen's catch in the waters of West Sumatra. Random sampling was conducted, and samples were measured for length and weight, followed by dissection to ascertain sex ratio, gonadal maturity level, gonadal maturity index, and fecundity. The results indicated that the fish's length ranged from 350 to 475 mm, with an average of 401.48 mm, and their weight ranged from 408 to 1,339 grams, with an average of 755.8 grams. The growth pattern is identified as positive allometric ($b>3$), indicating that weight gain surpasses length increases. The condition factor is in stable condition with an average of 1.24. The sex ratio is in an unbalanced condition with a ratio of males and females of 0.9: 1. The level of gonad maturity obtained is GML III and GML IV. The gonad maturity index of male fish ranged from 1.71 to 3.04 and female fish from 1.28 to 2.50. Estimated fecundity ranged from 261,468 to 2,775,590 grains. Based on several factors included in this study, the reproductive biology of frigate tuna in the waters of West Sumatra is favorable.

Keywords: *Auxis thazard*, reproductive biology, growth pattern, gonad maturity level, fecundity, frigate tuna.

Introduction

Indonesia is a country with very high potential marine resources. This high potential of marine resources is used as economic support by the state, including the fisheries sector, which includes pelagic fish. One area that has potential for pelagic fisheries is the waters of West Sumatra. According to Purbani *et al*., (2016), West Sumatra has potential resources for large pelagic fish, including skipjack, mackerel, tuna, and narrow-bared mackerel, based on habitat characteristics or fish habitat.

Fish that inhabit the water's surface to the middle layer are known as pelagic fish. Pelagic fish generally live in groups of both their own and other types of fish, but there is a tendency for pelagic fish to cluster based on their size group (Susilo, 2011). There are two types of pelagic fish resources, namely large pelagic fish and small pelagic fish. One of the differences between the two types of fish is that large pelagic fish are oceanic, while small pelagic fish are neritic (Marine Fisheries Research Center, 2014). In Indonesia, there are four types of tuna (neritic tuna) managed in the TCT Fisheries Management Plan (FMP) consisting of frigate tuna (*Auxis thazard*), bullet tuna (*Auxis rochei*), mackerel tuna (*Euthynnus affinis*) and longtail tuna (*Thunnus tonggol*) (KKP, 2015).

Frigate tuna (*Auxis thazard* Lacepède, 1800) is a sizable oceanic fish species that is perpetually migratory and inhabits schools. This fish has a distribution area in epipelagic, neritic

and oceanic waters (Collete and Nauen, 1983). Frigate tuna is a species that holds significant importance in Indonesia's fishing sector. According to Hartaty and Setyadji (2017), the exploitation of frigate tuna continues to increase every year with a variety of fishing gear (gill nets, purse seines and huhate). Over 90% of frigate tuna fishing is concentrated in four countries: Indonesia (59%), India (14%), Sri Lanka (11%), and Iran (7%) (IOTC, 2014). So, it can be illustrated that frigate tuna is a fish that plays an important role in fisheries in Indonesia, especially in West Sumatra waters. Overfishing without regard for the condition of the fish, including gonadal maturity, can lead to a decline in both the quality and quantity of fish resources (Abubakar *et al*., 2019). This will impact catches and may lead to a decline in fish distribution if fishers neglect the sustainability of fish resources (Heino and Godø, 2002).

Oceanographic conditions strongly influence the existence of fish in a body of water in the area. According to Sastra et al. (2018) oceanographic parameters in the form of sea surface temperature (SST) greatly affect the catch of fish in a body of water. A certain temperature range in a body of water can affect the distribution of fish in those waters (Tangke *et al*., 2015). In addition to sea surface temperature, there are additional oceanographic factors that can decide information on fishing areas, especially chlorophyll-a. According to Adnan (2010), chlorophyll-a can absorb blue and green light because of this ability, the presence of phytoplankton can be detected. Both phytoplankton and zooplankton have an important role in the marine ecosystem because plankton are food for various other types of marine animals. Both oceanographic parameters can be detected using remote sensing methods or satellite imagery.

There has not been much research on the reproductive biology of frigate tuna in West Sumatra waters. Therefore, this research needs to be done to add data and support information about the reproductive biology of frigate tuna in West Sumatra waters. So that this research can be utilized as a benchmark and reference in managing the resources and availability of frigate tuna and pave the path for other researchers to perform sustainable research.

Materials and Methods

Time and place

This study was conducted from February to August 2024. Samples of frigate tuna (*Auxis thazard* Lacepède, 1800) were obtained from the catch of fishermen in West Sumatra waters (Figure 1). The sampling locations of frigate tuna were conducted at the Air Bangis Fish Landing Center (PPI), West Pasaman Regency and Gaung Fish Auction Place (TPI), Padang City. Gonad observation and data analysis were conducted at the Animal Ecology Research Laboratory, Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Andalas.

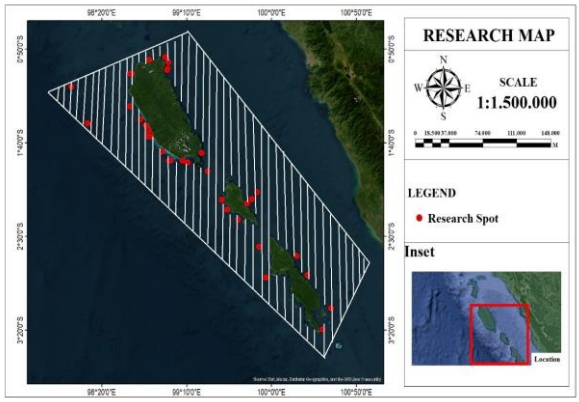

Figure 1. Fishing grounds of frigate tuna (*Auxis thazard*) in West Sumatra waters.

Sampling of Frigate Tuna

Frigate tuna samples were obtained at the Air Bangis Fish Landing Center (PPI), West Pasaman Regency, as many as 50 individuals and at the Gaung Fish Auction Site (TPI), Padang City, as many as 48 individuals were caught by fishermen in West Sumatra Waters. Fish sampling was conducted randomly. After that, the fish samples were put into a styrofoam box and given ice to keep the fish durable and undamaged for further transport to the laboratory.

Measurement of Length and Weight

Frigate tuna samples collected from PPI and TPI were taken to the laboratory for length (cm) and weight (kg) measurements. The length of frigate tuna is determined by measuring both the total length and the standard length of the fish. The total length is measured from the mouth tip (anterior) to the tail fin (posterior). The

standard length of fish is measured with a meter (Figure 3). The frigate tuna's weight was then determined with a digital mini-scale.

Gonad Maturity Level (GML)

The determination of gonadal maturity in frigate tuna is carried out by looking at morphological traits of the gonads, including size, shape, color, weight, and the development of gonadal contents. Determination of the level of gonad maturity refers to Effendie (1997), namely GML I Immature (unripe), GML II Developing (development), GML III Maturing/Ripening (maturation), GML IV Ripe (mature), and GML V Spent (spawn).

Gonad Maturity Index (GMI)

The gonad maturity index is determined by measuring the weight of the gonads in comparison with the body weight of the frigate tuna. Then, the GMI is determined based on the gonad's weight expressed in percent somatic weight.

Fecundity

Determination of fecundity is conducted by calculating the count of eggs in samples that have entered GML IV based on sub-samples using the gravimetric method. The gonad is divided into three subsamples by cutting the front (anterior), middle, and back (posterior) ends of the gonad to facilitate the estimation of fecundity in frigate tuna. Each anterior, middle, and posterior part was taken as much as 0.1 grams.

Statistical Analysis

In this study, data analysis was carried out using the Microsoft Excel ver 2019 application. The application is used to analyze biological data of frigate tuna consisting of growth pattern analysis through length-weight relationship, condition factor, sex ratio, gonad maturity level (GML), gonad maturity index (GMI), and fecundity. In this research, the determination of the interval class is based on the total length of the observed fish from the lowest length to the highest length.

Results and Discussion

Length-Weight Relationship

Measurements of total length (TL) from 98 individual frigate tuna (*A. thazard*) indicate a length range of 350 to 475 mm, with a mean length of 401.48 mm. The results of frigate tuna weight measurements were obtained in the 408 - 1,339 grams range, with an average weight of 755.80 grams. Length-weight measurements were also taken separately between males and females. The male frigate tuna group obtained a length range of 350 - 475 mm, while the female frigate tuna obtained a length range of 350 - 450 mm. In measuring the weight of male frigate tuna, the weight obtained ranged from 408 - 1,339 grams, while in female frigate tuna, the weight range obtained was 460 - 1,083 grams. The length and weight distribution of male and female frigate tuna are presented in Table 1.

When referring to Figure 2, both male and female frigate tuna are distributed into each size class. However, there is an exception in the 46.4 – 48.2 cm size class, which only contains male frigate tuna. Male frigate tuna were distributed in every size class from the lowest to the highest body length. In the 35 – 36.8 cm size class, the number of female frigate tuna exceeds that of male frigate tuna. The number of male frigate tuna is more in the size class 36.9 – 38.7 cm.

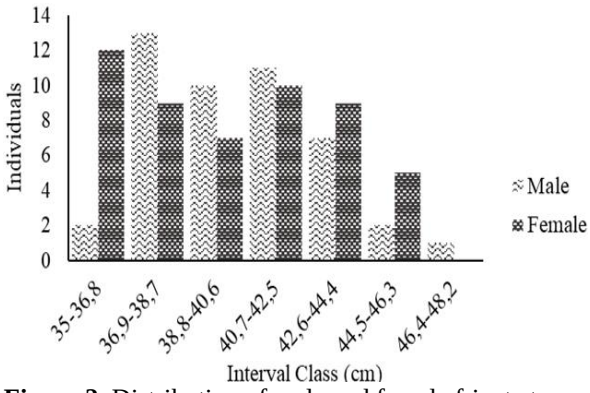

Figure 2. Distribution of male and female frigate tuna (*Auxis thazard*) caught by fishermen in West Sumatra waters based on total length size.

The regression analysis results on the length-weight relationship of frigate tuna (*A. thazard*) obtained the equation $W = 1x10^{-6}L^{3,3699}$ with a determination coefficient (R^2) of 0.8837 and a correlation coefficient (r) of 0.940053 (Figure 3). Total length (TL) measurements on 46 individual male frigate tuna obtained a length

range of 350 – 475 mm with an average length of 404.02 mm. The results of measuring the weight of male frigate tuna were obtained in the range of 408-1,339 grams, with an average weight of 776.98 grams. In the measurement of total length (TL) carried out on 52 individual female frigate tuna, the length range is 350-450 mm with an average length of 399.23 mm. At the same time, the measurement of the weight of female frigate tuna obtained a range of 460 – 1,083 grams with an average weight of 737.06 grams. Graphs of the length-weight relationship of male and female frigate tuna are illustrated in Figure 4 and Figure 5.

Table 1. Length and weight distribution of frigate tuna (*Auxis thazard*) caught by fishermen in West Sumatra waters

Sex	n	Length			Weight		
		Minimum (mm)	Maximum (mm)	SD	Minimum (gram)	Maximum (gram)	SD
Male	46	350 mm	475 mm	28.68	408 g	1.339 g	209.77
Female	52	350 mm	450 mm	32.22	460 g	1.083 g	192.22

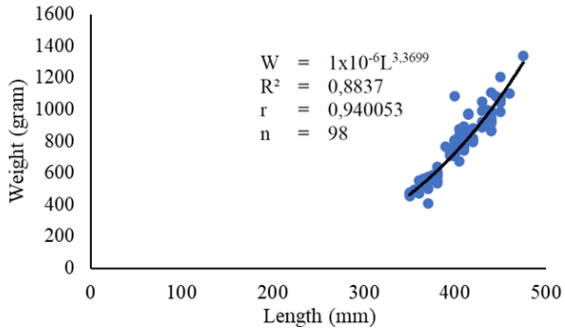

Figure 3. Length-weight relationship graph of frigate tuna (*Auxis thazard*) caught by fishermen in West Sumatra waters.

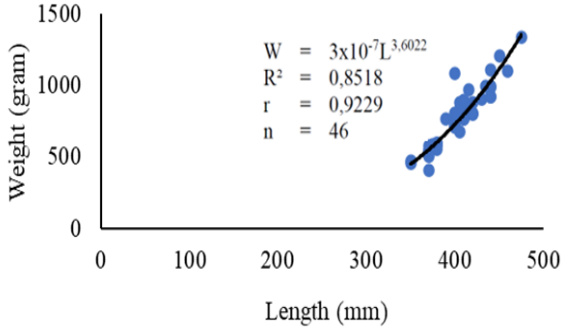

Figure 4. Length-weight relationship graph of male frigate tuna (*Auxis thazard*) caught by fishermen in West Sumatra waters

In male krai frigate tuna, the length-weight relationship equation obtained is $W = 3x10^{-7}L^{3,6022}$, with a determination coefficient (R^2) of 0.8518 or 85.18% and a correlation coefficient (r) of 0.9229. In female frigate tuna, the length-weight relationship equation obtained is $W = 3x10^{-6}L^{3,2058}$, with a determination coefficient (R^2) of 0.923 or 92.3% and a correlation coefficient (r) of 0.9607. Male frigate tuna had a value of b = 3.6022, and female frigate tuna had a value of b = 3.2058. This study indicates that male and female frigate tuna have a b value over 3 ($b > 3$), signifying a positive allometric growth pattern for both sexes.

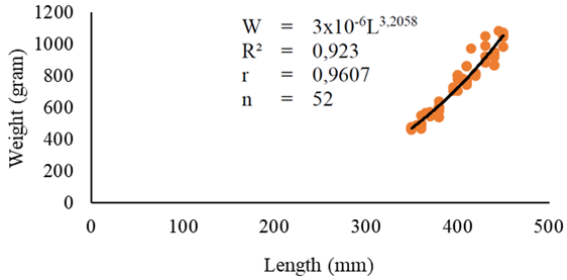

Figure 5. Length-weight relationship graph of female frigate tuna (*Auxis thazard*) caught by fishermen in West Sumatra waters

Table 1. The growth pattern of frigate tuna (*Auxis thazard*) caught by fishermen in West Sumatra water

Criteria	a	b	R^2	r	t value	Growth Pattern
Total	0.000001	3.3699	0.8837	0.940053	29.69	Allometric positive
Male	0.0000003	3.6022	0.8518	0.9229	16.75	Allometric positive
Female	0.000003	3.2058	0.923	0.9607	28.21	Allometric positive

Description: a (constant), b (constant), R^2 (determination coefficient), r (correlation coefficient)

Condition Factor

Based on the analysis results (Table 3), the condition factor value obtained from the total of all frigate tuna ranges from 0.90-1.85 with an average of 1.24, meaning that the frigate tuna has a proportional or relatively fat body condition. The condition factor value in male frigate tuna ranges from 0.76-1.53 with an average of 1.03, which means it has an ideal body, and female frigate tuna ranges from 0.96-1.31 with an average of 1.10, which means it has a fat body.

Table 2. Condition factor value of frigate tuna (*Auxis thazard*) caught by fishermen in West Sumatra waters

Individuals	Minimum to Maximum Condition Factor Value	Mean of Condition Factor Value
98 (Total)	0.90 – 1.85	1.24
46 (Male)	0.76 – 1.53	1.03
52 (Female)	0.96 – 1.31	1.10

Sex Ratio

Based on observations on the sex ratio of frigate tuna caught by fishermen in West Sumatra Waters during the study, the number of male fish is inferior to that of female fish, namely 46 individuals or 46.94%. In comparison, female frigate tuna are 52 individuals, or 53.06% of the total frigate tuna sample. The ratio of sex of male and female frigate tuna obtained was 0.9: 1, meaning that the sex ratio in this study was unbalanced based on the chi-square analysis.

Gonad Maturity Level

The data in Table 4 indicates that the maturity levels of male and female frigate tuna gonads are only obtained at level III and level IV. In male frigate tuna, the maturity level is dominated by level IV, which amounts to 27 individuals, while the maturity level III amounts to 19 individuals. The same thing is also obtained in female tuna frigates whose gonad maturity level is dominated by level IV, which amounts to 43 individuals, while level III amounts to 9 individuals.

Based on the graph above (Figure 6 and Figure 7), it can be seen that each measuring class is dominated by gonad maturity level IV. The exception is for the 35 – 36.8 cm size class in male frigate tuna, which only gets gonad maturity level III. There are no female frigate tuna in the 46.4 - 48.2 size class. Given that gonadal maturity level IV is more prevalent than level III, it may be inferred that in July, frigate tuna in the West Sumatra Waters are in a mature gonadal phase, indicating readiness for spawning.

Table 3. Gonad maturity level (GML) of cash frigate (*Auxis thazard*) caught by fishermen in West Sumatra waters based on sex

Sex	GML	
	III	IV
Male (♂)	19	Male (♂)
Female (♀)	9	Female (♀)

Description: GML (gonad maturity level)

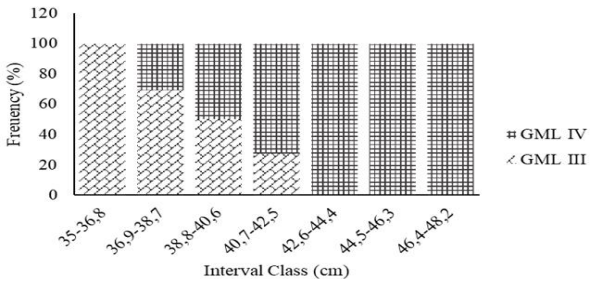

Figure 6. The gonad maturity level of male frigate tuna (*Auxis thazard*) caught by fishermen in West Sumatra waters

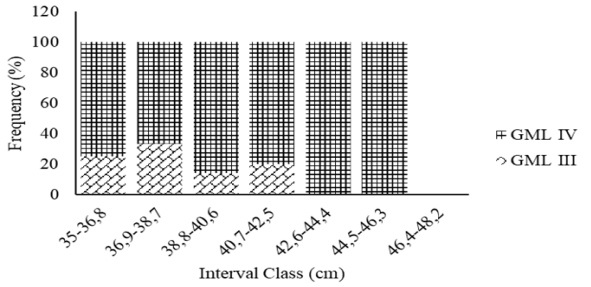

Figure 7. The gonad maturity level of female frigate tuna (*Auxis thazard*) caught by fishermen in West Sumatra waters

Gonad Maturity Index

Based on the analysis results, the average gonad maturity index value of male frigate tuna during the study ranged from 1.7167 – 3.0482, while the female gonad maturity index value ranged from 1.2867 – 2.5055. The range of gonadal maturity index values can illustrate that the fish gonads have reached the gonadal maturity phase. Nonetheless, the gonad maturity index in this study is not very high compared to the GMI value of frigate tuna in several other waters. Several factors could influence this.

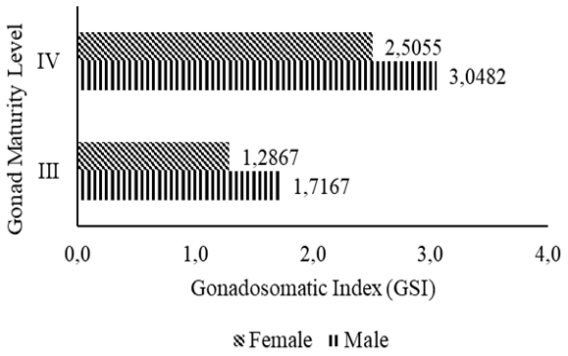

Figure 8. Gonad maturity index of frigate tuna (*Auxis thazard*) caught by fishermen in West Sumatra waters

Fecundity

Based on the results obtained, the fecundity value of frigate tuna caught by fishermen in the waters of West Sumatra ranges from 261,468 to 775,590 eggs (Figure 9). The highest fecundity was found in fish with a length class 42,6 – 44,4 cm with a body weight of 916 - 921 grams and the lowest fecundity was found in fish with a length class 36.9 – 38.7 cm with a body weight of 600 - 641 grams. The fecundity value in this study is high. Due to the huge number of eggs generated by the fish.

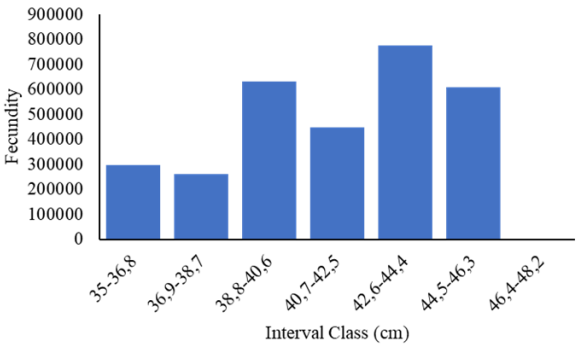

Figure 9. Fecundity of frigate tuna (*Auxis thazard*) caught by fishermen in West Sumatra waters

Sea Surface Temperature (SST)

The results indicate that the sea surface temperature (SST) in the West Sumatra Waters in 2023 ranges from 25.9°C to 30.7°C (Figure 10). The maximum sea surface temperature occurs in April as well as June at 30.7°C, and the minimum sea surface temperature is recorded in October at 25.9°C.

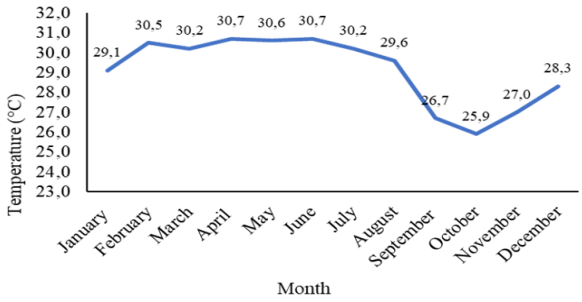

Figure 10. Distribution of sea surface temperature (SST) during 2023 in West Sumatra waters

Chlorophyll-a

Based on the results obtained from satellite imagery (Figure 11), the concentration of chlorophyll-a in 2023 in the waters of West Sumatra ranges from 0.121 to 0.674 mg/m3, with the highest concentration occurring in December, 0.674 mg/m3, and the lowest concentration occurring in March, 0.121 mg/m^3.

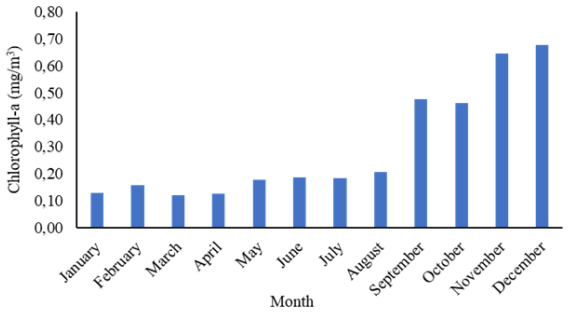

Figure 11. Distribution of chlorophyll-a during 2023 in West Sumatra waters

Discussion

Length-Weight Relationship

In this study, male and female frigate tuna have a b value over 3 ($b > 3$), showing the growth pattern for both sexes is positive allometric. This suggests that the frigate tuna population caught by fishermen in West Sumatra waters has a relatively fat body size. In a similar study that also obtained a positive allometric growth pattern ($b > 3$) was conducted by Tampubolon *et al.* (2016) along the West Coast of Sumatra on frigate tuna with a value of b = 3.1489. In addition, positive allometric growth patterns in frigate tuna were also found in the research of Arnenda *et al.* (2022), with a value of b = 3.234 in Sibolga waters, North Sumatra. Ajik and Tahiluddin (2021) research on frigate tuna in Tawi-Tawi waters, the Philippines, also has a

positive allometric growth pattern with a value of b = 3.139. However, this is inversely proportional to the research of Sanjaya *et al.* (2019), who found a negative allometric growth pattern in frigate tuna landed at PPI Kusamba, Bali, with a value of b = 2.6744.

The allometric growth pattern obtained in tuna can be classified as an effort or adaptation effort made by fish to adjust to the environment, including physical characteristics, water chemistry, food, and other factors (Wahana *et al*., 2021). Variations in b values can be correlated with ecosystems and biological influences, including temperature, salinity, and food availability; thus, species generalizations can only be established after taking into consideration all variables (Froese, 2006).

Condition Factor

Based on the data obtained (Table 4), this study shows that frigate tuna (*A. thazard*) caught by fishermen in West Sumatra waters has a proportional body condition (tends to be fat), as evidenced by a condition factor value higher than 1. If the condition factor value is more than 1, it indicates that frigate tuna in West Sumatra waters have a fairly heavy body weight. A high condition factor value shows compatibility among fish and their environment, aligning with Muchlisin's (2010) assertion that a condition factor value 1 represents a balanced aquatic ecosystem.

Observation of the condition factor value was also carried out by Nur et al. (2023) on bullet tuna (*Auxis rochei*) in Mamuju Regency waters, Southeast Sulawesi, showing average condition factor (K) values of 0.9957 for males and 0.7997 for females. In a study of this kind by Asrial *et al*. (2021) in Tanjung Luar Waters, West Nusa Tenggara, the condition factor of bullet tuna (*A. rochei*) ranged from 0.77 to 1.21, with an average condition factor of 1.00. Referring to the average condition factor, the body shape of bullet tuna (*A. rochei*) caught in Tanjung Luar Harbor is assumed to be optimal. The condition factor assesses the fish's condition, fatness, or quality of life (Ahmed *et al*., 2011). This suggests that fish are in a fat condition or a relatively mature gonadal maturity period.

Sex Ratio

The sex ratio of 0.9:1 represents the proportion of male fish less than female fish in these waters. Deviations from ideal conditions are caused by factors of fish behavior, and differences in mortality rates and growth (Bal and Rao, 1984). Differences in growth rates across both sexes might result in a disproportionate population. The sex that has a faster growth rate will grow large to reduce predation, otherwise, the sex that is slow to develop will become food for predators (Vicentini and Araujo, 2003). Several factors, including food availability and spawning season, influence differences in sex ratio. This can be seen from the location of frigate tuna fishing, which tends to be around the coastal area (Figure 3). Coastal areas are generally used as a place to find food and spawn fish. In the presence of abundant food, female fish will exhibit dominance. According to (Calicdan-Villarao *et al*., 2017), female fish may be easier to catch when compared to males because of their propensity to feed or spawn, resulting in increased time spent near the surface, which is accessible to shallow fishing gear.

Gonad Maturity Level

This study shows the existence of just GML III and GML IV, with GML IV being predominant. Arrafi et al. (2016) said that the discovery of GML III and GML IV can indicate that these fish are in the spawning phase. Tuna spawning occurs twice yearly, in January-May and July-December (Griffiths *et al.*, 2019). According to the study of Purwaningsih *et al.* (2022) in Kedonganan Waters, Bali, observations of gonad maturity levels conducted from January to March were dominated by Level II and Level III. Bahou *et al.* (2016) reported that in the waters of Cote d'Ivoire, Africa, there were monthly variations in the level of maturity of female frigate tuna gonads, namely Level III (immature), Level IV (mature) and Level V (resting), where Level IV (mature) was found from June to November.Most tuna are recognized to necessitate warm seas (>20°C) for spawning (Schaefer, 2001). According to Bahou *et al*. (2016), in Cote d'Ivoire, spawning transpires from July to October, at temperatures ranging from 22.14°C to 25.15°C; however, gravid females are noted at temperatures between

27°C and 28°C. A study conducted by Matsuura and Sato (1981) reported the spread of larvae in *Auxis* sp. along the Southeastern Brazilian coast, based on lots of samples obtained. The sea surface temperature (SST) exhibited a broad range of 16 to 28°C, predominantly between 22°C and 26°C. When associated with the distribution of sea surface temperatures obtained (Figure 15), these temperatures are suitable and tolerant for the reproduction of frigate tuna.

Gonad Maturity Index

The gonad maturity index's highest and lowest values are affected by gonad weight and body weight. As the spawning phase approaches, both the gonad and body weight of the fish will increase. According to the study by Kasmi *et al*. (2017), an elevated gonad maturity index value correlates with an increased body-weight ratio to gonad weight. The gonadal maturity index (GMI) is affected by the levels of gonadal maturity (GML). The results of this study indicate that the gonadal maturity index at level III is generally lower than that at level IV. The gonadal maturity index is correlated with the level of gonadal maturity. The gonad maturity index is influenced by body weight and gonad weight. The value of the gonad maturity index will increase if the fish is experiencing the spawning phase, which is indicated by the increasing level of maturity of the fish gonads. Tarigan *et al*. (2017) assert that an increase in GML value correlates with a higher GMI value, suggesting that gonad weight increases during spawning and immediately decreases fast until the spawning process finishes.

In the study carried out by Purwaningsih *et al*. (2022) in Kedonganan Waters, Bali, the average gonad maturity index for male and female frigate tuna was 6.24 and 6.26 in January, 8.21 and 8.28 in February, and 8.31 and 8.91 in March. According to Bahou et al. (2016), in the waters of Cote d'Ivoire, the GMI value of female frigate tuna peaked in August at 3.21, then declined until December. Variations in GMI enable the identification of four primary phases in the reproductive process of frigate tuna. These phases are resting, maturation, spawning, and post-spawning phases. From the data obtained, it can be concluded that the frigate tuna gonads are in the spawning phase of this study.

Fecundity

The number of eggs produced by the fish is very high. Based on the results obtained, the reproductive potential of frigate tuna in the waters of West Sumatra is favorable. Research by Tampubolon *et al*. (2016) in the West Coast Waters of Sumatra, frigate tuna fecundity ranged from 27,534 to 720,800 eggs. Purwaningsih *et al*. (2022) also researched the same species in Kedonganan waters, Bali, with fecundity ranging from 75,107 - 750,470 eggs with an average fecundity of 201,463 eggs. Frigate tuna are characterized by high fecundity due to their substantial egg production. According to Sarumaha *et al*. (2016), good reproductive potential can produce abundant individuals. The fecundity of fish is intricately linked to their habitat; environmental alterations will affect the fecundity of certain fish species (Sulistiono, 2012).

Sea Surface Temperature

Sea surface temperature has an impact on fish catches. In this study, frigate tuna caught by fishermen were dominated by gonad maturity level IV for both male and female fish, but there were also gonad maturity level III, but not many. Sea surface temperature will affect primary productivity in the waters. Furthermore, primary productivity will affect the availability of food that is utilized by fish for the gonad maturation process. The detection of sea surface temperature has been carried out in several waters. Bahou *et al*. (2016) said that gonadally mature frigate tuna were present in the Côte d'Ivoire waters, Africa, from June to November, within a temperature range of 27.56°C to 28.53°C. Nofrita *et al*. (2024) reported that the sea surface temperature distribution in skipjack (Katsuwonus pelamis) fishing grounds in West Sumatra Waters ranged from 27.9°C to 33.5°C.

Based on Figure 10, The distribution of sea surface temperature varies monthly due to the effect of numerous environmental factors, including seasonal changes. Temperature fluctuations, namely high and low temperatures, are essential factors that affect fish group movement (Jufri *et al*., 2014). Differences in sea surface temperature not only affect fish catches but also fish reproduction, one of which is the level of gonad maturity. Variations in gonadal developmental stages indicate that most

immature fish are associated with coastal waters with sea surface temperatures (SST) > 17°C (Vieira *et al.,* 2022). Frigate tuna larvae exhibit tolerance to a broad spectrum of temperatures, thriving in waters ranging from 21.6°C to 30.5°C (Valeiras and Abad, 2010). It can be assumed that frigate tuna favor warm waters for spawning.

Chlorophyll-a

The results of this study's satellite imagery (Figure 11) show a significant concentration of chlorophyll-a in the waters of West Sumatra. Fauziah *et a*l. (2020) argue that chlorophyll-a concentrations in surface water are classified into three categories: low (< 0.07 mg/m^3), medium (0.07 – 0.14 mg/m^3), and high (> 0.14 mg/m^3). In Adnan's (2010) research conducted in East Kalimantan waters in 2006, the peak chlorophyll-a concentration was in February, averaging 0.420 mg/m^3, while the lowest was in November, averaging 0.118 mg/m^3. In 2007, the highest chlorophyll-a concentration also occurred in February, averaging 0.376 mg/m^3, and the lowest was in May, averaging 0.153 mg/m^3. Fauziah *et al*. (2020) reported that the highest chlorophyll-a concentration in Natuna Waters occurred in January 2019, with an average value of 0.28 mg/m^3 at the fishing ground site. According to Effendi *et al*. (2012), chlorophyll-a concentration in a body of water is highly dependent on nutrient availability and sunlight intensity. If a body of water has sufficient light intensity and nutrient availability, the concentration of chlorophyll-a can increase. Thus, these waters have sufficient primary productivity to meet the food needs of marine biota, including pelagic fish.

Conclusions

The growth pattern of frigate tuna (*Auxis thazard*) caught by fishermen in West Sumatra Waters exhibits positive allometry (*b > 3*) for both males and females, indicating that weight increases at a rate beyond that of length. This growth pattern is supported by the frigate tuna (*Auxis thazard*) condition factor remaining consistent, with an average value obtained > 1, namely 1.24, meaning that the frigate tuna caught by fishermen in West Sumatra waters has a fat body condition. The sex ratio, 0.9:1, signifies that the number of male frigate tuna is lower than that of female frigate tuna. The gonad maturity level (GML) is predominantly GML IV in both male and female frigate tuna. The value of the gonad maturity index (GMI) increases as the gonad maturity level increases. Fecundity ranges from 261,468 to 775,590 grains, which indicates that the value of frigate tuna fecundity in West Sumatra Waters is high. Several reproductive biology parameters used in this study suggest that frigate tuna reproductive biology in West Sumatra Waters is in good condition, allowing the presence of these fish to be maintained.

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