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Reproductive biology of skipjack tuna *Katsuwonus pelamis* in Majene Waters, West Sulawesi Province, Indonesia

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Abstract. *Nur M, Tenriware, Utami S, Nasyrah AFA, Sapri R. 2024. Reproductive biology of skipjack tuna* Katsuwonus pelamis *in Majene Waters, West Sulawesi Province, Indonesia. Biodiversitas 25: 2828-2835.* Skipjack tuna *Katsuwonus pelamis* (Linnaeus, 1758) is a major global fishery resource and a target species in West Sulawesi Province. Therefore, this research aimed to examine various biological factors related to skipjack tuna, including sex ratio, Gonad Maturity Stage (GMS), Gonadosomatic Index (GSI), size at first maturity, and fecundity. The primary objective was to provide essential data that supported the sustainable management of skipjack tuna in Majene Waters located in West Sulawesi, Indonesia. Fish samples were collected by fishermen using purse seine fishing gear and hand lines, and landed at Fish Landing Sites Majene. This research was carried out from July to February 2024, with analysis performed at the Fisheries Department Laboratory, Universitas Sulawesi Barat. The analysis stages included measuring fish total body length with an accuracy of 0.1 mm and weighing the body weight using a digital scale with an accuracy of 0.01 g. A total of 340 skipjack tuna were sampled, consisting of 192 males and 148 females, indicating a nearly balanced sex ratio. The spawning season appeared to extend throughout the year, with a peak spawning period from November to February. This analysis result found five levels of gonad maturity, including GMS I (immature), GMS II (maturing), GMS III (mature), and GMS IV (ripe and running), as well as GMS V (spent). The size at first maturity for males skipjack tuna was 400.2 mm, ranging from 386.6-402.3 mm. Meanwhile, the size at first maturity for females varied between 396.6 and 462.3 mm, averaging 420.2 mm. The reproductive potential of skipjack tuna was relatively high, with an average fecundity ranging from 203,377-739,820 eggs.

Keywords: Makassar Strait, reproduction, Scombridae, skipjack tuna, West Sulawesi

Abbreviations: GMS: Gonad Maturity Stage, GSI: Gonadosomatic Index

INTRODUCTION

Sulawesi Island holds significant potential in the fisheries sector, which is recommended to be a primary focus for local government development efforts as a means to enhance regional revenue generation (Miar et al. 2020). Several key fisheries commodities in Sulawesi, particularly within the capture fisheries sector, include amphidromous fishes (Hasan and Islam 2020; Hasan et al. 2021; Gani et al. 2021, 2022; Nurjirana and Keith 2022, Nurjirana et al. 2023), demersal species such as groupers (Kadir et al. 2022), reef fish (Achmad et al. 2022), small pelagic fish such as mackerel scad (*Decapterus macarellus* (Cuvier, 1833)) (Tenriware et al. 2023), bullet tuna (*Auxis rochei* (Risso, 1810)) (Kantun et al. 2019; Nur et al. 2023), flying fish (Nur et al. 2022), as well as large pelagic fish such as yellowfin tuna (*Thunnus albacares* (Bonnaterre, 1788)) (Hoshino et al. 2020) and skipjack tuna (*Katsuwonus pelamis* (Linnaeus, 1758)) (Zainuddin et al. 2017). Skipjack tuna *K. pelamis* is classified as a pelagic fish belonging to the Scombridae family and is well-known for its habit of traveling long distances (da Cunha-Neto et al. 2022). This fish can be found across tropical and subtropical waters, living both near coastlines and open waters. Most skipjack tuna is caught in these tropical and subtropical regions of the Pacific, Atlantic, and Indian Oceans (Jin et al. 2015).

Skipjack tuna is an important fishery resource with significant commercial value in the international market, making it a widely targeted species (Soares et al. 2019; Hashemi et al. 2021; Vayghan and Lee 2022). It is ranked as the third most commonly caught fish, contributing around 3.2 million tons to global fishery production (FAO 2020). Approximately 70% of the estimated catch is sourced from the Pacific Ocean (Williams and Terawasi 2016) using purse seine vessels and Fish Aggregating Devices (FADs) (Govinden et al. 2021). However, this high fishing pressure over the past three decades has raised concerns about the sustainability of skipjack tuna populations (Matsumoto et al. 2016; Phillips et al. 2018).

Majene waters are situated in the Makassar Strait and belong to the Fisheries Management Regions of Indonesia (WPP-NRI) 713, which includes other bays, particularly Flores, Bali, and Bone. Similar to other regions, skipjack

tuna is a target species hunted by fishermen. Fishing activities in the Makassar Strait Waters, specifically in Majene, are conducted throughout the year using different tools such as hand lines, purse seines, as well as drift gill nets (Mallawa et al. 2016).

Skipjack tuna along with other fish of the Scombridae family such as bullet tuna in Majene District of West Sulawesi Province is highly regarded due to its socio-economic value. Freshly caught fish is sold in local markets and transported to other districts, including of Makassar City (Nur et al. 2023). This fish serves as the primary source of income for fishermen and a crucial protein supply for the community (Genti and Marsoedi 2016). The fish is marketed in fresh, frozen, and processed forms, making it a significant export commodity to various countries (Prieto-Carolino 2021; Kawamoto 2022). Additionally, several Micro, Small, and Medium Enterprises (MSMEs) in West Sulawesi use skipjack tuna primarily to produce products, such as smoked fish and fish floss. Due to its high economic value, the fish faces a high pressure that leads to frequent and extensive fishing activities.

The number of skipjack tuna caught by fishermen in West Sulawesi continues to decline due to smaller fish sizes or fishing locations situated at farther distances. According to production data from 2014-2021, there was a drastic decline in Catch Per Unit Effort (CPUE), nearly 50%. The highest catch was 8,174.5 tons/per year in 2014, dropping to only 3,914.2 tons/per year in 2021 (West Sulawesi Province Maritime and Fisheries Office 2023). This information implies that overfishing (over-exploitation) occurs within waters surrounding West Sulawesi where such species thrive, thereby negatively impacting their conservation efforts.

Sustainable management efforts are needed to guarantee the longevity of skipjack tuna population. These efforts require data and information on the reproductive biology, specifically concerning spawning season policies which can be informed by comprehending traits such as spawn timing (Artetxe-Arrate et al. 2021). The appropriate size for catching fish is determined by size at first maturity (Tenriware et al. 2023). The reproductive biology plays an important role in assessing fish ability to regenerate while also providing insight into how a species survives and responds to stress or exploitation conditions (Artetxe-Arrate et al. 2021).

A lack of analysis exists examining the reproductive biology of skipjack tuna in West Sulawesi Province. Therefore, this research is novelty and can serve as a reference for skipjack tuna management in the province. The intense fishing activity targeting this species has made it highly vulnerable to degradation. Additionally, monitoring efforts to date have been very limited. Therefore, this reproductive biology research provides essential baseline data needed by the government for decision-making and management policies. However, the reproductive biology has been carried out in other Indonesian waters, such as the South Indian Ocean in Bali (Hartaty and Arnenda 2019) and the Banda Sea, Maluku (Hermawan et al. 2023).

This research aims to determine the biological factors of skipjack tuna, including sex ratio, Gonad Maturity Stage (GMS), Gonad Somatic Index (GSI), size of the first mature gonad, and fecundity. Analyzing the reproductive biology of the fish can present crucial insights into the balance between males and females populations, spawning season, size at which gonad first reach maturity, reproduction rates, and stock size. This investigation is beneficial by providing basic data for the sustainable management of skipjack tuna in Majene Waters situated within West Sulawesi.

MATERIALS AND METHODS

Procedure

From July 2023 to February 2024, skipjack tuna fish samples were taken from Fish Landing Sites Majene, situated in the West Sulawesi Province, Indonesia (Figure 1). These samples were caught by fishermen using purse seine fishing gear and hand lines before they arrived at Fish Landing Sites for further examination.

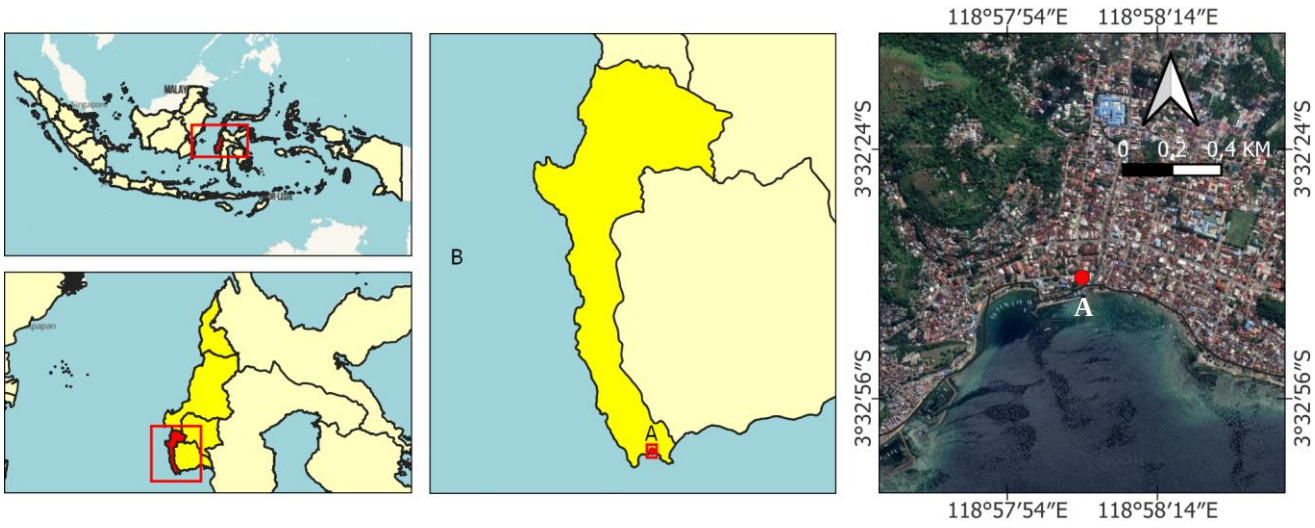


Figure 1. Sampling location of Majene Waters, Majene District, West Sulawesi, Indonesia. A. Fishing landing site; B. Fishing ground

The primary data used in this research consisted of measurements for total length, weight, sex, level of gonad maturity, gonad somatic index, and fecundity. Sampling occurred once monthly over a duration of eight months, where different-sized fish were randomly chosen through the use of a simple random sampling method. All collected fish samples were stored in a cold box containing ice before being moved to the Fisheries Department's Integrated Laboratory at the Universitas Sulawesi Barat.

The total length was measured using a ruler with an accuracy of 0.05 mm, and the total weight was weighed using a scale with an accuracy of 0.05 g. Furthermore, the total length was measured from the mouth to the tip of the fish's tail. Skipjack tuna was first measured for their length and weight, followed by dissection to ascertain sex and gonad maturity stage. The sex of the fish could be determined based on the characteristics of gonad, which differed between males and females. Furthermore, the classification of Gonad Maturity Stages (GMS) was based on the criteria established by Yanglera et al. (2016). Females with matured gonad, specifically those in GMS III, IV and V stages were subjected to preservation using 10% buffered formalin before being stored inside sample bottles for fecundity analysis purposes.

Fecundity analysis was carried out by dividing gonad into three sections, including the anterior, middle, and posterior. The weight and volume of the three sub-gonad sections were then measured. A subsample from every section of gonad was subjected to dilution with 10 mL of water within a petri dish. The number of eggs diluted was counted manually using a magnifying glass or hand counter and this gravimetric method facilitated the determination of fecundity value.

Data analysis

The sex ratio was determined by comparing the frequency of males and females. The following formula was used to determine the balance of the sex ratio.

$$Sex\ ratio = \frac{\sum M}{\sum F}$$

Where: ∑M: number of males; ∑F: number of females

Subsequently, the comparison results were continued with the chi-square test (Zar 2010). Gonad maturity stage was analyzed by grouping data regarding skipjack tuna into immature and matured gonad. Gonad somatic index was calculated using the formula provided by (Johnson 1971).

$$GSI = \frac{Wg}{W} \times 100$$

Where: Wg: gonad weight (grams); W: total body weight (grams)

The Spearman-Karber method was adopted to estimate the average size of gonad at first maturity (Udupe 1986).

The gonadal maturity stages were analyzed by presenting each stage of gonadal maturity observed for each month (Dahlan et al. 2018).The fish size of the first gonad matured was calculated by Spearmen-Karber method (Udupe 1986), with the formula:

$$M = (Xk + X/2) - (X, \Sigma pi)$$

Where the length range was estimated using the equation:

$$\text{antilog } [m \pm 1{,}96 \sqrt{(\text{var } (m))}]$$
$$\text{var } (m) = (X)2 \text{ x } \Sigma [(pixqi) / (ni-1)]$$

Where: M: size at first maturity (antilog of m), m: logarithm of fish length at first maturity, Xk: logarithm of length class median at 100% matured fish, X: increment of logarithm of length class median, pi: number of matured fish and each length class ratio (ri/ni), ri: number of matured fish at class I, ni: number of fish samples at class i, qi: 1-pi

Fecundity is calculated from the proportion of ripe eggs. If the specimens had overall ripe eggs in the gonad, fecundity is the overall number of eggs. Total fecundity was calculated using the gravimetric method (Chodrijah et al. 2020).

$$F = \frac{G \text{ x } f}{g}$$

Where: F: fecundity, G: total weight of gonad (gram), f: number of eggs from subsamples, and g: partial weight of gonad/subsamples (gram)

RESULTS AND DISCUSSION

Sex ratio

The sex ratio referred to the proportion of males to females in a given population. A total of 340 skipjack tuna fish samples were obtained, consisting of 192 males and 148 females, as presented in Table 1.

Based on the Chi-square test of males and females at the 95% confidence interval, the $\chi 2$- count was 4,842, smaller than the $\chi 2$-table (0.05;8) of 14.0671. Therefore, both genders were categorized as having a near 1:1 ratio, showing a balanced state.

Table 1. Sex ratio of skipjack tuna *Katsuwonus pelamis*

Month	Total (n)	Sex		Sex ratio
		Male	Female	
Jul-23	94	56	38	1.00:0.68
Aug	68	34	34	1.00:1.00
Sep	43	28	15	1.00:0.54
Oct	43	22	21	1.00:0.95
Nov	33	21	12	1.00:0.57
Dec	20	10	10	1.00:1.00
Jan-24	15	9	6	1.00:0.67
Feb	24	12	12	1.00:1.00
	340	192	148	1.00:0.77

Gonad maturity stage

In fish species, the development of gonad often followed a cyclical or seasonal pattern. The renewal of germinal cells, differentiation, development, and release of sperm/oocytes throughout each reproductive cycle caused changes in the gonad that characterize the reproductive phase of the species, suggesting whether they were about to spawn or have already spawned. This analysis result found five levels of gonad maturity (Figure 2 and Table 2), including GMS I (immature), GMS II (maturing), GMS III (mature), and GMS IV (ripe and running), as well as GMS V (spent). Gonad maturity stage showed the sexual maturity of skipjack tuna, with most of the metabolic products being used during gonad development phase. Figure 3 presented the frequency of gonad maturity stage.

Based on Figure 3, males and females skipjack tuna caught between July and October predominantly had GMS I and GMS II gonad maturity phases. This suggested that most of the sampled fish were in their initial stages of development without fully matured reproductive organs. From November to December, skipjack tuna with mature gonad began to appear, but there were still some in the GMS I phase. By January and February 2024, fish with mature gonad (GMS III and IV) were more prevalent.

Gonadosomatic index

The gonadosomatic index value of skipjack tuna for each month of observation can be used as information to predict the spawning season, as shown in Figure 4. Understanding the spawning season was important for evaluating stock potential and sustainable fisheries management.

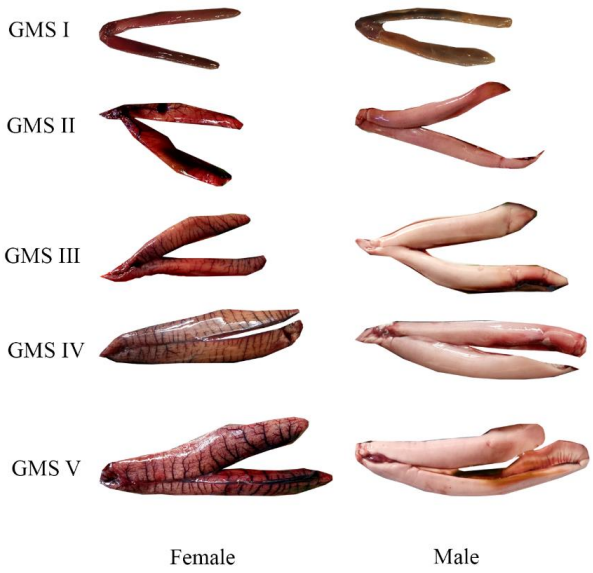
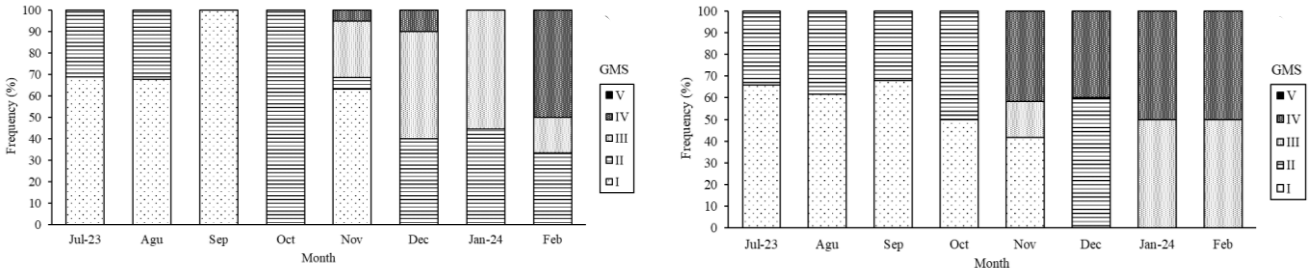


Figure 2. Gonad maturity stage of skipjack tuna *Katsuwonus pelamis*



A **B**

Figure 3. Frequency of gonad maturity stage of skipjack tuna *Katsuwonus pelamis*. A. Males; B. Females

Table 2. Classification of gonad maturity stages of skipjack tuna *Katsuwonus pelamis*

GMS	Male	Female
I Immature	Testes are thin, elongated, and reddish-white	The gonad is thin and elongated like a thread. Egg granules in the gonad are not yet visible
II Maturing	The testes appear reddish-white, with a more defined shape than in stage I. The gonad is visible covering a small part of the abdominal cavity	The gonad is dark red, with a smooth surface. The size of the gonad has increased and is larger than in stage I, covering half of the abdominal cavity. Egg granules are not yet visible
III Mature	The surface of the gonad appears serrated, with a whiter color. The size of the testes seems to cover one-third of the abdominal cavity	Most of the gonad is dark red, with the remainder appearing light pink. The gonad covers half of the abdominal cavity. The entire gonad is dark red. The intestines are compressed. The Egg granules are becoming more clear
IV Fully mature	The testes are more defined, with an increasingly serrated surface. The testes appear to cover most of the abdominal cavity and look solid	The gonad covers almost the entire abdominal cavity. The gonad is dark red. The intestines are compressed. The Egg granules are becoming more clear
V Resting	Some of the testes are shriveled, appearing milky white. The size of the testes is decreasing	The gonad is shriveled, with remnants of eggs from stage IV mixed with fine, dark red egg particles. Residual Egg granules are also found in the reproductive organ

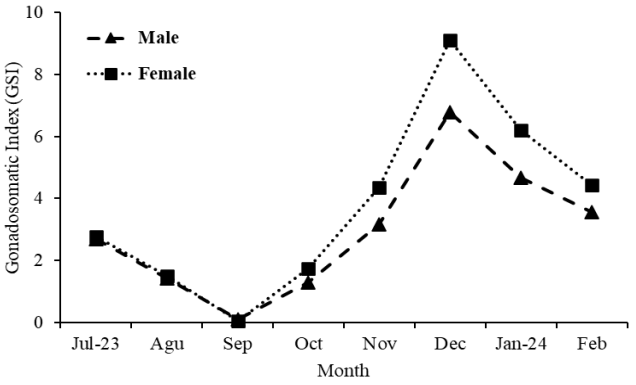
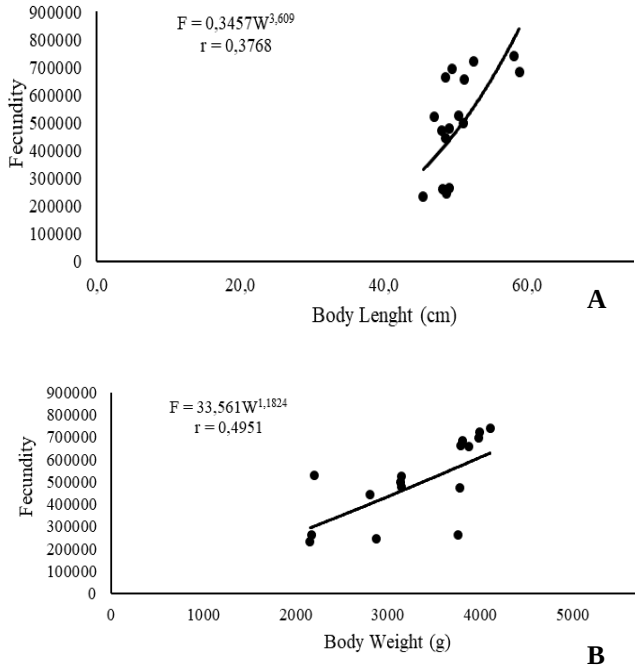


Figure 4. Gonadosomatic index of skipjack fish *Katsuwonus pelamis*. A. Male; B. Female



Figures 5. Relationship between body length and weight with the fecundity of skipjack fish *Katsuwonus pelamis*. A. Male; B. Female

Table 3. The fecundity of skipjack tuna (*Katsuwonus pelamis*) based on the sampling period

Samling period	Fecundity (eggs)	Average ± Std	Body length range (cm)
November	231,941-739,820	440,257±239,743	45.4-58
December	244,158-498,286	416,028±116,838	48.5-51
January	263,188-662,533	479,832±143,395	47-49
February	656,564-721,516	683,828±26,191	48.5-58.8
Total	231,941-739,820	506,393±179,690	45.4-58.8

Gonadosomatic index generally followed a pattern of decreasing from August to September, increasing and peaking in December, as well as decreasing again until February (Figure 3). The highest value for the maturity index was observed in December which showed the peak spawning season from October to February with potential continuation till July. Gonad Somatic Index reflected the progression of gonad development, decreasing after spawning. Throughout the research period, females skipjack tuna showed more advanced stages of gonad maturity when compared to males.

Size at first maturity

In fish reproductive strategy, the size at first maturity played a crucial role along with factors such as sex ratio, spawning period and type, oocyte development, and fecundity. In this research, males skipjack tuna first matured at 400.2 mm, ranging from 386.6-402.3 mm, while females matured at 420.2 mm, ranging from 396.6-462.3 mm. This showed that females fish generally matured at an earlier size than males counterparts.

Fecundity

The term fecundity pertained to the total number of eggs released during spawning. Knowledge of fecundity is a critical aspect of fisheries biology. In this research, the fecundity of skipjack tuna (*K. pelamis*) is presented in Table 3, while the relationship between body length and weight with fecundity is illustrated in Figure 5.

Discussion

Biological aspects of reproduction, including sex ratio, size at first maturity, spawning season, and fecundity, offered basic information used to estimate the spawning stock biomass of fish species (Ugrin et al. 2023). These reproductive factors were critical reference points that aided in assessing stock status and devising effective management strategies for fisheries (Hartaty and Arnenda 2019).

During the observation period, a male-to-female sex ratio of roughly 1.0:0.7 was recorded, suggesting that both genders were present in nearly equal proportions. According to Dahlan et al. (2018), a balanced sex ratio of 1:1 was ideal for ensuring species maintenance during the spawning period. Research conducted in other regions such as the Indian Ocean (Grande et al. 2014) and Pacific Ocean (Ashida 2020) has also reported a similar balanced sex ratio of close to 1:1. However, observations from the Eastern Pacific Ocean suggested variations in these patterns with males being more dominants (Schaefer and Fuller 2019). According to Mejuto (2018), the data on sex ratios for pelagic fish species such as skipjack and tuna, which migrate, can provide insights into possible differences in growth and mortality phases between sexes, as well as differences based on space and time. In the case of certain tuna species (*Thunnus* Spp.), it is often observed that there is a decline in the proportion of larger females in catches as size increases. In general, several factors influence this sex ratio including fish activity in waters, adaptability, genetic factors, food, fishing factors, migration, changes in new fish species in existing populations, and growth patterns (Ngabito et al. 2023).

The stages of gonad development, both before and after spawning, were showed by the levels of gonad maturity. These distinct phases were not only defined temporally but also coincided with fluctuations in gonadsomatic index. Gonadosomatic index would be higher as GMS increased, showing that gonad weight reached its maximum level during spawning before rapidly declining thereafter. The decrease in GSI implies energy transformation as a result of increased adjustment for stresses (Awal et al. 2023)

According to Arizmendi-Rodríguez et al. (2012), Gonadosomatic Index (GSI) was used as an indicator for gauging gonad maturity stage. The average value for the maturity index during the research period could also show the spawning season for fish species (Hossain et al. 2014). According to this research, skipjack tuna in Majene Waters typically spawn between October and February with a peak spawning in January. However, there was a possibility that spawning might continue until July. Previous reviews have suggested that skipjack tuna spawning could occur throughout the year (Jatmiko et al. 2015; Hartaty and Arnenda 2019). In this research, the size of the fish caught from July to October was predominantly below adult size, thereby they were immature (<35 cm). Adult-sized fish were rarely caught, and only a small number had mature gonad. According to Hosseini et al. (2017), the frequency of maturity stages and GSI values in skipjack tuna showed an extended spawning period from November to May, peaking in April-May. Differences in gonadal maturity in each species or one species are influenced by various factors, such as differences in population genetic characteristics, differences in growth rate, water quality, area differences and fishing pressure (Ngabito et al. 2023).

Skipjack tuna spawning has been recorded in the Western Indian Ocean during January-February and June-July. When spawning, females fish had asynchronous (non-uniform) oocyte development, resulting in ovaries containing oocytes at different developmental stages simultaneously (Grande et al. 2014). Based on observations by Hartaty and Arnenda (2019), adult females spawned actively throughout the year with a peak from April to September. Jatmiko et al. (2015) reported that skipjack tuna spawning occurred from April to November with the potential for year-round opportunities, specifically within the southern waters of Java and Nusa Tenggara. Furthermore, Ohashi et al. (2019) showed regional differences in the spawning season, particularly in temperate climates (>30°N), where spawning was concentrated in the summer months of July and August.

Skipjack tuna was a species with the capability to spawn multiple times during one season. An investigation conducted by Hartaty and Arnenda (2019) found evidence of various levels of oocyte development in active gonad, showing their ability for repeated spawning events. The spawning season generally coincided with the monsoon and intermonsoon periods (Grande et al. 2014), facilitated by suitable waters conditions. Skipjack tuna was typically found in warm waters (>28°C), preferring upper waters (<100 m) above the ocean's mixed layer across tropical oceans between 45°N and 40°S (Kim et al. 2020). Furthermore, the fish's preference for food availability played a role in driving the spawning behavior as they patrol vast regions feeding on pelagic fish, squid, crustaceans, and young while migrating long distances toward high chlorophyll concentrations zones when necessary (Mugo et al. 2020).

Females size at first maturity length (Lm) at 44.7 cmFL (Hartaty and Arnenda 2019), with maturity occurring between 49.4-63.3 cm in the Western Central Pacific Ocean (WCPO). Males matured at smaller sizes compared to females counterparts due to different growth coefficients that affected gonad maturation rates.

Fish of both the same and different species had distinct lengths of gonad maturity. The reasons behind this could be divided into two categories, including internal and external factors. Internal factors included the species differences in age, size, and physiological characteristics affecting adaptation and the availability of reproductive hormones. Meanwhile, the external factors consisted of differences related to diet and sex (Lagler et al. 1977).

Size-based fecundity estimates served as an important component of population dynamics models used for stock assessment (Dick et al. 2017) and support the reproductive potential of fish stocks in their habitats (Latuconsina 2022). This research found that skipjack tuna had fecundity values ranging from 231,941-739,820 eggs, and based on the sampling period, January exhibited the highest fecundity, with an average of 479,832 eggs. In the Flores Sea, the fish species had a fecundity of 1,256,760 eggs (Mallawa et al. 2014), while in the Indian Ocean South of Bali, fecundity ranged from 74,177-1,553,792 eggs (Hartaty and Arnenda 2019). Moreover, in the Menui Islands Waters, Morowali District, Central Sulawesi, fecundity ranged from 13,959-649,700 eggs (Yanglera et al. 2016), and the average fecundity in the eastern Pacific Ocean was 296,475 eggs (Schaefer and Fuller 2019). Skipjack tuna with an average fecundity above 10,000 eggs were classified as having high reproductive potential (Dick et al. 2017). The relationship between fecundity and total length and body weight of skipjack tuna shows a moderate correlation, indicating that increases in length and body weight are associated with increases in fecundity. The relatively high fecundity and long spawning season could support the widespread of skipjack tuna in various marine waters. The amount of fecundity in fish is influenced by factors such as feed availability, fish length and weight, egg diameter, and environmental factors (Ngabito et al. 2023).

In conclusion, the sex ratio for both males and female's skipjack tuna was nearly equal. The spawning season was thought to happen all year, with a peak period from November to February. In this research, male's skipjack tuna first matured at 400.2 mm, ranging from 386.6-402.3 mm, while females matured at 420.2 mm, ranging from 396.6-462.3 mm. The reproductive potential of skipjack tuna was relatively high, with an average fecundity ranging from 57,761-1,151,439 eggs.

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