

Aspects of Reproductive Biology of Flying Fish, *Hirundichthys Oxycephalus* (Bleeker, 1853) in Majene Waters, West Sulawesi Province, Indonesia

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Abstract: Flying fish (Family Exocoetidae) are small pelagic species with high commercial value and represent one of the main catches for local fishermen. Therefore, this study aims to explore the reproductive biology of flying fish, including the sex ratio, Gonad Maturity Index (GMI), Gonad Maturity Stage (GMS), and first gonad maturity size in Majene Waters, West Sulawesi Province. The study procedures were carried out for 1 year from October 2021 to September 2022. Sampling was performed at the flying fish fishing base in the Labuang and Somba areas, Mosso Village, Majene Regency, West Sulawesi Province. Data analysis was conducted at the Integrated Laboratory of the Fisheries Department, West Sulawesi University. During the study period, a total of 708 *H. oxycephalus* species were obtained, comprising 383 males and 325 females. The average sex ratio of the samples in Majene Waters was imbalanced with a male-female ratio of 1.00:0.85. The Gonad Maturity Level found in the area was classified into various categories, including GMS I (undeveloped), GMS II (early development), GMS III (mature gonad), GMS IV (overdue development), and GMS V (spawning). The spawning period was predicted to occur from March to July, with the highest peak in May. Furthermore, male fish reached gonad maturity at a size range of 19.94-20.60 mm with an average of 20.27 mm, which was earlier compared to females at 20.15-20.85 mm, with an average of 20.50 mm.

Keywords: Fisheries management, gonad maturity level, spawning season, sex ratio, Makassar Strait

1. Introduction

Hirundichthys oxycephalus (Bleeker, 1853) is a prominent flying fish species known for its wide distribution across various regions in the world. Furthermore, its distribution spans the South China Sea (Chang et al., 2012), the Western Pacific Waters near the Ryukyu Islands, Kyushu, Honshu in Japan, Australia, Western Polynesia (Shakhovskoy & Parin, 2013), the Northwestern Pacific (Chou et al., 2015), Taiwan (Chang et al., 2012), Brazil (Oliveira et al., 2015), and the Philippines (Emperua et al., 2017). In Indonesia,

flying fish have been found in several areas, including Takalar Waters; South Sulawesi (Ali et al., 2004), Makassar Strait; South Sulawesi (Indrayani et al., 2020a, 2021), Banten Waters (Harahap & Djamali, 2005), Kaimana and Fak-Fak Waters; Papua (Tuapetel et al., 2015), and Majene Waters; West Sulawesi. *Hirundichthys oxycephalus* is one of the dominant species, which is often caught by fishermen in Majene Waters, West Sulawesi (Nur et al., 2022; Tuapetel et al., 2015).

Flying fish (Family Exocoetidae) are small pelagic species with relatively high demand due to their enormous commercial value (Churnside et al., 2017; Indrayani et al., 2020; Syahailatua, 2006). These fish, along with their eggs, are exported to various countries around the world due to the high demand (Indrayani et al., 2021). In Indonesia's fishery history, the species are the second-largest foreign exchange earner after shrimp in the 1980s (Ali et al., 2004). The West Sulawesi Province particularly benefits from the fishery resources due to their significant socio-economic value. Local communities also rely on them as a vital source of income for fishermen, protein for consumers, as well as employment in egg harvesting, fish catching, drying, and smoking activities (Fitriah et al., 2020; Nur et al., 2022). Apart from their economic functions, flying fish also play a crucial ecological part in the trophic levels of marine food

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chains by acting as a link between primary producers and next-level consumers (Churnside et al., 2017).

At present, the main concern is the declining catch reported by fishermen year after year. Data from 2008 to 2020 show a drastic decreasing trend in catch per unit effort (CPUE) by 50%, where the highest catch of 1064 tons/year has reduced to only 564 tons/year (Marine and Fisheries Service of West Sulawesi Province, 2021). The high demand for flying fish and their eggs, particularly due to the presence of investors, has led to increased fishing activities. However, the lack of proper management caused a decline in the fish population. Over the past 2 years, flying fish exports in West Sulawesi have only occurred twice. This serves as a warning, specifically in light of studies indicating signs of overexploitation in the flying fish population in the Makassar Strait and Flores Sea, with a production decline of more than 67% after more than 30 years of utilization (Tuapetel, 2020). To address this situation, sustainable management efforts are needed to ensure sustainability and the sources can be used continuously for this species in the future. One essential foundation required is information related to the species' reproductive biology as it is crucial for effective management (Shuaib et al., 2011) and to ensure the population's sustainability against excessive exploitation (Pinheiro et al., 2011).

Various studies have been undertaken on the reproductive biology of flying fish (Family Exocoetidae) in Indonesia across various areas, including Takalar Waters, South Sulawesi (Ali et al., 2004), Geser Strait, East Seram, Maluku (Tuapetel, 2021), as well as *Cypsilurus ologolepis* and *Cypsilurus spilopterus* in Tual Waters, Southeast Maluku (Syam et al., 2004). Despite the long-standing exploitation of this species by local fishermen, there is still limited information on its reproductive biology in Majene Waters, West Sulawesi. This indicates that it is important to undertake a study on the reproductive biology aspects of flying fish (*Hirundichthys oxycephalus*), encompassing sex ratio, Gonad Maturity Index (GMI), Gonad Maturity Stage (GMS), and first gonad maturity size in Majene Waters, West Sulawesi. The results are expected to serve as a scientific basis for resource management efforts to support sustainable fisheries in West Sulawesi.

2. Method

This study was undertaken for 1 year period from October 2021 to September 2022. Furthermore, fish samples were collected at the flying fish fishing landing in the Labuang and Somba areas, Mosso Village, Majene Regency, West Sulawesi Province. The samples were carefully placed in a cold container fish with ice and were carried back to the Integrated Laboratory of the Fisheries Department, West Sulawesi University for analysis.

The procedures involved cleaning the sample fish thoroughly and then arranging them on a preparation board. Each fish was labeled with a sequential number, and the total length was measured from the front mouth to the end of caudal fin using a digital caliper with a precision of 0.01 mm. The weight of the samples was determined using a digital scale with a precision of 0.01 g. The determine male and female fish are by dissecting and observed the gonads.

Data Analysis

The sex ratio based on the number of male and female flying fish samples was calculated using the following formula as shown in Eq. (1) :

$$SR = \frac{\sum J}{\sum B} \tag{1}$$

Where SR = sex ratio, $\sum J$ = the total of male flying fish, and $\sum B$ = the total of female flying fish

To determine the sex ratio between each sex both male and female fish at each sampling time and the Gonad Maturity Stage (GMS), a chi-square test was conducted and organized in the form of a contingency table (Zar, 2010).

To determine the GMS in female samples, the following characteristics were observed, namely form, quantify, color, texture, and size of ovaries in the body cavity, as well as the size, shape clarity, and color of eggs within the ovaries. Meanwhile, for the males, the observed characteristics included shape, size, color, and the size of testes within the body hole. The GMS were determined based on the male and female gonad characteristics as described by Tuapetel (2021). The analysis involved grouping the frequency (%) data into immature and mature gonads, based on the GMS obtained during the observation.

The Gonad-Somatic Index (GMI) was analyzing using the following formula as shown in Eq. (2) (Johnson, 1971):

$$GMI = \frac{Bg}{W} \times 100 \tag{2}$$

Where Bg = gonad weight (grams) and W = total body weight (grams).

To estimate the average first gonad maturity size, the Spearman-Kärber method (Udupa, 1986) was used with the following formula as shown in Eq. (3):

$$m = x_k + \frac{X}{2} - \{X \sum p_i\} \tag{3}$$

With a 95% confidence interval, the equation below was obtained as shown in Eq. (4):

$$\text{Antilog } m = \left[m \pm 1,96 \sqrt{X^2 \sum \left(\frac{p_i - q_i}{n_i - 1} \right)} \right] \tag{4}$$

Where m = log of fish length at first gonad maturity, X_k = log median of last length class at first gonad maturity, X = log increase in length at the median, p_i = Part of gonad maturity fish in length class i to the quantity of fish in length interval i, n_i = the count of mature fish in length class i, $q_i = 1 - p_i$, and m = antilog m of fish length at first gonad maturity.

4. Results

Sex ratio

During the study in Majene Waters, a total of 708 flying fish (*H. oxycephalus*) were obtained, composed of the males and female fish of 383 and 325, respectively. Based on the sampling time and location, the sex ratio was 1.00:0.85, but varied each month, as shown in Table 1.

Table 1. Sex ratio of flying fish (*Hirundichthys oxycephalus*)

Month	Sex		Sex Ratio
	Male	Female	
Oct 2021	19	15	1.00:0.79
Nov	20	17	1.00:0.85
Dec	47	23	1.00:0.49
Jan 2022	39	45	1.00:1.15
Feb	76	29	1.00:0.38
Mar	34	43	1.00:1.26
Apr	46	24	1.00:0.52
May	48	52	1.00:1.08
Jun	34	52	1.00:1.53
Jul	20	25	1.00:1.25
Aug	36	14	1.00:0.39
Sep	30	37	1.00:1.23
Total	383	325	1.00:0.85*

Build upon the Chi-square test analyze of male and female fish, the χ^2 - count was 47,351, which was greater than the χ^2 -table (0.05;1) = 19.675. Therefore, the male and female flying fish in Majene Waters were categorized as imbalanced.

Gonad Maturity Stage (GMS)

The Gonad Maturity Stage (GMS) refers to specific stages of gonad maturing before and after spawning (Effendie, 2002). The samples obtained in this study were in various categories, including GMS I (undeveloped), GMS II (early development), GMS III (mature gonad), GMS IV (late development), and GMS V (spawning). The complete GMS of flying fish observed is shown in Table 2 and its distribution is presented in Figure 1.

Based on Figure 1, flying fish with GMS I and II were found mostly from October to February, while the proportion of GMS III increased in March-April and then decreased. GMS IV and V showed an increase from March to July with the highest peak in May, which was estimated to be the climax of the spawning period. During this month, GMS V was predominantly found, along with a significant number of mature gonads and spawning fish (GMS III-IV).

Table 2. Gonad Maturity Stage (GMS) of flying fish

GMS	Ovaries	Testes
I Young fish	The ovaries are very small, resembling threads, white, and transparent.	The gonad is very small, resembling threads, white, and transparent.
II Getting mature	The ovaries are rounded, light yellow in color, with no visible egg grains, and a smooth surface.	The testes are thick, flat, whitish in color, and increasing in size.
III Mature	The ovaries are bloated, with fine egg grains becoming visible, thick egg sacs, and a yellowish color.	The gonad's surface appears whiter, with a longitudinal black line in the middle of the testes, and the testes' size is observed to cover about a third of the triangular-shaped abdominal cavity.
IV Spawning	The ovaries are fully developed within the abdominal cavity, with egg grains becoming clearer, the egg membrane thinning, and a yellowish color.	The testes are fully developed within the abdominal cavity, and a thick white seminal fluid is released when slightly pressed.
V Spent	The ovaries shrink, egg grains are very evident, the egg membrane is very thin, part of the gonad has deflated due to oviposition (spawning), and a yellowish color.	The testes shrivel or deflate, appear less dense, and have a white, milky color.

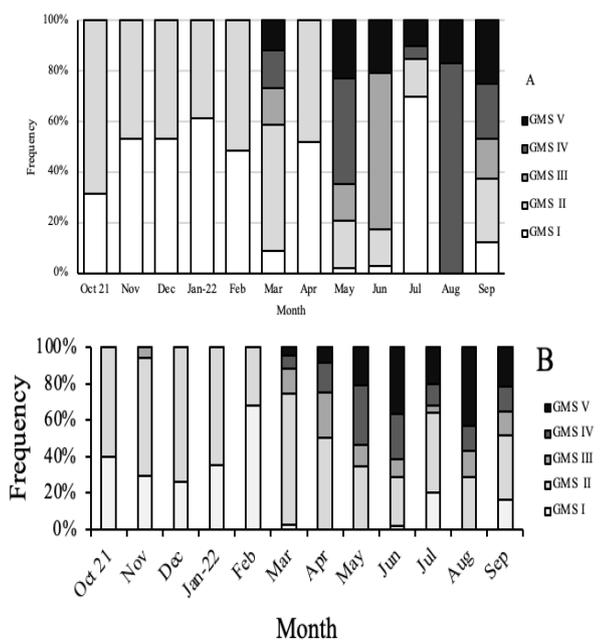


Figure 1. GMS composition of flying fish (*H. oxycephalus*) from October 2021 to July 2022 in Majene Waters

Gonado-Somatic Index (GSI)

The Gonad-Somatic Index (GSI) was a percentage value obtained from the comparison between the gonad weight and the body weight of the fish. The GSI value could be used to identify the peak spawning period of the samples. Furthermore, the GSI of flying fish (*H. oxycephalus*) during the study is presented in Table 2 and Figure 2.

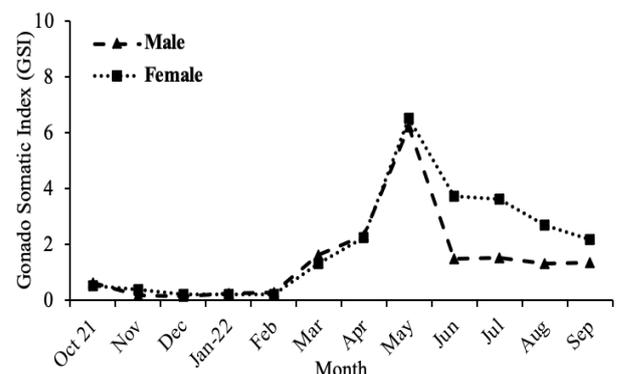


Figure 2. Monthly GSI value of male (n= 383) and female (n= 325) *H. oxycephalus* collected from October 2021 to July 2022 in Majene Waters

Table 2. Range, mean and standard deviation of GSI of in male and female *H. xycephalus* collected from October 2021 to July 2022 in Majene Waters.

Month	Male			n	Female			n
	Range	Mean	Sd		Range	Mean	Sd	
Oct 21	0.0130-1.8841	0.5991	0.5082	19	0.0103-2.3088	0.5242	0.5987	15
Nov	0.0395-0.4688	0.1783	0.1228	20	0.0789-0.8393	0.3792	0.2062	17
Dec	0.0089-0.5288	0.1455	0.1250	47	0.0098-0.4796	0.2074	0.1395	23
Jan 22	0.0091-0.5983	0.2312	0.2340	39	0.0093-1.2312	0.2171	0.2307	45
Feb	0.0093-2.6047	0.2629	0.4626	76	0.0476-0.6630	0.2052	0.0993	29
Mar	0.1217-4.5122	1.6112	1.3553	34	0.0839-3.9749	1.3009	1.0686	43
Apr	0.1338-1.9714	2.3078	0.3856	46	0.1053-4.1111	2.2316	1.1019	24
May	0.2429-13.4562	6.2024	3.0527	48	0.2545-13.9799	6.5035	3.6411	52
Jun	0.0308-5.3086	1.4601	1.8054	34	0.1639-7.1970	3.7161	1.6848	52
Jul	0.0832-10.9965	1.5264	2.8684	20	0.1689-12.5781	3.6072	4.6073	25
Aug	0.1143-1.0627	1.3182	0.2046	36	0.5395-4.4088	2.7000	2.1177	14
Sep	0.0290-6.9298	1.3320	2.0897	30	0.0749-8.7417	2.1532	1.1569	37
Total	0.0089	1.4313	1.1012	449	0.0093-13.9799	2.0788	1.1794	376

Note: n = number of fish used in the analysis

Based on Figure 2, the GSI composition of flying fish from October 2021 to February 2022 did not show any increase. In March, the value began to increase, reaching its peak in May, and started to decrease in June and July down to its lowest point in September. This information indicated that the spawning period of flying fish tended to occur from March to July, with the highest peak in May. Furthermore, Table 2 showed the average GSI for both male and female samples, and the highest values were obtained in May. This corresponded to the proportion of flying

fish with mature gonads, which was also dominant in May. Additional information in Table 2 also revealed that female fish had relatively higher GSI compared to males.

First Gonad Maturity Size

The first gonad maturity size was an essential aspect in the biology of *H. Oxycephalus*. The result of the first gonad maturity is shown in Table 3.

Sex	Range (mm)	Average (mm)	The Average size of Gonad Mature (mm)
Male	19.94-20.60	20.27	19.73
Female	20.15-20.85	20.50	19.63

From October 2021 to July 2022, male fish in Majene Waters exhibited gonad maturity at a size of 19.94-20.60 mm and a size average of 20.27 mm. Meanwhile, the female samples matured at 20.15-20.85 mm and a size average of 20.50 mm. From the result indicated that the male fish had faster maturity compared to female fish.

5. Discussion

Based on the chi-square analysis, the proportion of *H. oxycephalus* was imbalanced. Similar findings were observed by Hermawati (2015) on *H. oxycephalus* in Binuangeun waters, Banten, with a ratio of 2:1 or 69% male and 31% female. Furthermore, Armanto (2012) found a male-female ratio of 1.8:1.0 for *Cheilopogon katoptron* in Pemutaran waters, Bali, which had not entered the spawning period. Oliveira et al., (2015) also reported an imbalanced sex ratio of 1 male to 1.6 females in *H. affinis*. Balanced ratios in flying fish were only found in specific locations, such as *H. affinis* in Barbados waters (Khokiattiwong, 2000), *H. oxycephalus* in the Flores Sea and the Makassar Strait (Ali et al., 2004), and the waters of West Papua (Tuapetel, 2020).

Some fish populations exhibited sex ratio deviations from the balanced 1.00:1.00 due to the influence of temperature, selective mortality, sexual behavior, and different growth rates (Pinheiro et al., 2011; Dahlan et al., 2018). Differences in growth rates could lead to an imbalance in the population's proportions. The sex with a faster rate was likely to grow larger, reducing predation, while the slower-growing group became prey for predators (Vicentini & Araujo, 2003). Another influential factor was food availability, which often led to the dominance of females, while limited supply caused male dominance. In some fish populations, the dominance of the males in the reproductive process was hypothesized as a response to environmental pressures (Kuljanishvili et al., 2018).

The sex ratio of flying fish in certain months is a ratio of 1:<1 and 1:>1. From May to June, female fish are seen to dominate and this period coincides with the peak of spawning or reproduction activity of flying fish. This is in line with the proportion of GMS and GSI values which increased in that month. Pursuant to Soewardi (2007), several variables caused distinction in sex ratios among fish groups, including chance events, selective mortality, and specific sex harvesting. Furthermore, Latuconsina (2020) stated that ratio balance determines the effective population size and affected each fish's ability to pass on genetic variation to the next generation through reproduction, ultimately influencing the population's sustainability in the wild.

Based on the analysis of GMS in Figure 1 and GSI in Figure 2, the spawning period of flying fish began from March to July, with the highest peak in May. This finding was consistent with Ali et al., (2004) and Tuapetel (2021), that the spawning season of *H. oxycephalus* occurred from May to September, with the peak

happening in June and August. A previous study also obtained similar reports regarding *H. affinis*, which spawned from March to July (Oliveira et al., 2015). The spawning of flying fish during this period was influenced by seasonal conditions, specifically during the eastern monsoon. Upwelling enriched nutrients and food elements that supported the life cycle and larval growth (Ali et al., 2004). The high abundance of flying fish in fertile areas indicated their preference for specific locations for spawning (Suwarso et al., 2017), particularly in areas with upwelling (Randall et al., 2015). Based on this study, efforts must be made to restrict fishing during the spawning season to maintain the sustainability of the samples.

Table 2 and Figure 2 showed that the average GMS of female flying fish was higher compared to that of males. A similar condition regarding the greater increase in ovary weight compared to testes had also been reported by Makmur et al., (2007). The increase in ovary weight in female fish could gain 10-25% of the total body weight, while in male fish, it ranged from 5-10% (Dahlan et al., 2018). The ovaries were heavier than the testes due to vitellogenesis, which involved the formation of yolk (vitellin) during the development of female gonads (Nur et al., 2017).

The first gonad maturity size was a crucial aspect in the biology of flying fish. The estimation of this aspect aimed to understand the population's development, such as predicting the best time for spawning or determining the completion of the process (Dahlan et al., 2018). Information on the first-time fish reach gonad maturity can also be a basis for managing flying fish, such as setting gear mesh sizes, hence the fish that have never spawned can reproduce, at least the first time to add new stock in waters. In this study, male fish matured their gonads faster compared to females. This indicated that the males reached gonad maturity earlier than the females. A similar finding was also obtained by Tuapetel (2021), who studied the flying fish species *Cheilopogon abei* in the waters of Geser Strait, Seram Timur - Maluku, reaching first gonad maturity at sizes of 210.5 mm and 214.1 mm FL for male and female fish, respectively. These findings were inconsistent with a study in Brazil, where female *Hirundichthys affinis* had matured gonads earlier than the males, with the first gonad maturity occurring at sizes of 27.1 cm and 27.3 cm for females and males, respectively (Oliveira et al., 2015).

The differences in the first gonad maturity size in fish of the same genus could be attributed to variations, regions, and habitats. This situation was also caused by geographic distribution and surrounding conditions including biotic and abiotic, growth characteristics, as well as differences in overexploitation of fish population and the number of each stock (Faghani-Langroudi & Mousavi-Sabet, 2018; Faghani-Langroudi et al., 2014; Mousavi-Sabet et al., 2011). Lappalainen et al., (2016) stated that increasing fishing stressors could alter life cycle characteristics, such as accretion and first gonad maturity size. The first size of fish reach gonad maturity was indicated to growth and environmental influences, as mentioned by Affandi & Tang (2017). Meanwhile, refers to Lagler et al., (1977), age, size, the function of fish body organs condition, and external surrounding

factors, such as temperature, flows, sea levels, lunar phase, and spawning, were the dominant factors influencing the onset.

6. Conclusion

In conclusion, the flying fish (*H. oxycephalus*) in Majene Waters, had an unbalanced sex ratio with a male-female ratio of 1.00:0.85. The spawning period began from March to July, with the highest peak in May. Furthermore, the first gonad maturity size for males ranged from 19.94-20.60 mm TL, with an average of 20.27 mm TL. This was faster compared to females at 20.15-20.85 mm TL, with an average of 20.50 mm TL. Proper fishery management for the sustainable utilization of *H. oxycephalus* flying fish in the Majene Waters, could include regulating the fishing season, taking into account the peak spawning season, and implementing technical considerations for gear selectivity related to first gonad maturity size as a reference for appropriate or allowable catch size. This information hopefully can be used for the management stock of flying fish in Majene Waters.

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