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Maturity and Spawning of Flying Fish (*Hirundichthys oxycephalus* Bleeker, 1852) in Makassar Strait, South Sulawesi

S A Ali

Fisheries Department, Marine and Fisheries Faculty, Universitas Hasanuddin, Makassar, Indonesia

Email: syamsualam.ali@gmail.com

Abstract. Flying fish, *Hirundichthys oxycephalus* Bleeker 1852 is one species with important social economic values. There are strong indications that this species is over-exploited in the waters of the Makassar Strait. This study aimed to analyse the spawning season, spawning frequency, level of productivity, and the length at first maturity. The spawning season analysis was based on GML (gonad maturity level) and GSI (gonad somatic index) distribution, while spawning frequency analysis was based on the distribution of egg diameter and gonad histology. Determination of size at first maturity used a formula based on the relationship between fish length and a 50% proportion of mature gonads. Determination of productivity level refers to the reproduction index criteria. The study found that flying fish begin to spawn between the months of February-March, with a spawning peak from June to July, and the spawning season ends around September-October. Flying fish spawn partially around 3-4 times in one season, with mature gonads starting to be found at a fork length of 151.5 mm. The flying fish productivity was classified as high, indicating potentially high resilience.

1. Introduction

Biological studies of flying fish (H. oxycephalus Bleeker, 1852) (Figure 1) in the Makassar Strait and Flores Sea were first performed around 40 years ago [1,2]. These studies found a sex ratio of 1:1.94 with mostly gonad maturity level (GML) II to V in Makassar Strait [1] and a sex ratio of 1: 1 for flying fish caught by traps drifting in the Flores Sea, with GML IV and GML V predominating [2]. Both researchers stated that fishing coincides with the spawning season during the East season (March to October). Flying fish spawn close to a floating substrate, preferably one that is soft or supple such as Sargassum [3]. Different types of material floating can be used as a substrates for flying fish eggs, including palm, banana, and sugarcane leaves; seagrass; straw, sticks of wood; nets, rope, plastic, bottles, and floating cans [4]. In South Sulawesi, fishermen use a kind of FAD (fish attracting device) locally called 'bale-bale', as flying fish attach their eggs to the palm or banana leaves and Sargassum used [1]. A flying fishing found in the waters of Barbados, H. affinis, has two peak spawning seasons: December to January and April to May [5], as do the flying fish in the waters of the eastern Caribbean [6]. In Manado Bay, Cypselurus sp. nurseries peak in March and May (Bataragoa, 1997 in [7]. In Barbados, the Caribbean flying fish, H. affinis, spawn 3-4 times and then dies after spawning [5].

Figure 1. Flying fish, *Hirundichthys oxycephalus* Bleeker 1852 [8]

Exploitation of eggs and adults in the spawning season could threaten the survival of flying fish [1,2,9]. Some studies showed the average catch per unit effort decreased from 2002 to 2004.The CPUE and production declined by up to 62% over 27 years from 1975 to 2002, with a decline in MSY of about 50% from 1975 to 2002 [10]. These declines are symptomatic of overfishing at a level likely to have negative effects on sustainability, and call for improved resource management [8]. One form of good management could be an ecosystem approach to fisheries management to evaluate and formulate strategies for the sustainable management of flying fish [11].

2. Methods

Research was conducted in the waters around Takalar in the Makassar Strait, South Sulawesi, Indonesia from March to August 2016. The study was done by the Marine and Fisheries Research and Development of Agency in partnership with the Faculty of Marine Sciences and Fisheries of Universitas Hasanuddin (Unhas). Flying fish *H. oxycephalus* (Bleeker) were randomly sampled using drift gill net gear with a mesh size of 1 to 1.5 inches. Parameters measured were fork length, total weight, sex, gonad maturity level, and gonad weight. Analysis of the samples was conducted in the Laboratory of Fisheries Biology at the Unhas Faculty of Marine Sciences and Fisheries. Gonad maturity level (GML) was determined based on the flying fish GML classification in [3]. Gonad somatic index (GSI) was calculated as the ratio of gonad weight to total body weight multiplied by 100% [3]. Spawning frequency was determined from the mode of the egg diameter distribution, while productivity level referred to the criteria of [12]. Length at first maturity (Lm) was determined based on the (fork) length weight relationship, as the length L at which (on average) 50% of fish would have mature gonads [13], as follows:

$$P = 1/\{1 + \exp^{-0,09646(L-151,5)}\}$$

Where:

P = proportion of mature fish by length
L = fork length of the fish
r = angle of slope of the curve

3. Results and Discussion

The 1229 flying fish caught and used in this study comprised 711 males and 518 females. The fish were caught with drift gill nets and most had not spawned (Figure 2). The fish gonad maturity levels in Figure 2 show that approximately 89% of fish caught had not completed spawning. The use of drift gill nets can thus be considered to pose a threat to the flying fish stocks, and furthermore it has been alleged that this fishing gear can block fish spawning migrations, preventing them reaching their spawning grounds.

The gonad maturity level of fish caught with drift gill nets were more varied (GML I to GML V) compared to those of fish caught by drifting traps (mostly GML IV and GML V), showing that the latter had a higher selectivity [2]. Drifting traps are equipped with palm fronds and/or banana leaves, as well as *Sargassum,* in order to attract flying fish to come and spawn. Thus, in general only mature flying fish were caught. In addition to catching the spawning fish, the drift traps enable the exploitation of the eggs.

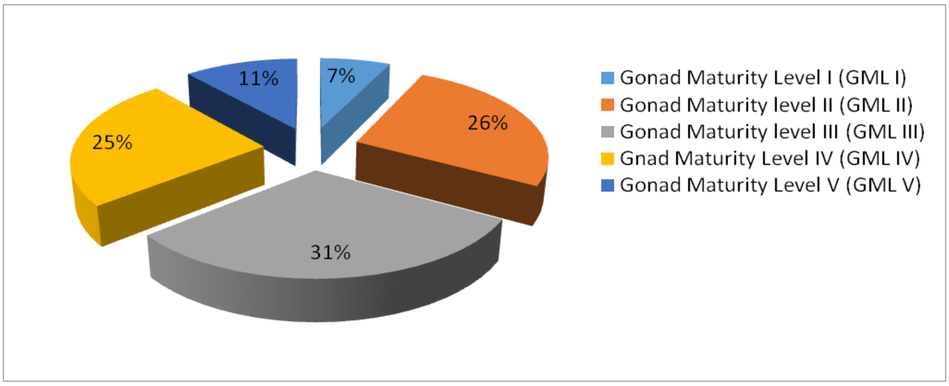

Figure 2. Percentage of each GML (Gonad Maturity Level) in 1229 flying fish caught with drift gill nets in 2016.

Although the use of traps drift is selective with respect to GMLs, vigilance is required to ensure the sustainability of spawning, as the eggs deposited on palm leaves in the mouth traps are the prime target for fishermen. Nowadays drift traps are no longer used, as fishermen have replaced them with a gear called *bale-bale,* a kind of FAD that only targets the flying fish eggs and is economically very profitable. This technology is simple, as the appliance is only made of a series of coconut palm leaves which attract the flying fish to lay their eggs. In Galesong, Takalar District, it was estimated that there were about 1000 vessels harvesting flying fish eggs using *bale-bale*. *Bale-bale* operates in spawning areas, unlike the drifting gill nets which can prevent fish from migrating to these spawning areas. Bale-bale fishing grounds are further offshore than drifting gill nets. Failure of fish populations to rebound to former abundance could be due to a decline in recruitment, low spawner abundance, and degradation of the population.

The percentage of each gonad maturity level (GML) for female flying fish (Figure 3) shows that GML I was rare in female fish and only found in March (8.89%) and April (30.77%). GML II was common in March (60%) and April (48.2%), and lowest in August (22.69%). GML III continued to increase in frequency in May (43.94%), and 50.93% in June. GML IV was high in June (24.26%), July (30.25%), and August (22.86%). The ripe phase or phase of spawning (GML V) appeared in May (3.8%) and increased through to a peak level of 10.08% in August. These data show that the main likelihood of spawning began around May, even though it is though that spawning can occur as early as March.

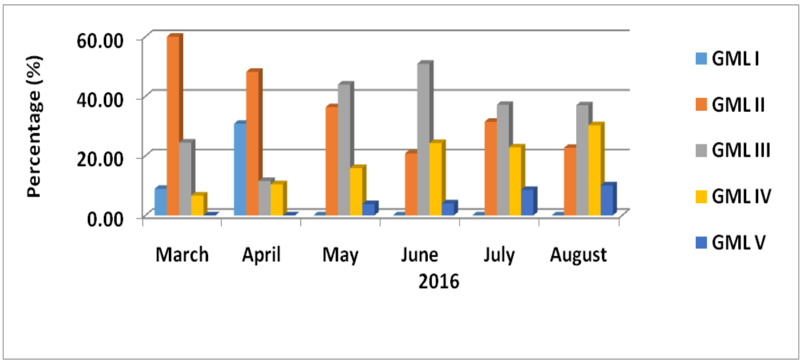

Figure 3. Percentage and distribution of female flying fish GML (Gonad Maturity Level) during March to August 2016

Male GML levels (Figure 4) also show the highest GML percentage in March (41.9%), falling to 1.2% by July, and was not found in August. GML II was most common in March (47.7%) and April (57.8%) and very rare in August (3.3%). GML III was most common in June (36.2%), then in July and August (18.1% and 18.5%, respectively), while GML IV was also most commonly found in June (47.1 %), followed by July (20.5%), and in August (21.7%). Lastly, male GML V was found in May (10.9%), peaking in July and August with respective values of 51.8% and 56.5%.

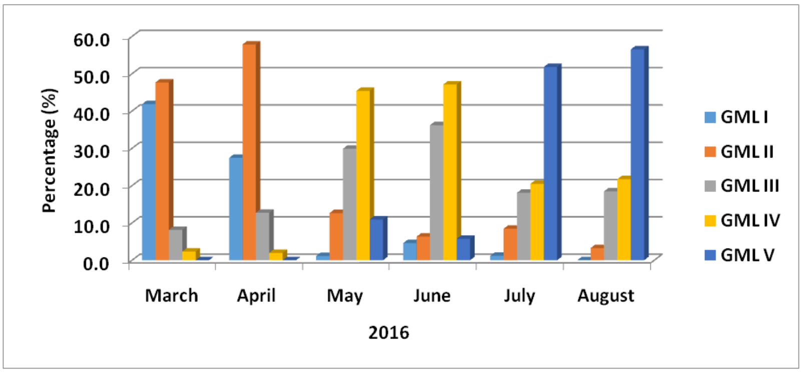

Figure 4. Percentage and distribution of male flying fish GML (Gonad Maturity Level) during March to August 2016.

Based on the percentage distribution GML by month, it can be assumed that the first flying fish spawning occurred in May, indicated by the presence of ripe phase or spawning phase gonads. In March and April spawning did occur, albeit on small scale, because flying fish eggs were found attached to the drift gillnet. Flying fish spawning probably continued until September and October, based on the high percentage of fish with GML III and GML IV in August. Peak spawning occurred between June-July and even during August spawning frequency was still relatively high. Generally fishermen stop catching flying fish eggs in September-October, one reason being that, in addition to the catch beginning to decline, the weather patterns can make fishing dangerous.

The large number of flying fish caught with mature gonads and fish that have spawned shows that the gillnets catch flying fish moving towards or already in spawning areas. There are differences in timing but a large overlap in the drift gill net and *bale-bale* (FAD) fisheries. Drift gill net fishermen who want to catch adult fish generally start their operations early in February to March and stop in July. Fishermen who use the FADs want to exploit the eggs start their operations starting in March and generally stop fishing in September-October.

Gonadosomatic index (GSI) for both males and females rose from March to a peak in June, followed by a relatively slow decline (Figure 5). In March the average male GSI was 2.07% while for females it was 1.83%. In April average male GSI 5.26%, with 4.56% for females. In May the average female GSI (7.72%) was higher than that of males (7.32%). In June the average GSI of females peaked at 9.66% while male GSI peaked at a slightly lower value of 8.96%. The GSI peak in June coincided with the high incidence of MGL (maturity gonad level) IV in June.

In June when the average GSI was high, it was common to find female and male gonads weighing as much as 13.42 g and 9.50 g. Furthermore, many of the fish caught were already beginning to spawn, while new eggs beginning to mature or developing were found in the gonad indicating the fish would soon be spawning. In July the average GSI of males and females began to decline to 7.74% 5.98%, and in August the average GSI had decreased significantly in females (4:12%) but less so in males (6.40%).

The GSI pattern was similar for both sexes and shows that June-July was the peak in gonad maturity and spawning. It can be expected that the majority of flying fish take part in this spawning peak. However the slow decline indicates the flying fish eggs or sperm are released gradually or in stages in a process of partial spawning. Flying fish spawning peaks in the Makassar Strait have also been reported by [14]. Figure 5 also shows that spawning probably began earlier around February to

March, albeit in low percentages, and that after the peak between June and July the end of the spawning season can be expected to occur during September to October.

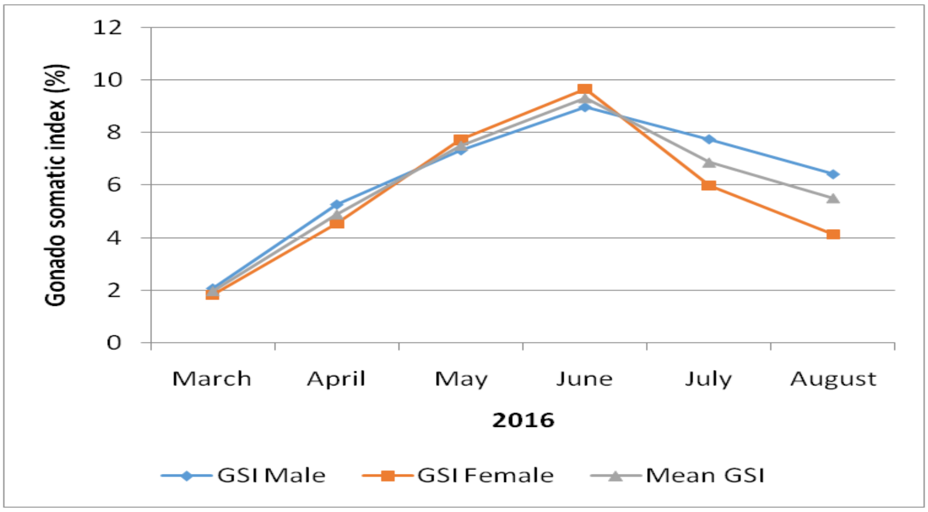

Figure 5. Flying fish Gonadosomatic index (GSI) trends

Based on the analysis of 850 eggs from TKG IV fish, flying fish egg diameter ranged from 0.57 to 1.45 mm and contained approximately 3-4 modes (Figure 6). Furthermore, the results of structural analysis diameter flying fish eggs in the ovary [15] showed three groups based on egg diameter: (1) young eggs, small in size between 0.03 to 0.49 mm in diameter, dark and dense, found in all phases of flying fish gonad maturity; (2) developing or maturing eggs with diameter ranging between 0.50 to 0.99 mm, white and opaque, and already have a filament that appears around the wall of the egg; (3) mature eggs which are yellow, 1.00 to 1.75 mm diameter, clear and transparent, there is a filament that connects the mature egg, the egg is ready to be released. If one mature egg is spawned, more mature eggs will spill out.

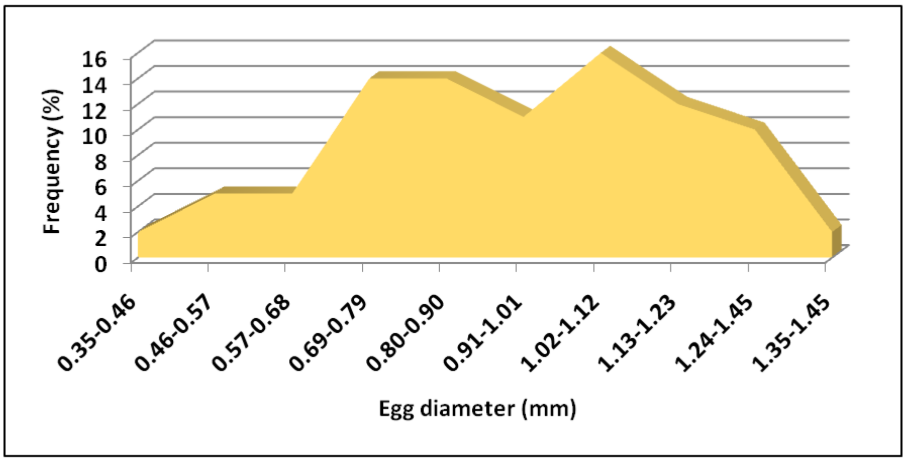

Figure 6. Flying fish, *H. oxycephalus* Bleeker egg diameter frequency distribution at Gonad Maturity Level IV (MGL IV), in the Makassar Strait (2016).

Gonad histology at MGL IV showed variations in the size of eggs within each of these three egg categories. Groups of mature eggs show that the fish is ready to breed as a partial spawner. The number of modes in the distribution of the diameter of the eggs in the ovary explained that flying fish spawn 3-4 times (partial spawning). A similar pattern was also observed in fly fishing (*H. affinis*) in the waters of Barbados [5]. Partial spawning in the Makassar Strait can be expected to take place between February and October. Based on the partial spawning nature of this fish, populations in and around the Makassar Strait can be expected to comprise several cohorts with different age classes within each year; however it is still difficult to determine the difference in age between cohorts. Flying Fish (*H. affinis*) in the eastern part of Brazil spawn in March and July with an average fecundity of 9092 eggs and a balanced sex ratio (1:1); based on the microscopic description of gonad maturity, locations important as flying fish spawning areas of *H. affinis* were identified [16].

Based on reproductive index parameters, fish can be categorized as having high, medium, or low levels of productivity [12]. Fish are classified as having high levels of productivity when annual fecundity> 10,000; von Bertalanffy growth coefficient > 0.30; age of maturity <1 year, and the maximum age is less than 3 years. Based on these guidelines, flying fish can be classified as having high levels of productivity. Flying fish can have an annual fecundity of over 20,000, while the coefficient of growth can be as high as 1.3, and the age at first maturity is around 6-8 months with a maximum lifespan of 1-2 years [17]. This means that flying fish are classified as having a high degree of resilience so that the population will still be likely to survive despite the exploitation of eggs being conducted using fish attraction devices (*bale-bale* or *balla-balla*) to aggregate the fish which come to the spawning grounds. Despite this, based on a sustainability analysis of the flying fish fisheries in the Makassar Strait, there are two domains that do not support the continuity; these are the fishing techniques and the condition of the flying fish biological resources themselves [11].

The length at first maturity analysis using the formula in [13] resulted in an average Lm of 15.15 cm fork length as the length of first maturity (50% of fish with mature gonads). This can be compared to *H. affinis* in Brazilian waters where Lm for males was 27.3 cm and 27.1 cm for females [17], while the gonad maturity index of flying fish in North Carolina peak in in June, July, and August, with spawning from July to August and a sex ratio of 1:1 [18]. Furthermore the spawning season was characterized by symptoms of high gonad maturity index, increased egg diameter, filament growth on the eggs and the discovery of young flying fish larvae.

4. Conclusion

Flying fish in the Makassar Strait begin to spawn between March and May, with spawning peaks between June-July through August, and spawning ending in September or October. Analysis of egg diameter and size class distribution as well as gonad histology detected three groups of eggs: young eggs, growing/maturing eggs, and mature eggs. Based on the modes of the egg diameter distribution, flying fish are expected to have a multiple partial spawning pattern, with individuals expected to spawn 3-4 times in one season. The first maturity of flying fish was calculated as Lm = 151.5 mm fork length, with relatively high productivity. Based on the spawning season peak, egg exploitation is concentrated on the peak spawning period between June and July every year. We strongly recommend controlling the number of boats as well as the number of FADs used by each fishing boat in the Strait of Makassar.

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