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Reproduction of *Glossogobius flavipinnis* and *Glossogobius intermedius* as a Basis for the Domestication of Endemic Fish in Lake Towuti

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ABSTRACT

This study aimed to contribute to the sustainable management of endemic fish species from the *Glossogobius* genus in Lake Towuti through conservation initiatives focused on domestication, particularly by investigating the reproductive characteristics of *G. flavipinnis* and *G. intermedius*. The research was conducted between June and September 2024 in Lake Towuti, South Sulawesi, with fish sampling taking place at three sites: Tanjung Timbala, Tanjung Lengkobutanga, and Tanjung Bakara. At Station 1 (Tanjung Timbala), the gonado somatic index (GSI) for male *G. flavipinnis* ranged from 0.22 to 1.40%, while for females, it varied from 0.22 to 2.18%. For *G. intermedius*, males exhibited a GSI ranging from 0.71 to 1.05%, and females from 0.97 to 1.68%. At Station 2 (Tanjung Lengkobutanga), GSI values for male *G. flavipinnis* ranged from 0.01 to 1.34%, and for females, from 0.01 to 2.40%. In *G. intermedius*, male GSI values were between 0.93 and 1.16%, while females ranged from 0.99 to 1.31%. At Station 3 (Tanjung Bakara), the GSI for male *G. flavipinnis* varied between 0.01 and 1.76%, with females ranging from 0.01 to 2.40%. The fecundity of *G. flavipinnis* was recorded to be between 54 and 130 eggs, whereas *G. intermedius* produced between 75 and 138 eggs. The diameter of *G. flavipinnis* eggs across all stations in Lake Towuti ranged from 0.03 to 0.23mm, with the highest frequency for GML III found between 0.06 and 0.08mm, and for GML IV between 0.18 and 0.20mm. In contrast, the egg diameter for *G. intermedius* ranged from 0.03 to 1.22mm, with the most frequent size for GML III between 0.03 and 0.17mm, and for GML IV between 0.93 and 1.07mm.

INTRODUCTION

The distinctive features of Lake Towuti, recognized as an ancient lake, make it an ideal site for investigating evolutionary biology theories **(Tweedley *et al.*, 2013)**. Referred to as “Wallace’s dream pond,” the lake serves as a natural laboratory for exploring species origins, particularly due to its rich diversity of endemic fish species **(Herder *et al.*, 2012)**.

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The diversity of these endemic fish resources has economic significance, providing income and nutritional benefits to local communities **(Zulkifli, 2023)**. These species also play a crucial role in ecological processes within aquatic ecosystems, such as regulating food webs, contributing to nutrient cycling, and modifying biophysical habitats through ecological engineering **(Villéger *et al.*, 2017)**. The endemic fish fauna in the Malili Complex includes the genera *Oryzias, Nomorhamphus, Telmatherina, Mugilogobius*, and *Glossogobius*. Species from the *Glossogobius* genus found in this region include *Glossogobius flavipinnis, Glossogobius intermedius, Glossogobius mahalonensis*, and *Glossogobius matanensis* **(Kottelat, 2013; Hadiaty, 2018)**.

According to the IUCN Red List of Threatened Species, all four species of the *Glossogobius* genus in Lake Towuti are classified as threatened, with the following designations: *G. flavipinnis* (eT40707A90982306) **(Lumbantobing & Larson, 2019a)**, *G. mahalonensis* (eT90982416A90982420) **(Lumbantobing & Larson, 2019b)**, *G. matanensis* (eT9254A90982434) **(Lumbantobing & Larson, 2019c)**, and *G. intermedius* (eT9253A90982342) **(Lumbantobing & Larson, 2019d)**. Several factors contribute to the threats facing these endemic species, including overfishing **(Samuel *et al.*, 2009)**, pollution from land-based sources such as domestic waste, sawmill industry runoff, agriculture, nickel mining, and deforestation around the lake **(Nasution *et al.*, 2010**), as well as the introduction of invasive species **(Herder *et al.*, 2012; Syafei & Sudinno, 2018)**. These conditions have the potential to disrupt the aquatic ecosystem, particularly water quality, and increase exploitation pressure on endemic fish populations, leading to shifts in species composition and population structure **(Samuel *et al.*, 2009; Jompa & Arief, 2023)**. This could result in reduced genetic diversity within species **(Jayadi *et al.*, 2019)**, impaired reproductive processes, diminished natural recruitment, smaller fish sizes, and altered growth patterns at both individual and population levels **(Nursyahran *et al.*, 2022a; Tamsil *et al.*, 2024)**, as well as unstable population conditions **(Nursyahran *et al.*, 2022b; Jayadi *et al.*, 2024)**. The declining populations of the endemic fish *G. flavipinnis, G. intermedius, G. mahalonensis*, and *G. matanensis* are particularly vulnerable to extinction **(Lumbantobing & Larson, 2019b, c, d)**. Consequently, effective management strategies are required to ensure their conservation and sustainability, with an emphasis on domestication efforts **(Jayadi *et al.*, 2016; Nursyahran *et al.*, 2022, 2023)**. For successful domestication, a comprehensive understanding of reproductive biology is critical.

This study aimed to establish sustainable management strategies for the endemic *Glossogobius* species in Lake Towuti by advancing conservation efforts through domestication, with a particular focus on investigating the reproductive biology of *G. flavipinnis* and *G. intermedius.*

MATERIALS AND METHODS

Study site

This study was carried out over a six-month period, from June 2024 to September 2024, at Lake Towuti in South Sulawesi, Indonesia. Fish samples were obtained from three locations: Tanjung Timbala, Tanjung Lengkobutanga, and Tanjung Bakara (Fig. 1).

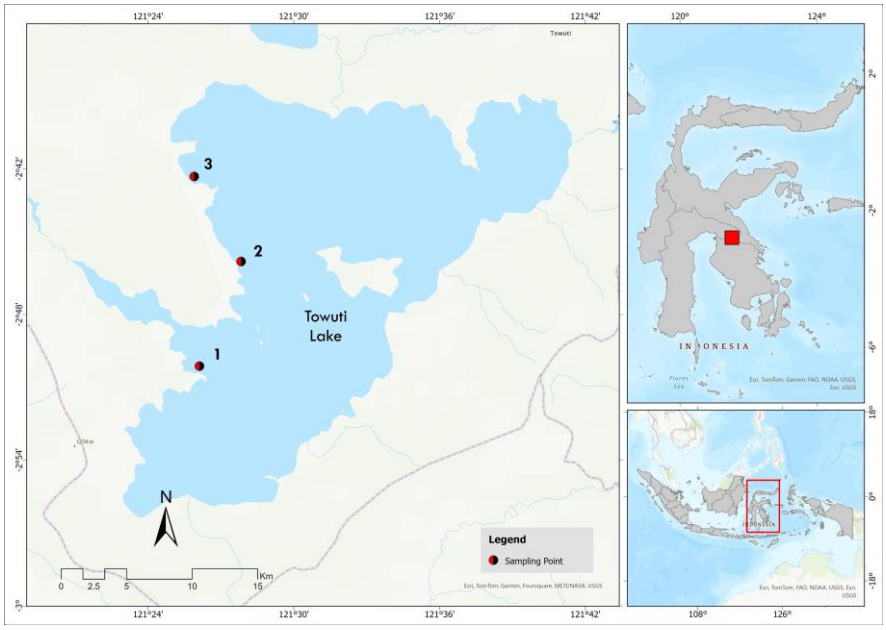

Fig. 1. Research station point map

Fish sampling

Fish samples were collected from three stations in Lake Towuti: Tanjung Timbala, Tanjung Tominanga, and Tanjung Bakara. The locations for capturing *Glossogobius flavipinnis* and *G. intermedius* were identified using GPS (*Global Positioning System*). Sampling for these species at each station was carried out using a net with a mesh size of ¾ inch, measuring 15 meters in length, 1.50 meters in height, and with a 3-meter bag. The net was deployed on the lakebed, with each end held by a fisherman, while another fisherman directed the fish into the net, which was then lifted to the surface. The entire catch was used as the sample.

Handling of fish samples

The *G. flavipinnis* and *G. intermedius* fish caught at the designated stations were separated by gender, then preserved in 10% formalin and labeled according to their capture locations.

Data analysis

***Gonado somatic index* (GSI)**

To calculate the gonado somatic index (GSI), the following formula was used **(Johnson, 1971)**:

$$GSI = \frac{GW}{BW} x\ 100\%$$

Information: GSI = *Gonado Somatic Index* (%); GW = Gonad weight (g); BW= Body weight (g).

Fecundity

Total fecundity was calculated using a direct counting method, where all the eggs present in the female gonads at GML III and GML IV were used as samples **(Omar, 2013)**.

Egg diameter

The outcomes of the measurements for each egg diameter were presented in a histogram for GML III and IV. The calculation for egg diameter is done as follows **(Omar, 2013)**.

$$ED = \sqrt{Hd \times ve}$$

Information: ED = actual egg diameter (mm); Hd = horizontal egg diameter (mm); ve= vertical egg diameter (mm).

RESULTS

Glossogobius flavipinnis

***Gonado somatic index* (GSI)**

Based on the results of GSI analysis, *G. flavipinnis* fish at station 1 (Tanjung Timbala) experienced peak spawning in July and August, for male fish the GSI value ranged between 0.22-1.40% (Fig.2a), and for female fish 0.22-2.18% (Fig. 2b). The gonado somatic index for male fish was found in August 2024, while for females, it was found in July 2024 (Fig. 2).

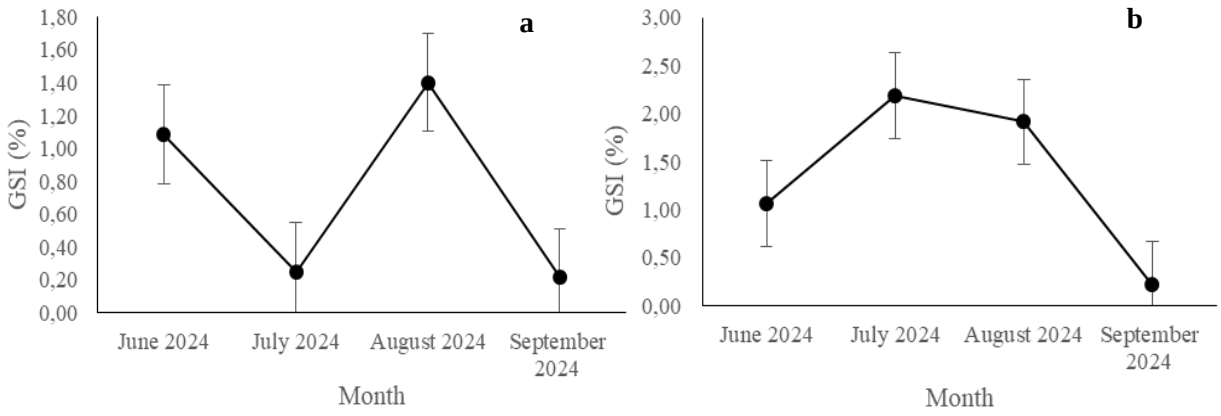

Fig. 2. The mean gonado somatic index (%) for **(a)** male and **(b)** female *Glossogobius flavipinnis* fish, categorized by sampling time at Station 1, Tanjung Timbala

The results of the GSI analysis of *Glossogobius flavipinnis* fish at station 2 (Tanjung Lengkobutanga) experienced a peak spawning in June and August 2024, for male fish the GMI value ranged between 0.01-1.34% (Fig. 3a), and for female fish 0.01-2.40% (Fig. 3b). The maximum gonad maturity index male fish were found in August 2024, and females were found in June 2024.

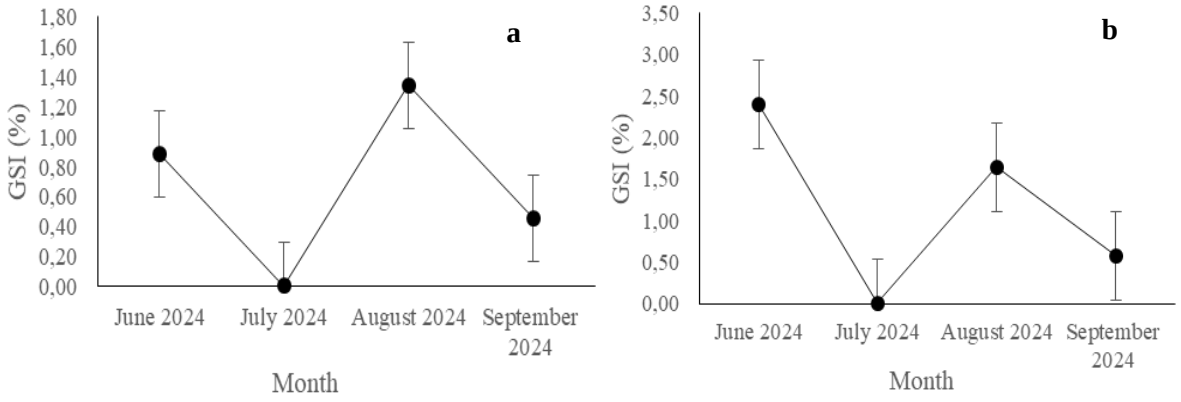

Fig. 3. The mean gonado somatic index (%) for **(a)** male and **(b)** female *Glossogobius flavipinnis* fish, categorized by sampling time at Station 2, Tanjung Lengkobutanga

The results of the GSI analysis of *G. flavipinnis* fish at station 3 (Tanjung Bakara) experienced peak spawning in June and August 2024, for male fish the GSI value ranged between 0.01-1.76% (Fig. 4a), and for female fish 0.01- 2.40% (Fig. 4b). The maximum gonado somatic index male fish were found in August 2024 and females were found in June 2024.

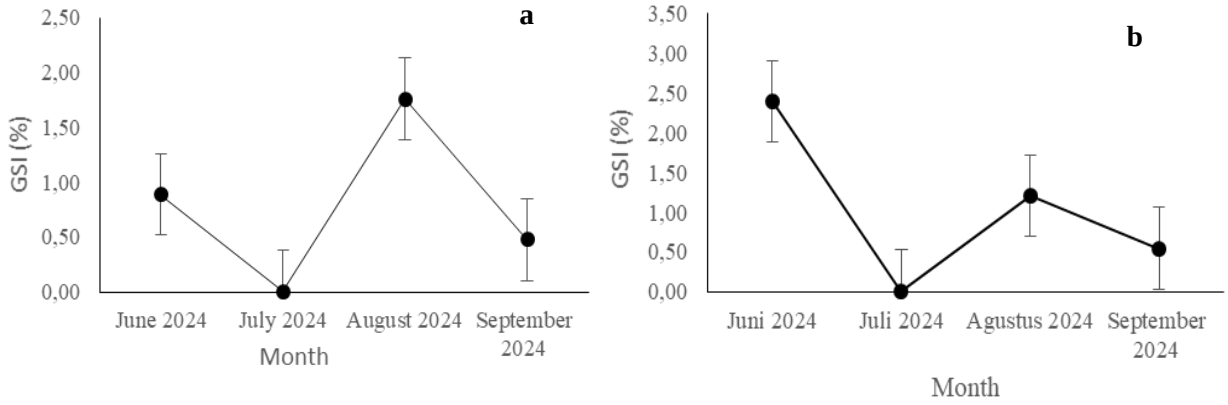

Fig. 4. The mean gonado somatic index (%) for **(a)** male and **(b)** female *Glossogobius flavipinnis* fish, categorized by sampling time at Station 3, Tanjung Bakara

Figs. (2-4) illustrate the varying fluctuations in GSI across different months and stations. Generally, the GSI for female fish is higher than that of male fish, with the exception of June 2024 at Station 1, Tanjung Timbala, and in June and August 2024 at Station 3 (Tanjung Tominanga).

Fecundity

Observations of *G. flavipinnis* fecundity revealed an egg count ranging from 54 to 130. The lowest number of eggs was recorded in a fish with a total length of 48.9mm and a body weight of 1.7 grams (GML III), while the highest egg count was found in a fish measuring 56.60mm in length and weighing 2.60 grams (GML IV). Figs. (4-6) present the analysis of the relationship between total length and body weight of *G. flavipinnis* in Lake Towuti. At Station 1, Tanjung Timbala, the relationship between fecundity and total length is

described by the equation $F = 0.7505L^{12973}$ ($R^2 = 0.2704$), while the relationship with body weight is given by $F= 100.26L^{0.4829}$ ($R^2 = 0.4034$) (Fig. 5). At Station 2, Tanjung Lengkobutangan, the correlation between fecundity and total length is represented by $F= 18.348L^{0.4639}$ ($R^2 = 0.0865$), while the relationship with body weight is given by $F= 109.64L^{0.064}$ ($R^2 = 0.0144$) (Fig. 6). At Station 3, Tanjung Bakara, the relationship between fecundity and total length is expressed by $F = 0.2429L^{15323}$ ($R^2 = 0.2769$), and with body weight by $F = 69.138L^{0.6846}$ ($R^2 = 0.3633$) (Fig. 7).

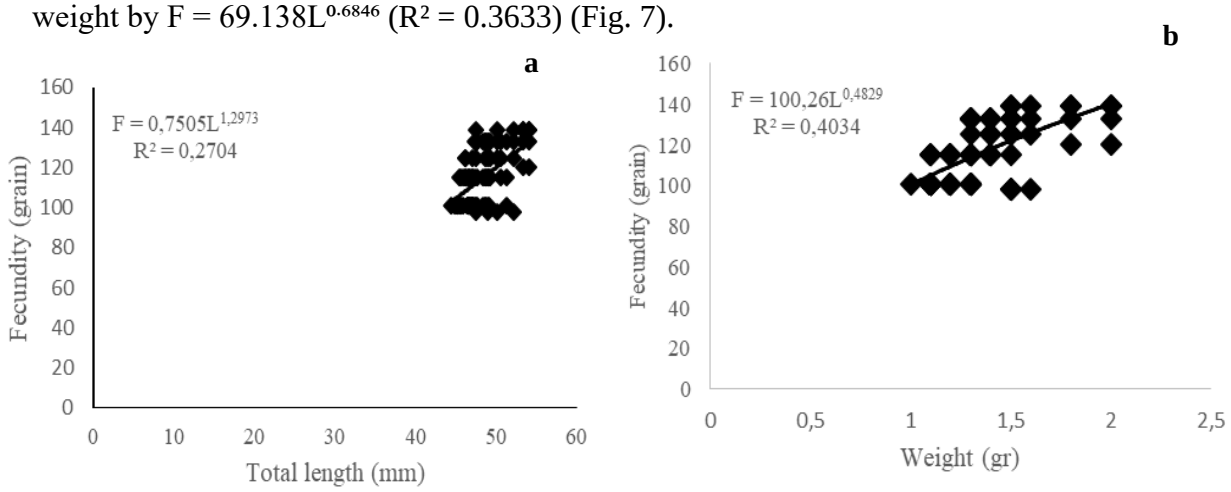

Fig. 5. Fecundity's correlation with **(a)** length and **(b)** total weight at Station 1, located at Tanjung Timbala

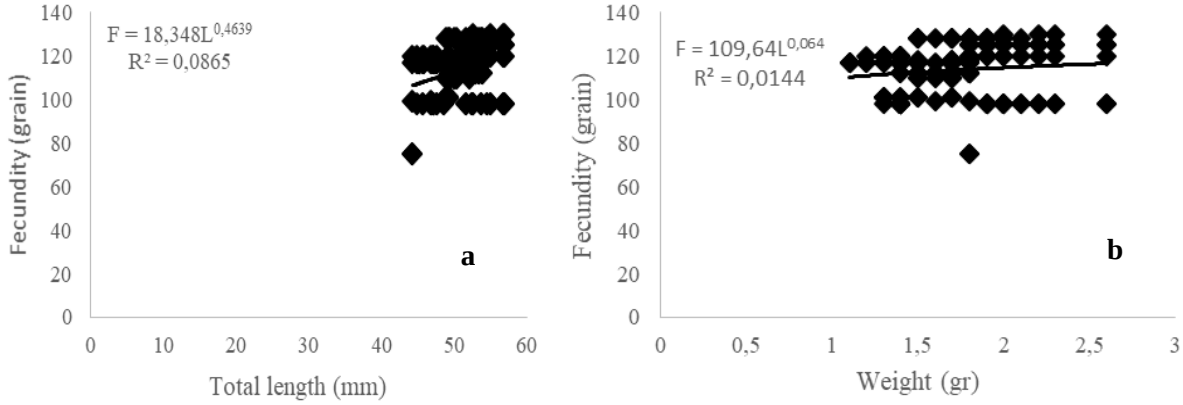

Fig. 6. Fecundity's correlation with **(a)** length and **(b)** total weight at Station 2, located at Tanjung Lengkobutanga

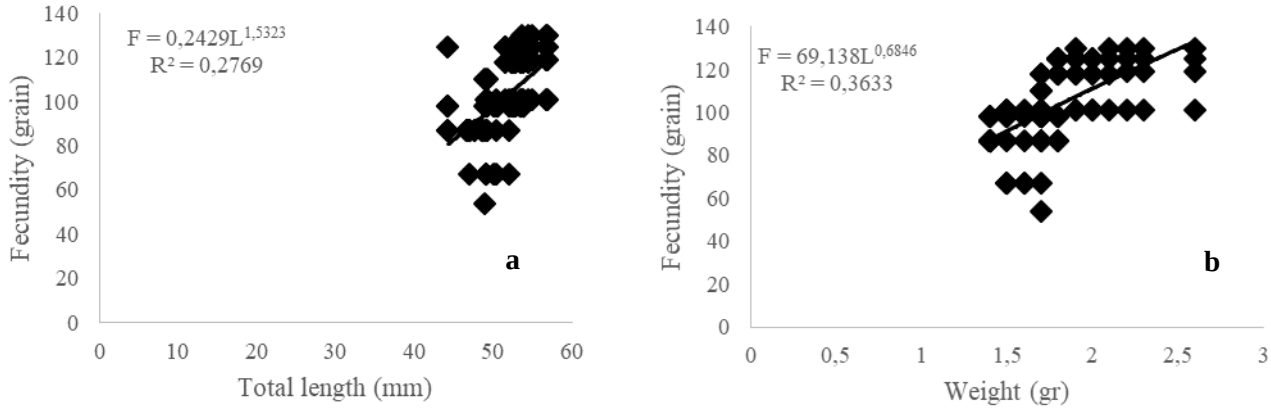

Fig. 7. Fecundity's correlation with **(a)** length and **(b)** total weight at Station 3, located at Tanjung Bakara

The correlation between fecundity and the total length of *G. flavipinnis* fish at Station 1 (Tanjung Timbala) is represented by an R^2 value of 0.2704, indicating that 27% of the variability in fecundity is attributed to total length. In contrast, the relationship between fecundity and total weight has an R^2 value of 0.4034, suggesting that 40% of fecundity is affected by total weight (Fig. 5). At Station 2 (Tanjung Lengkobutanga), the R^2 value for the relationship between fecundity and total length is 0.0865, which means that 8% of fecundity is influenced by total length, while the relationship with total weight has an R^2 value of 0.0144, indicating that only 1% of fecundity is influenced by weight (Fig. 6). At Station 3 (Tanjung Bakara), the relationship between fecundity and total length shows an R^2 value of 0.2769, meaning 27% of fecundity is influenced by total length, and the correlation with total weight has an R^2 value of 0.3633, indicating that 36% of fecundity is influenced by total weight. The graph demonstrates that as the weight of the fish increases, so does fecundity, highlighting a correlation between fish weight and fecundity.

Egg diameter

The diameter of *G. flavipinnis* eggs in Lake Towuti ranged from 0.03 to 0.23mm across all sampling stations, with the most frequent size for GML III being between 0.15 and 0.17mm, and for GML IV between 0.18 and 0.20mm. An analysis of egg diameter distribution across all stations for both GML III and GML IV, as depicted in Figs. (7-9) shows a single peak mode at Station 1 for GML III, with the most common size range being 0.06-0.08mm. In GML IV, the peak mode occurred within the 0.15-0.17mm size range across all stations. At Station 2, the peak mode for GML III was again in the 0.06-0.08mm range, while for GML IV, it was in the 0.18-0.20mm range. At Station 3, the peak mode for GML III was observed in the 0.03-0.05mm range, whereas for GML IV, it was in the 0.18-0.20mm range.

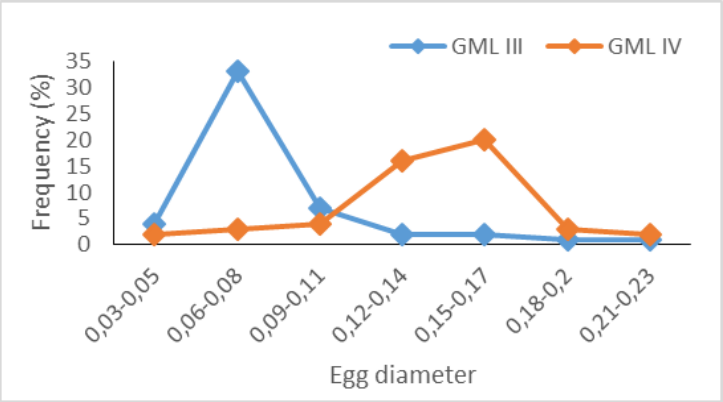

Fig. 8. Diameter of *Glossogobius flavipinnis* fish eggs at gonad maturity levels III and IV at station 1 Tanjung Timbala

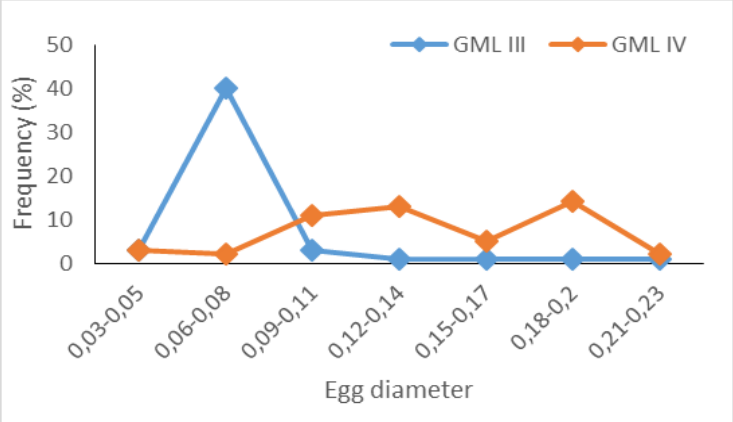

Fig. 9. Diameter of *Glossogobius flavipinnis* fish eggs at gonad maturity levels III and IV at station 2 Tanjung Lengkobutanga

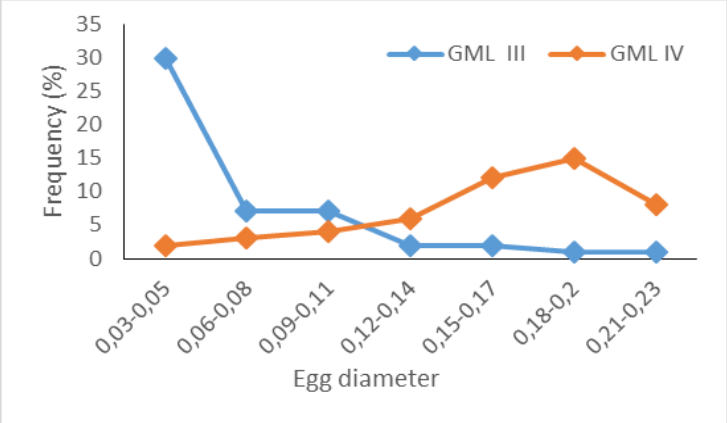

Fig. 10. Diameter of *Glossogobius flavipinnis* fish eggs at gonad maturity levels III and IV at station 3 Tanjung Bakara

Glossogobius intermedius

Gonado somatic index (GSI)

According to the results of the GSI analysis, *G. intermedius* at Station 1 (Tanjung Timbala) exhibited peak spawning in July and September 2024. The gonado somatic index (GSI) values for male fish ranged from 0.71 to 1.05% (Fig. 11a), while for female fish, the values ranged from 0.97 to 1.678% (Fig. 11b). The maximum GSI for males was recorded in September 2024, whereas the peak for females occurred in July 2024 (Fig. 11a, b).

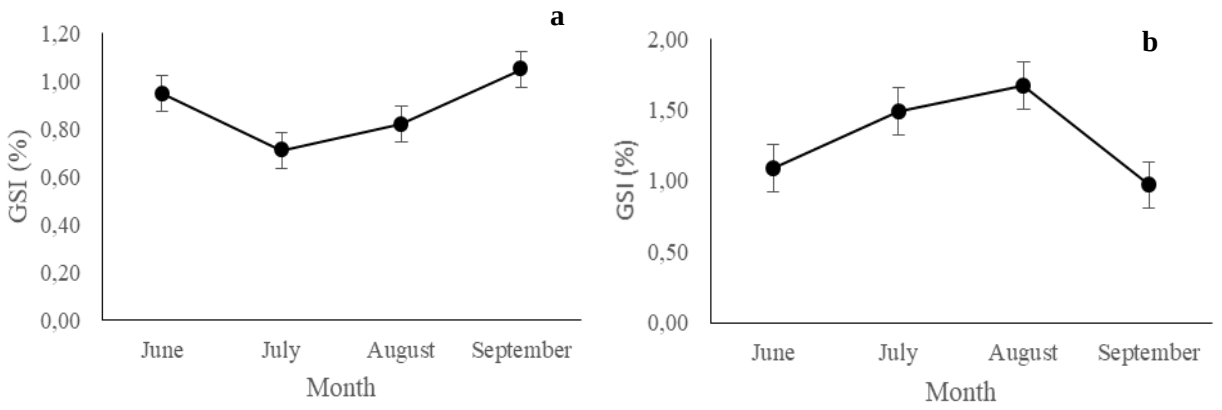

Fig. 11. The gonado somatic index (%) averages for male and female *Glossogobius intermedius* fish, as assessed during sampling at Station 1, Tanjung Timbala

The results of the GSI analysis of *G. intermedius* fish at station 2 (Tanjung Lengkobutanga) experienced peak spawning in June and September 2024, for male fish the GSI value ranged between 0.93-1.16% (Fig. 12a), and for female fish 0.99-1.31% (Fig. 12b). Maximum gonado somatic index male fish were found in June 2024 and females were found in September 2024.

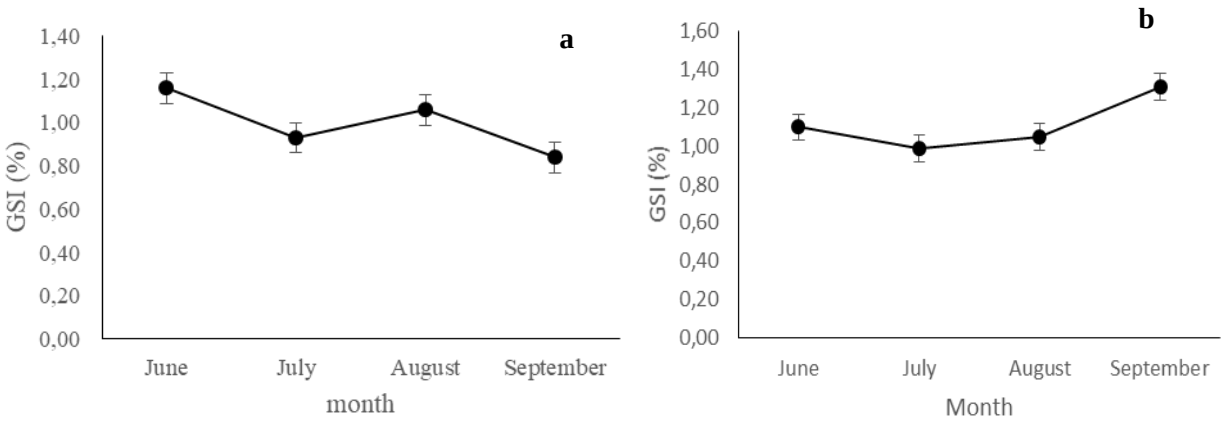

Fig. 12. The gonado somatic index (%) averages for male and female *Glossogobius intermedius* fish, as assessed during sampling at Station 2, Tanjung Lengkobutanga

The results of the GSI analysis of G. *intermedius* fish at station 3 (Tanjung Bakara) experienced peak spawning in August 2024, in male fish the GSI value ranged between 0.89-1.29% (Fig. 13a), and for female fish 1.05-1.58% (Fig. 13b). The maximum gonado somatic index male fish were found in August 2024 and females were found in August 2024.

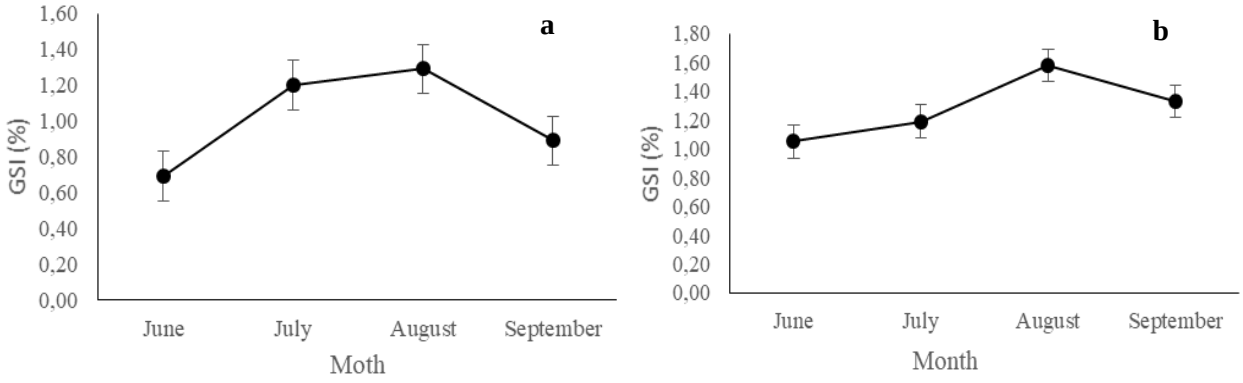

Fig. 13. The gonado somatic index (%) averages for male and female *Glossogobius intermedius* fish, as assessed during sampling at Station 3, Tanjung Bakara

Fecundity

Observations of the fecundity of *G. intermedius* fish revealed a range of 75 to 138 eggs. The minimum number of eggs was found in a fish measuring 26.3mm in total length and weighing 0.5 grams (GML III), while the maximum count was observed in a fish with a total length of 61.5mm and a body weight of 2.6 grams (GML IV).

Based on the analysis of the relationship between total length and body weight of *G. intermedius* fish in Lake Towuti, as illustrated in Figs. (14-16), the relationship between fecundity, total length, and body weight at Station 1 (Tanjung Timbala) is described by the equations F = 45.889L^0.241 (R^2 = 0.346) and F = 115.09L^0.0429 (R^2 = 0.836) (Fig. 14). At Station 2 (Tanjung Lengkobutanga), the fecundity relationship with total length and body weight is given by F = 53.637L^0.2044 (R^2 = 0.749) and F = 114.09L^0.1117 (R^2 = 0.812) (Figure 15). At Station 3 (Tanjung Bakara), a correlation between fecundity, total length, and body weight was found, represented by F= 38.833L^0.3025 (R^2 = 0.1714) and F = 119.85L^0.1283 (R^2 = 0.1148) (Fig. 16).

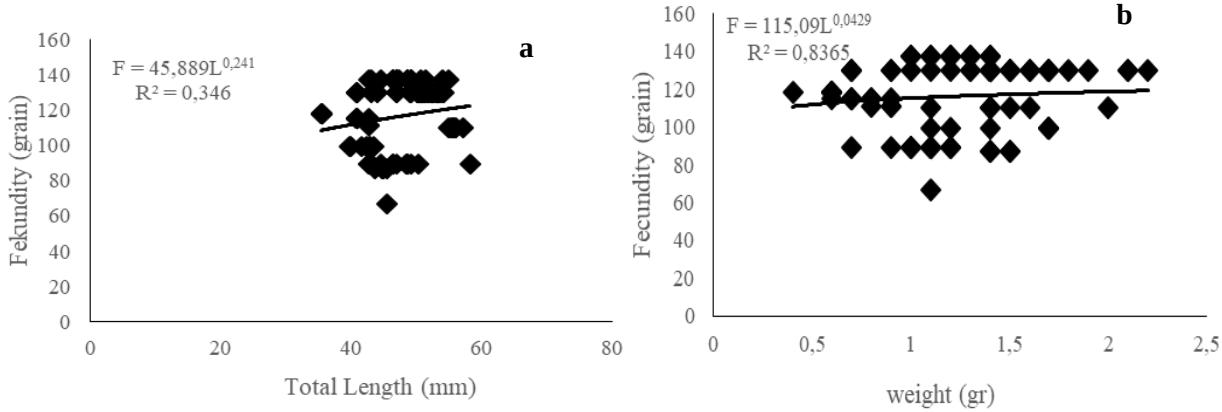

Fig. 14. Relationship between fecundity and **(a)** length as well as **(b)** total weight at Station 1 (Tanjung Timbala)

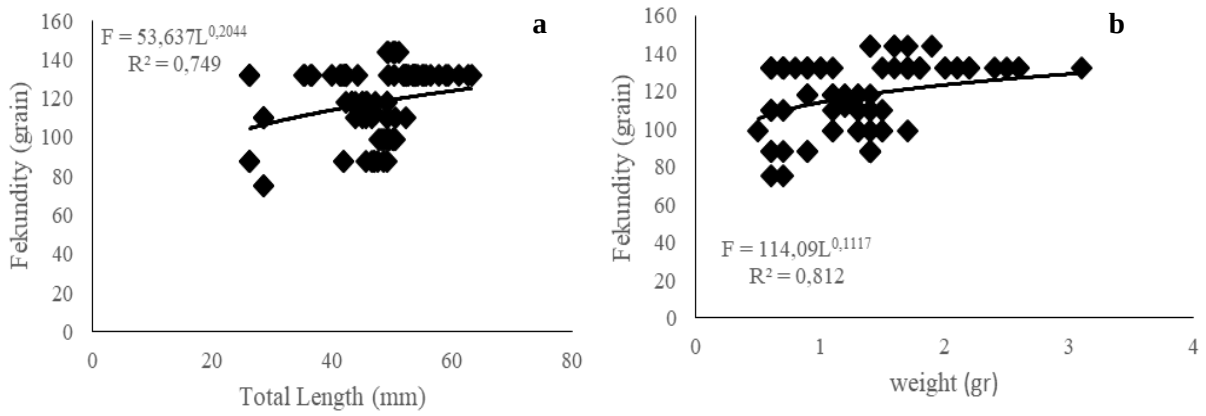

Fig. 15. Relationship between fecundity and **(a)** length as well as **(b)** total weight at Station 2 (Tanjung Lengkobutanga.)

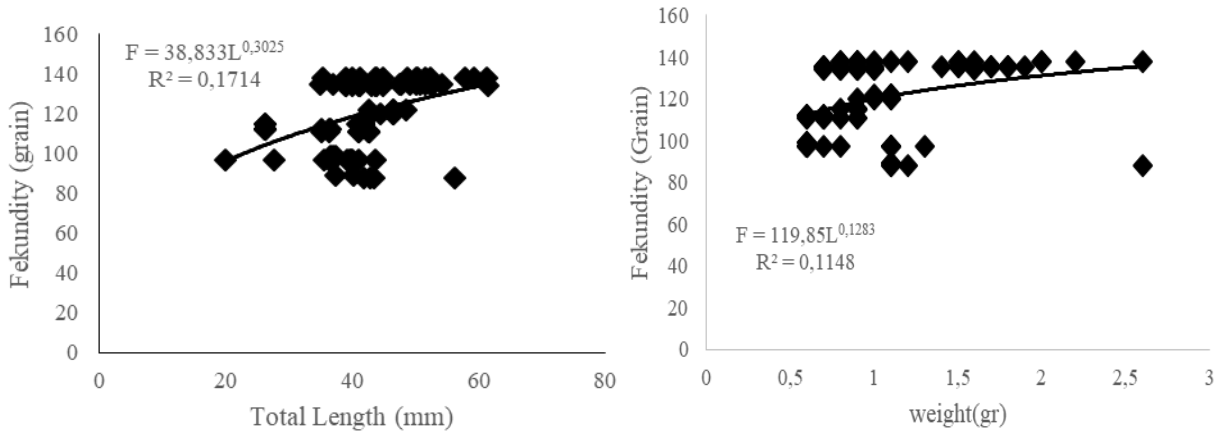

Fig. 16. Relationship between fecundity and **(a)** length as well as **(b)** total weight at Station 3 (Tanjung Bakara)

Egg diameter

The diameter of *G. intermedius* fish eggs collected from Lake Towuti across all stations ranged from 0.03 to 1.22mm. The highest frequency for GML III was observed in the size range of 0.03 to 0.17mm, while for GML IV, it was found in the range of 0.93 to 1.07mm.

Figs. (17-19) illustrate the analysis of egg diameter distribution at all stations for both GML III and GML IV. A single peak mode was identified for all stations at GML III, where the peak mode for egg diameter fell within the range of 0.03 to 0.17mm. In contrast, for GML IV, the peak mode was observed in the size range of 0.93 to 1.07mm at all stations.

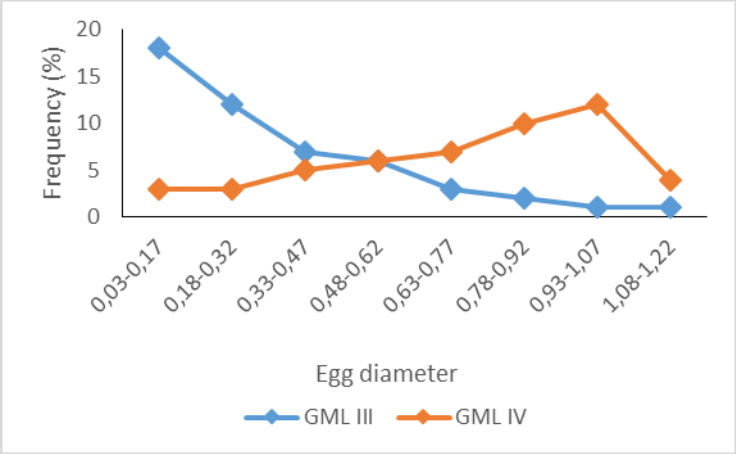

Fig. 17. Diameter of *Glossogobius intermedius* fish eggs at gonad maturity levels III and IV at station 1 Tanjung Timbala

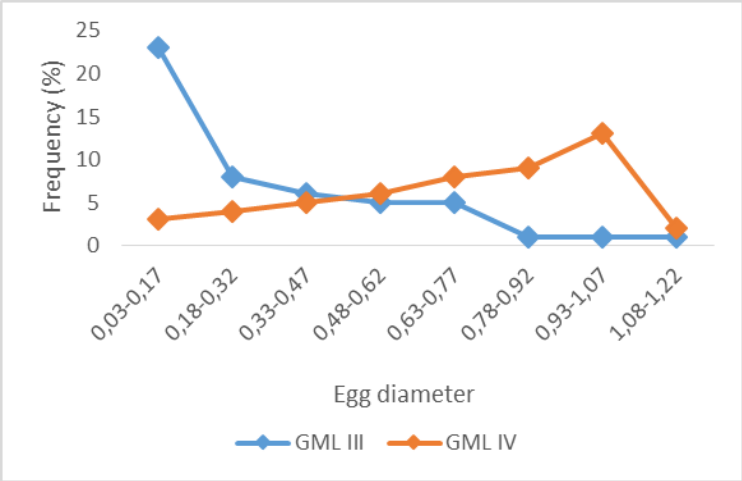

Fig. 18. Diameter of *Glossogobius intermedius* fish eggs at gonad maturity levels III and IV at station 2 Tanjung Lengkobutanga

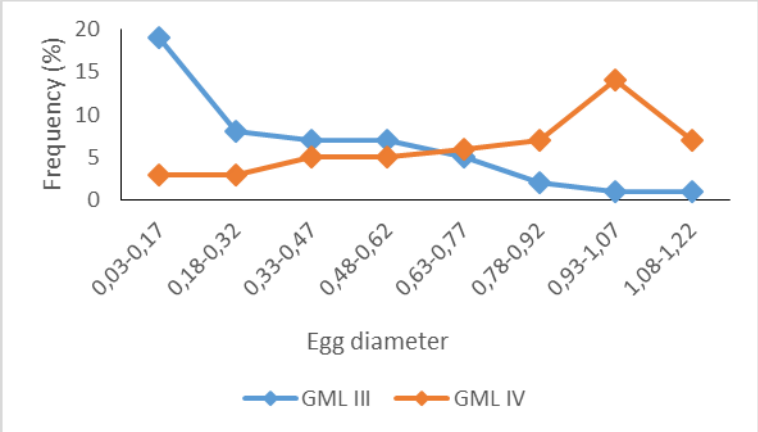

Fig. 19. Diameter of *Glossogobius intermedius* fish eggs at gonad maturity levels III and IV at station 3 Tanjung Bakara

DISCUSSION

Gonado somatic index

Quantitative changes in the gonads act as indicators of the gonado somatic index (GSI). By monitoring fluctuations in the GSI over time, researchers can ascertain the size at which fish begins to spawn. The GSI values for female *G. flavipinnis* and *G. intermedius* were consistently higher than those for male fish of the same species across all sampling sites (Tanjung Timbala, Tanjung Lengkobutanga, and Tanjung Bakara).

These findings corroborate with those of **Effendie**'s **(2002)** assertion that male fish typically exhibit lower GSI values than females. In Lake Towuti, male endemic *Telmatherina bonti* have been shown to have lower GSI values compared to females **(Nasution *et al.*, 2010; Omar *et al.*, 2012)**. Research by **Jayadi *et al.* (2016)** indicates that female *Telmatherina ladigesi* have higher GSI values than males. Similarly, in Lake Limboto, female *G. giuris* fish demonstrate greater GML values than their male counterparts **(Juliana *et al.*, 2018)**. Furthermore, the GML values reported in this study align with those of **Eragradini (2020)**, who found that female Matano medaka fish have higher GML values than males.

Fecundity

Fecundity is a vital component of fish reproductive strategies, alongside factors such as sex ratio, age at first gonadal maturity, spawning period and type, and oocyte development **(Gomiero *et al.*, 2008)**. Understanding fish fecundity is critical for evaluating stock potential, life cycles, aquaculture practices, and species management **(Hussain *et al.*, 2007)**. Fecundity is defined as the total number of eggs released by female fish during spawning **(Nursyahran *et al.*, 2021)**. In Lake Towuti, the fecundity of *G. flavipinnis* ranges from 54 to 130 eggs, while *G. intermedius* exhibits fecundity between 75 and 138 eggs. In comparison, the fecundity of *G.giuris* varies from 88,495 to 264,104 eggs and ranges from 39,173 to 557,892 eggs **(Bin *et al.*, 2007; Roy *et al.*, 2014)**. The lowest fecundity recorded was in July, with 25,446 eggs from a fish measuring 31.08cm in total length and weighing 5.92g **(Mamangkey & Nasution, 2012)**.

The relationship between fecundity and total length is weakly correlated, whereas fecundity demonstrates a strong correlation with body weight in both *G. flavipinnis* and *G. intermedius* in Lake Towuti. This suggests that an increase in body weight is associated with higher fecundity. For instance, the fecundity of rainbow *Telmatherina celebensis* in Lake Towuti shows a strong association with weight but a weak correlation with length **(Nasution, 2011)**. Variations in body size among fish can influence the number of eggs present in their ovaries **(Effendie, 2002; Nasution *et al.*, 2006; Ali, 2019)**. Factors such as body size, age, environmental conditions, and egg diameter can impact fecundity within a species. Generally, fecundity increases with body size, which is influenced by food availability and other environmental factors, including temperature and seasonal variations. For example, the fecundity of *T. bonti* in Lake Towuti ranges from 442 to 1,569 eggs **(Nursyahran *et al.*, 2021)**, while *Oryzias profundicola* in Lake Towuti have been reported to produce 70,467 eggs, including a single instance of 24,292 eggs **(Tamsil *et al.*, 2024)**.

Egg diameter

The duration of spawning can be assessed by examining the frequency of egg diameters, which aids in identifying the spawning patterns of fish, categorized as either total spawning or partial spawning. When ovaries contain mature eggs of uniform size, this indicates a short spawning period, while a prolonged and continuous spawning period is characterized by the presence of eggs of varying sizes within the ovary **(Katiandagho & Marasabessy, 2017)**. In the case of *O. profundicola*, the peak egg diameter at GML III was observed in the 0.03-0.15mm range, whereas at GML IV, it ranged from 0.93 to 1.07mm across all sampling stations. The findings indicate that egg diameter distributions at all stations exhibit a single peak for both GML III and GML IV; however, the size distribution differs among the stations. Specifically, at GML III, the frequency of eggs diminishes as their diameter increases, while at GML IV, the frequency rises with larger egg diameters. This distribution of egg diameters at various stages of gonadal maturity reflects the spawning patterns of the fish **(Effendie, 1979)**. Changes in average egg diameter, along with increases in egg size, total length, total weight, and ovary weight, are influenced by environmental factors and the degree of gonadal maturity in the fish **(Mostafa *et al.*, 2008)**.

For *G. flavipinnis*, the peak egg diameter at GML III was identified in the 0.15-0.17mm range, while at GML IV, it ranged from 0.18 to 0.2mm. For *G. intermedius*, the peak egg diameter at GML III was found to be between 0.03 and 0.17mm, and at GML IV, it ranged from 0.93 to 1.07mm across all stations. This study reveals that the egg diameter distribution at all stations shows a single peak for both GML III and GML IV, with variations observed between stations. At GML III, the frequency of eggs declines as the diameter increases, while at GML IV, the frequency rises with larger egg diameters. The distribution of egg diameters at different stages of gonadal maturity reflects the spawning pattern of the fish **(Effendie, 1979)**. Variations in egg size within the ovary indicate the duration of the spawning period, suggesting that the diameter of eggs at each gonadal maturity stage corresponds to the spawning pattern **(Nursyahran *et al.*, 2022)**. In Lake Towuti, the diameter of *O. profundicola* eggs across all stations ranged from 0.03 to 1.19mm, with the highest frequency occurring at gonadal maturity level III, specifically between 0.03 and 1.08mm **(Tamsil *et al.*, 2024)**. The egg diameter of *G. giuris* ranged from 49 to 372µm, with GML I displaying a range of 49-103µm, GML II ranging from 49-210µm, GML III from 49-291 µm, and GML IV from 49-372µm **(Sulistiono, 2012)**.

CONCLUSION

The gonado somatic index (GSI) for male *G. flavipinnis* in Lake Towuti varied between 0.01 and 1.76%, while for females, it ranged from 0.01 to 3.24%. In male *G. intermedius*, the gonado somatic Index (GSI) fluctuated from 0.01 to 1.76, with females exhibiting a range from 0.01 to 1.31. The fecundity of *G. flavipinnis* was observed to be between 54 and 130 eggs, whereas *G. intermedius* demonstrated a fecundity range of 75 to 138 eggs. The diameter of *G. flavipinnis* eggs in Lake Towuti was recorded to span from 0.03 to 0.23mm, with the highest frequency for GML III found between 0.06 and 0.08mm, and for GML IV between 0.18 and 0.20mm. Similarly, the diameter of *G. intermedius* eggs at all

stations in Lake Towuti ranged from 0.03 to 1.22mm, with the highest frequency recorded for GML III between 0.03 and 0.17mm, while for GML IV, it ranged from 0.93 to 1.07mm.

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