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“Reproductive biology of silver barb, *Barbonymus gonionotus* (Bleeker, 1850),
in Lake Tempe, Indonesia”

Andi Tamsil, Hasnidar Hasnidar

NAMA JURNAL : **Iranian Journal of Fisheries Sciences, 2024, 23(6): 877-892.**

No.	Kegiatan	Waktu	Keterangan
A.	Article profile (article review procedur)		By OJS
B.	Article profile (article review procedur)		By email
	1. Editorial system registration	27 November 2023	By email
	2. “Submitted Manuscript to the journal Iranian Journal of Fisheries Sciences”	27 November 2023	By mail
	3. Under review	16 Desember 2023	By email
	4. Proses review	12 Januari – 28 Agustus 2024	By email
C	Publish	11 September 2024	By email

Article Information

Article Code	A-10-3030-1
Submission Status	Published
Title of the article (en)	Research Article: Reproductive biology of silver barb, <i>Barbonymus gonionotus</i> (Bleeker, 1850), in Lake Tempe, Indonesia
Title of the article (fa)	
Short English Title (Running head) (en)	
Short Persian Title (fa)	
Subject	aquaculture
Submit date	2023/11/27
Poster	hasnidaryasin () [Code : 3030]

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Registrant information (date):	2018/07/7 - General

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**Reproductive biology of silver barb, *Barbonymus gonionotus* (Bleeker, 1850)
in Tempe Lake, South Sulawesi, Indonesia**

Abstract

Information on the reproductive biology of silver barb is needed for conservation and domestication purposes. This study aims to analyze the reproductive biology of silver barb in Tempe Lake. Aspects of reproductive biology analyzed were length-weight structure, sex ratio, length-weight relationship, condition factor, size at first gonad maturity (L_{50}), gonad of maturity and fecundity. This study used primary data, silver barb were caught using gill nets every two weeks from January to July 2023. The total length of fish was measured using an ichthyometer with an accuracy of 0.1 cm, and weight using a digital scale with an accuracy of 0.01 g, gonads were preserved in 4% formalin solution, fecundity was calculated based on the gravimetric method. Length structure of males 8.9 - 22.9 cm and females 8.9 - 28.5 cm; weight of males 21.2 - 183.2 g and females 21.2 - 312.8 g. The overall sex ratio of males and females was 1:1, while the sex ratio during spawning was 1:3 (polygamous). Length-weight relationships between males and females were $W = 0.0234L^{2.7349}$ and $W = 0.0172L^{2.8766}$. The condition factor for males and females was the same at 1.02. The size of first maturing gonads for females was 18.3 cm and 19.9 cm for males. Partial spawning, fecundity ranged from 253-13,398 egg.

Keywords: Reproductive biology, silver barb, Tempe Lake, length, weight

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Introduction

Silver barb, *Barbonymus gonionotus* (Bleeker, 1850) is an economically important freshwater fish in several countries such as Indonesia, Malaysia, Thailand, Myanmar, Bangladesh, India, and China. The taste is good and the price is relatively cheap so it becomes the main consumption of the community, especially some places in the territory of Indonesia. Silver barb production still mainly depends on fishing, so fishing pressure continues to increase.

Tempe Lake has a diversity of fish species consisting of native fish, introduced fish and migratory marine fish. According to Dina *et al.* (2019), the native fishes of Tempe Lake are *Monopterus albus*, *Anabas testudineus*, *Glossogobius aureus*, *Channa striata*. Introduced fish species are *Barbonymus gonionotus*, *Clarias batrachus*, *Trichopodus pectoralis*, *Pangasianodon hypophthalmus*, *Osteochilus vittatus*, *Oreochromis niloticus*, *Helostoma temminckii*, *Cyprinus carpio* (Yanuarita *et al.*, 2020). Migratory marine fish species are *Megalops cyprinoides*, *Stenogobius gymnopomus*, *Anguilla marmorata* and *Caranx sexfasciatus*. Introductions are carried out to increase the production of fishery products to meet increasing demand, optimize water productivity, increase production in a sustainable and increase biodiversity (Yanuarita *et al.*, 2020; FAO, 2022).

Tempe Lake is presently experiencing various environmental problems, including eutrophication (Aisyah and Nomosatryo, 2016). Eutrophication occurs allegedly due to the load of nutrients derived from the activities of humans, plantations and farms that are often found on the shores of the lake. Nitrate and phosphate nutrients are in the range of 0.1063-0.2620 mg/l and 0.0245-0.0655 mg/l respectively in the water (Samuel *et al.*, 2012). These conditions trigger the growth of aquatic weeds such as *Ipomoea aquatic* and *Eichhornia crassipes*. *E. crassipes* is the most dominant of these plants and its population is estimated to have covered the lake surface by about 30 - 40%. According to (Yani *et al.*, 2019), Lake Tempe has experienced moderate to severe pollution in several parameters including turbidity, total suspended solid, biological oxygen demand, nitrate, and phosphate.

Another problem is overfishing and the use of fishing gear that is not environmentally sustainable (Nasution, 2012), and a serious problem is the presence of invasive fish, i.e. *Pterygoplichthys* spp (Hasnidar *et al.*, 2021). The high population of *Pterygoplichthys* spp has caused fishermen's catches of target fish to decline (Hasrianti *et al.*, 2020). The presence of *Pterygoplichthys* spp impacts the lake ecosystem through competition for habitat, diet, and can even be a predator of native and endemic fish, as well as an agent of various diseases. It can change the species composition and structure of fish communities, dominating and excluding native and endemic fish (Syafei and Sudinno, 2018).

Silver barb, *B. gonionotus* was introduced to Lake Tempe in 1937 (Dina *et al.*, 2019; Yanuarita *et al.*, 2020). Although an introduced fish, Tawes (Silver barb) successfully adapted well to the lake environment. The condition of Tempe Lake, which is rich with dominant aquatic plants, enables to survive well. Silver barb are herbivorous, with phytoplankton (Chlorophyceae) as their main food (Ain *et al.*, 2021); aquatic plants (80%), detritus (12%), phytoplankton (8.5%) (Aida, 2018; Pratiwi *et al.*, 2021). Silver barb are considered useful in controlling excessive vegetation in lake waters. Although silver barb successfully lives in Tempe Lake, the declining environmental conditions of Tempe Lake certainly have an impact on the production of these fish.

Silver barb production has fluctuated in recent years, with capture mortality higher than natural mortality due to overfishing (Sukarman, 2022). This condition is thought to be due to the presence of *Pterygoplichthys* spp as an invasive fish (Hasnidar *et al.*, 2021). There are two species that are still caught in large numbers, e.i. silver barb and bloso (*Glossogobius* sp), therefore both fish species are under very high fishing pressure. Conservation and domestication efforts will be carried out, but these efforts require the latest information including aspects of silver barb reproductive biology for the future management. The study aims to analyze the reproductive biology of silver barb including size distribution, sex ratio, length and weight relationship, condition factor, gonad maturity, size of first mature gonad, and fecundity.

Materials and methods

The study was conducted from January to July 2023 in Tempe Lake, Wajo Regency, South Sulawesi Province, Indonesia (Fig. 1). Fish sampling was collected every week for six months, using a gill net response tool. Fish samples caught were cleaned, put in a cooler box and given ice cubes. Sample observations were carried out at the Biota and Environmental Engineering Laboratory, Faculty of Fisheries and Marine Science, Universitas Muslim Indonesia (UMI) Makassar.

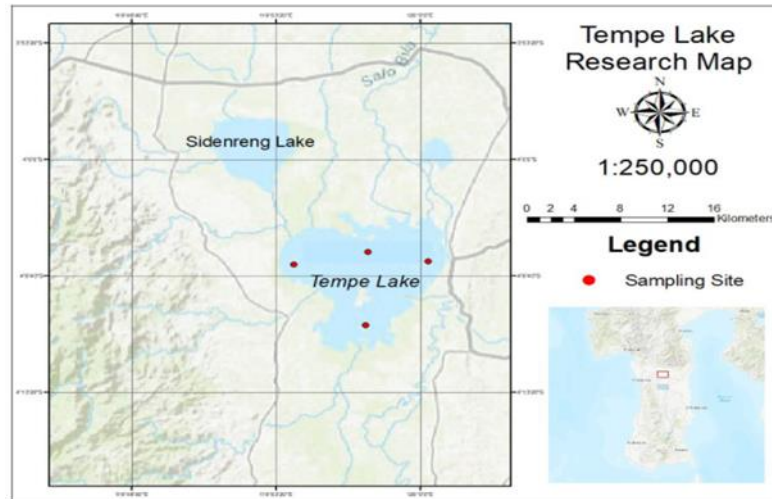


Fig 1. Silver barb fishing sampling points on the site in Tempe Lake, Wajo Regency, South Sulawesi, Indonesia.

The total length (Lt) of silver barb was measured using an ichthymeter (Vernier calipers, Mitutoyo) with an accuracy of 0.1 cm, body weight and gonads (g) were measured using digital scales (Digital elektrik scale, DIGI DS880) with an accuracy of 0.01g. The parameters analyzed were:

Length and weight structure

Length and weight size structures were determined as follows: determining the number of classes; determining the length class interval of 1 cm and weight of 1 g; inserting each fish sample in the predetermined class. The size structure was determined within the same class interval and then plotted on a graph.

Sex ratio

The sex of silver barb was determined morphologically and anatomically by dissecting the fish to see whether the gonads developed into testes or ovaries. Determination of male and female sex ratio is done by calculating the number of male fish and female fish caught using the formula (Oliveira *et al.*, 2012):

$$N = \frac{\text{number of male or female fish}}{\text{total number of fish observed}} \times 100$$

Next, sex ratio variability was tested using the Chi-square test (Oliveira *et al.*, 2012):

$$X^2 = \frac{\sum (oi - ei)^2}{ei}$$

Description: X^2 = Value for a random variable whose sampling distribution approximates the Chi-square distribution

oi = Observed frequencies of male and female fish

ei = Expected frequencies of male and female fish

Length-weight relationship

The relationship between length and weight was analyzed using the formula (Le Cren, 1951):

$$W = a L^b$$

Description W = Fish body weight (g), L = Total length of fish (cm), a = Coefficient of determination, b = exponent that indicates isometric or allometric.

To obtain the equation, the values of W and L were transformed into logarithms (base 10) as follows:

$$W = \log a + b \log L$$

The b values obtained were used to estimate the two parameters (length and weight) analyzed, with hypotheses: 1) $b = 3$ indicates an isometric growth pattern, 2) $b \neq 3$ indicates an allometric growth pattern, a) $b > 3$: faster weight gain (positive allometric), b) $b < 3$: faster length gain (negative allometric).

Condition factor

Because the growth pattern of tawes in this study is negative allometric ($b \neq 3$), the formulation (Le Cren, 1951) is:

$$Kn = \frac{W}{a L^b}$$

Description Kn = Condition factor, W = Fish body weight (g), L = Total length of fish (cm), a = a = Intercept, b = slope

Size at first gonadal maturity (L_{50})

The size of the first time the fish matures gonads is obtained by finding the value of L_{50} by plotting the cumulative percentage of gonadal mature fish with the size of the fish body length, so that a standard logistic curve will be obtained and the intersection point between the curve and 50% cumulative frequency is the length when 50% of the fish first matures gonads.

Gonad maturity

The stage of gonadal maturity was observed macroscopically, the observation procedure is when the silver barb was first dissected, and the visceral cavity was opened to observe the morphology of the gonads including: shape, color, size, gonad position in the abdominal cavity and egg diameter. Maturity stages were classified according to Brown-Peterson *et al.* (2011), and modified according to silver barb conditions, i.e. stage I (Immature); II (Developing); III (Maturing); IV (Mature) and V (Spent). Egg diameter was observed by taking samples of stage IV fish gonads then each fish gonad was taken in 3 parts, i.e. posterior, anterior, and middle gonads. Eggs were taken from each part of the gonad sample, with 30 eggs in each part. A total of 90 fish egg samples were measured in diameter using an ocular micrometer (0.01 mm) brand UYCP-12.

Fecundity

Fecundity can be known the procedure that the weight of the total gonads (WG), then take a subpart of the total gonad at each end of the bottom, middle and top then measure

its weighed (Ws). The weight of the gonad subpart was then preserved in a 4% formalin solution to facilitate the calculation of the number of eggs (n). Fecundity was observed in maturity stage IV, calculated using the gravimetric method (Hasan *et al.*, 2020):

$$F = \frac{\text{weight of the total gonad (WG)}}{\text{weight subpart gonad (Ws)}} \times \text{number of eggs of the subpart gonad (n)}$$

The relationship between fecundity and total length and body weight using the formulation Hasan *et al.* (2020) is:

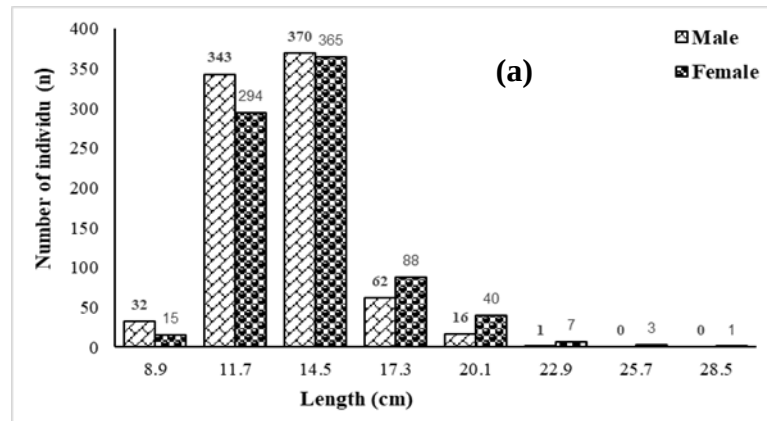
$$F = a L^b \quad \text{and} \quad F = a W + b$$

Description F = Fecundity (egg), L = Total length of fish (cm), W = Fish body weight (g), a = Intercept, b = slope

Results

Length and weight structure

The results of the length structure analysis of male tawes are 8.9 - 22.9 cm and females are 8.9 - 28.5 cm, the largest proportion caught at 14.5 cm both males and females. While the size structure of male weights is 21.2 - 183.2 g and female are 21.2 - 312.8 g; and the largest proportion of males and females caught is the same weight size of 21.2 g (Fig. 2 a and b).



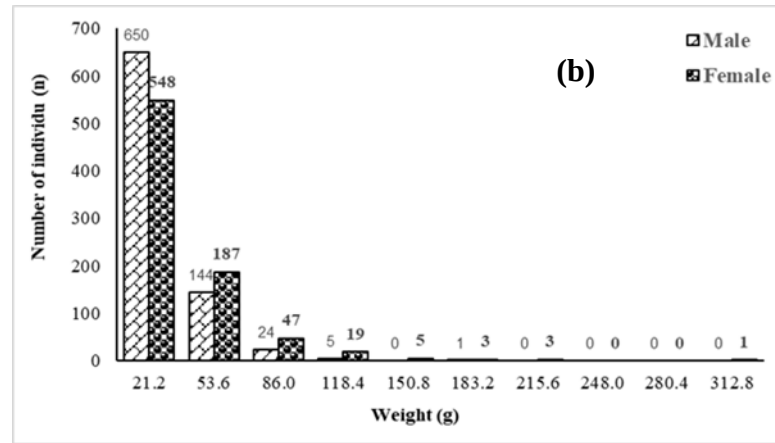


Fig 2. Length (a) and weight (b) structure of silver barb

Sex Ratio

The total sex ratio of males and females was 824 (50%) and 813 (50%), indicating a male-to-female sex ratio of 1:1 (Fig. 3a). The sex ratio of gonadally mature males and females was 27 (25%) and 83 (75%), indicating that 1 male was partnered with 3 females for spawning activities (Fig. 3b).

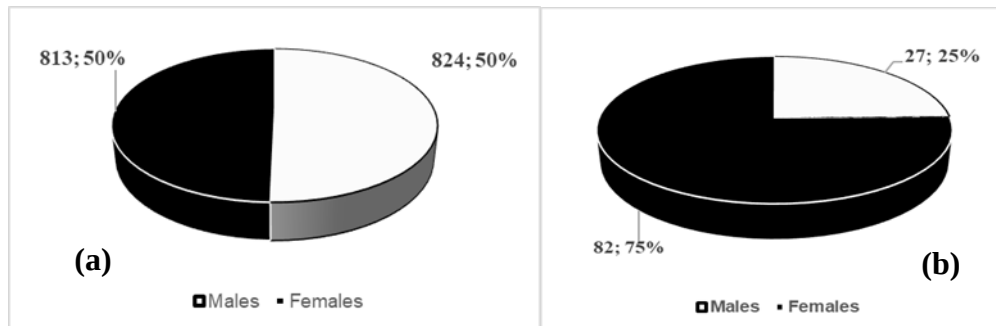


Fig 3. Male-to-female sex ratio of silver barb total fish (a), and gonad of maturity (b)

Length-weight relationship

The results of the analysis of the length-weight relationship of male was $W = 0.0234 L^{2.7349}$ and female $W = 0.0172 L^{2.8766}$ and combined (male and female) $W = 0.0183 L^{2.8415}$ (Fig. 4 a, b, c). The t-test results showed that the b value of male, female and combined (male and female) silver barb is different from 3 ($b \neq 3$) so it can be

concluded that the growth pattern is allometric. Because the value of $b < 3$, it is negatively allometric.

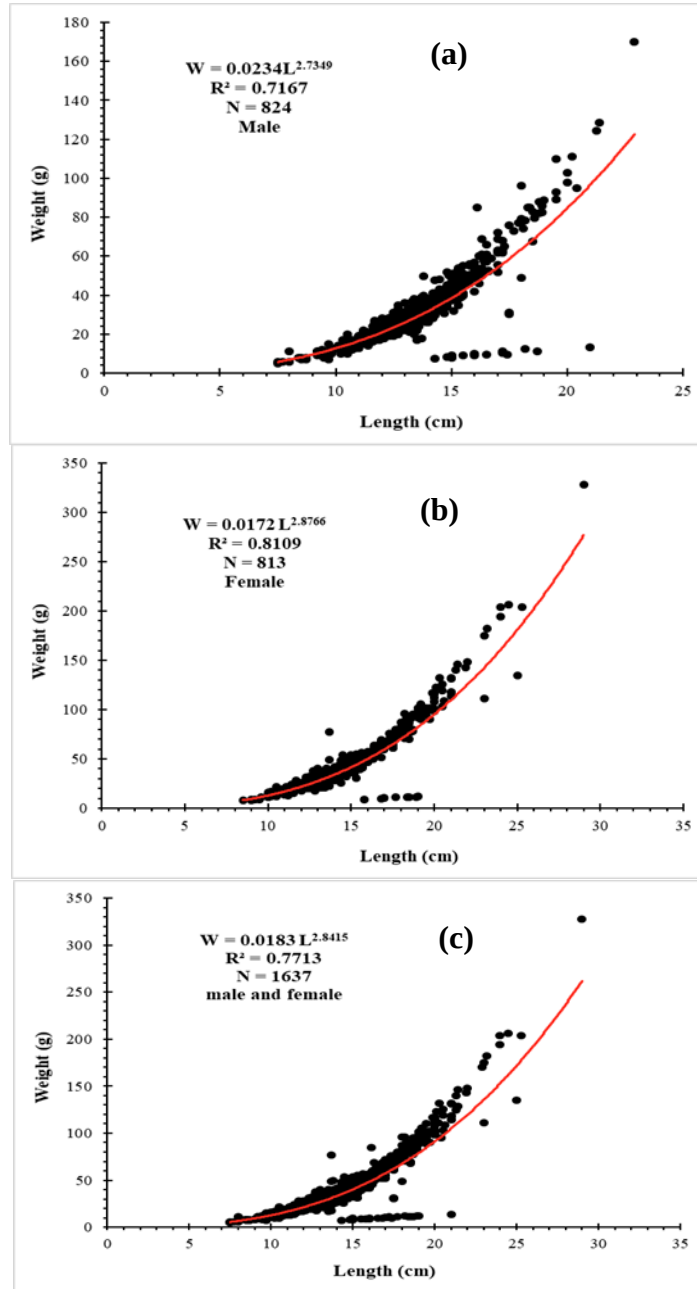


Fig 4. Length-weight relationship of male (a), female (b) and combined (male and female) (c)

Condition Factor

Condition factors for male and female tawes were 1.0243 ± 0.0061 and 1.0181 ± 0.0054 , respectively.

Size at first gonad maturity (L_{50})

The results of the analysis of the size of the first mature gonads (L_{50}) of male fish are different from females. Female fish are faster to mature gonads, i.e. $L_{50} = 18.3$ cm than males $L_{50} = 19.9$ cm.

Gonad maturity

Determination of gonad maturity criteria is macroscopic by observing the morphological shape, size, color and position of the gonads in the abdominal cavity. The development of gonads (ovary and testes) of silver barb is classified into five levels according to the instructions Hasnidar *et al.* (2022) and the condition of silver barb gonads. The gonadal stages are stage I (Immature), II (Developing), III (Maturing), IV (Mature) and V (spent) (Table 1).

Table 1. Gonad maturity of female and male silver barb

Maternity stage	Note	Female	Male
I	Immature	Ovary is small, extending anteriorly to posteriorly in the dorsal abdominal cavity, filled with white and viscous fluid, eggs not yet visible, estimated to fill <15% of the abdominal cavity.	Testes are small and thin, extending from anterior to posterior of the abdominal cavity, filled with clear white fluid
II	Developing I	Ovary is larger than immature ovaries, white in color, egg grains are visible, estimated to fill 20-30% of the abdominal cavity. The average egg diameter is 0.20 – 0.425 mm	Testes are enlarged, larger than stage I (immature) testes; filled with white liquid
III	Maturing	Ovary is enlarged, filled with greenish-white soft granules, egg granules are still difficult to separate. Estimated to fill almost 30%-60% of the abdominal cavity. The average egg diameter is 0.450 - 0.750 mm	Testes are getting bigger and larger than stage II, the surface of the testes appears to be ridged. Contains thick white liquid
IV	Mature	Ovary is getting bigger, filling about 60-80% of the abdominal cavity. ovaries contain yellowish-green egg grains, the average egg diameter is 0.800 - 1.25 mm	Testes are getting bigger larger than stage III, the surface of the testes is grooved. Contains thick milky white liquid

V	Spent	Ovary reduced, creased, ovary wall thick and lobed, yellowish-green color containing unspawned residual eggs	Testes reduced in size, wrinkled edges
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Fecundity

The number of gonads mature female (stage IV) was 82 fish with a length range of 7.5-17.5 cm and weights of 7-82 g, gonad weights of 1.25-10.11 g. The fecundity of silver barb obtained in this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The fecundity of silver barb obtained from the results of this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The relationship between fecundity and total length is $F = 4.6297 L^{2.958}$ ($R^2 = 0.3526$), fecundity with body weight is a linear relationship that is $F = 444.66W + 1489.3$ ($R^2 = 0.5145$) (Fig. 5 a, b).

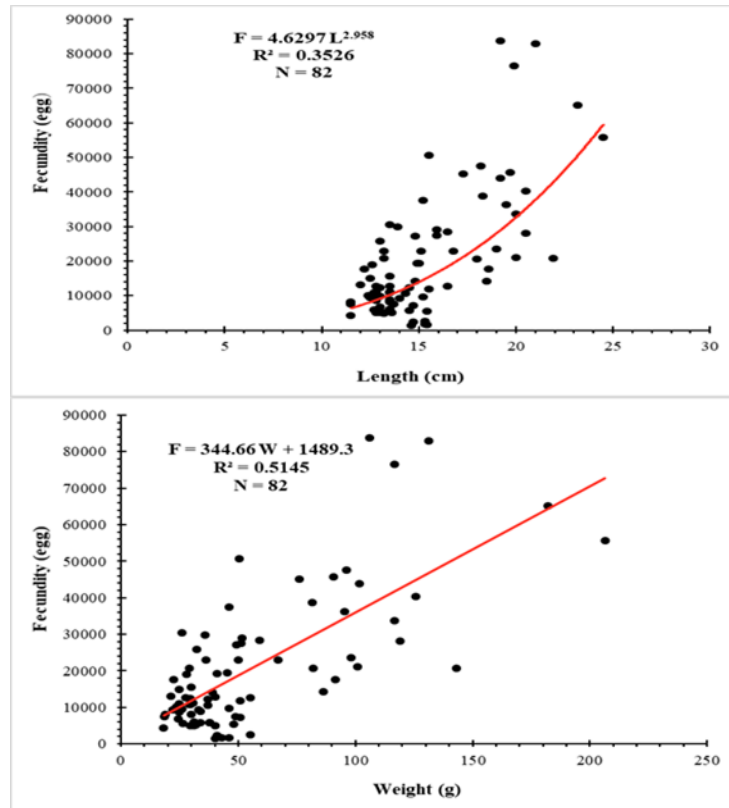


Fig 5. Fecundity-length (a), fecundity-weight (b) relationships of silver barb

Discussion

The length size structure of silver barb is 8.9 - 28.5 cm, with the highest proportion caught size 14.5 cm. Furthermore, the weight size structure is 21.2 - 312.8 g; and the largest proportion caught is 21.2 g in weight size. The data shows that the length and weight of silver barb captured are dominant in small size. The distribution of length and weight of silver barb in several locations is presented in Table 2.

The length and weight structure of silver barb from several waters show low values compared to silver barb caught in Dan Tchang Reservoir, Thailand, which is 45 cm and 2,100 g (Chheng *et al.*, 2004). These data indicate that silver barb fishing, in Lake Tempe in particular, is very intensive and even overexploited (Sukarman, 2022). Silver barb do not have the opportunity to grow large due to intensive fishing. In addition, the less optimal environmental conditions of the lake, the presence of predators or competitors, and the limited ability of swimming larvae to escape from environmental factors are thought to affect the survival and growth. According to (Arevalo *et al.*, 2023), 99% mortality of a large number of fish species occurs in the early phase of fish life. Such high mortality is thought to have influenced variations in silver barb population size.

The total sex ratio of male and female is 1:1, indicating a balanced number of male and female fish. Silver barb with a male and female ratio of 1:1 (Maknuu, 2016), 1:1.27 (Jasmine and Begum, 2016), 1:2 (Ardelia *et al.*, 2023), 4:1 (Efizon *et al.*, 2021). Sex ratios can differ between the same fish species, because sex determination is not only determined by genetic factors but also by the environment (Capel, 2017), a sex ratio of 1:1 is an ideal description because both male and female fish have the same opportunity to maintain their species. Although silver barb experience high exploitation pressure, the sex ratio data shows that silver barb still have a high ability to maintain their population.

Furthermore, the sex ratio of gonads mature males and females is 27 fish (25%) and 83 fish (75%) or 1:3, meaning that 1 male is paired with 3 females for spawning

activities (polygamy). The sex ratio in spawning is related to the interaction and synchronization between male and female fish (Mylonas *et al.*, 2010) as well as the efficient use of the number of male or female fish in spawning. Each fish species has a different optimal male and female sex ratio for spawning, such as climbing perch, *Anabas testudineus* is 1:2 (Hasnidar *et al.*, 2022); sailfin molly, *Poecilia latipinna* is 1:10 (Tamsil and Hasnidar, 2019); silver barb, *Barbonymus* sp. is 6:1 (Efizon *et al.*, 2021).

The results of the analysis of the length-weight relationship of male silver barb obtained relationship model $W = 0.0234 L^{2.7349}$, female $W = 0.0172 L^{2.8766}$, combined (male and female) $W = 0.0183 L^{2.8415}$ (Figure 5). The t test results obtained the value of b silver barb male, female and combined different from 3 ($b \neq 3$) so it can be concluded that the growth pattern is allometric. Because the value of $b < 3$, it is called negative allometric. Some research results on the length-weight relationship of silver barb in several aquatic locations as shown in Table 3.

Differences in tawes growth patterns are due to differences in aquatic conditions. An important factor affecting the growth of fish in the tropics is the availability of food (Froese, 2006). Therefore, the same fish species in different locations will have different growth patterns due to this factor. In addition to food, other factors are the stage of gonad development, water physico-chemistry, fish health conditions, season, time and sampling techniques (Sheridan, 2011; Mehanna and Farouk, 2021). The number of fish caught in this study was 1623 fish, of which only 109 fish or 6.7% were mature gonads (stage IV), which is thought to be the cause of the negative allometric growth pattern.

Condition Factor (CF) is a value that reflects the influence of environmental factors on the physiological condition (Faradonbeh *et al.*, 2015). Good environmental conditions including the availability of food will support good growth so that the weight of the fish is higher and the $CF \geq 1$, on the other hand, environmental conditions are not suitable and limited food availability causes small weight gain and $CF < 1$ (Dirican & Cilek, 2012). The CF value of the results of this study is 1.024 - 1.018; this

value indicates the condition of the fish body is thin (compressed), the same as the growth pattern, which is negative allometric, that is length growth is faster than weight. The condition factor of silver barb from several studies is 0.84 - 1.4 (Buwono *et al.*, 2019), 1.05 – 317 (Sidik *et al.*, 2020), 1.01 – 1.02 (Dwirastina and Marson, 2021), 0.82 – 1.10 (Syaiful *et al.*, 2019), 0.76 – 2.27 (Laila, 2018), 1.145-1.328 (Maknuu, 2016). The varying CF are due to differences in aquatic environment, density, food availability, and physiological conditions such as fish reproductive cycles. The higher the CF value indicates the compatibility of the fish with its environment.

The results of the analysis of the level of maturity of the gonads macroscopically show that in each level of maturity there are differences in size, color, and volume of gonads in the abdominal cavity of the ovary and testes. In the ovary, the higher the level of maturity, the diameter of oocytes tends to increase, but there are variations in the diameter of oocytes at the same maturity stage (Table 1). Similarly, histological observations show that there are different sizes of oocyte diameter in the (Efizon *et al.*, 2021). These data indicate that tawes are gradual spawners, that is, they release their eggs not all at once during spawning. Gradual spawners have a long spawning season. The spawning season of silver barb in Tempe Lake is thought to be throughout the year, it can be seen in every fish sampling from January to June that mature (stage IV) is found every month of observation, with the highest mature in January. In contrast to silver barb in Padma River Bangladesh, the spawning season is April - July and the peak spawning is in June (Jasmine and Begum, 2016).

Length at first maturity (L_{50}) is the value at which 50% of individuals in a group have reproduced at least once (Barzotto and Mateus, 2017). The length at first maturity of male = 19.9 cm, and female = 18.3 cm. The L_{50} value of the results of this study is greater than the L_{50} of silver barb from Nagan river, Aceh Province, Indonesia, e.g. male = 7.3 cm and female = 8.5 cm (Efizon *et al.*, 2021). The length of the first maturing gonads of fish can differ due to competition and predation, fishing pressure and environmental conditions (de Souza *et al.*, 2019). Fish will perform the first maturation with a shorter length to reduce the risk of death before reproduction if

environmental conditions are unfavorable (Barzotto and Mateus, 2017). Based on the L_{50} value of male and female in relation to the length of the dominant silver barb caught in this study, $\pm 90\%$ of the fish caught have never reproduced.

Silver barb identified as maturity stage IV in this study were 82 fish, having a length range of 12.2 - 21.28 cm (average ± 15.0 cm) and body weight of 21.0 - 124.4 g (average ± 41 g), producing fecundity with a range of 1,443 - 83,822 eggs (average = 20,239 eggs). Fecundity data of silver barb in several aquatic are presented in Table 4.

The estimated coefficient of determination (R^2) of the relationship between fecundity-length (F-L) and fecundity-weight (F-W) showed that 35.3% of the variation in fecundity occurred due to variation in total fish length and 51.5% of the variation in fecundity due to the influence of variation in body weight. Similar observations on tawes from Nagan river, Aceh Province, Indonesia; the coefficient of determination (R^2) of the relationship between F-L and F-W was 51% and 24.2%, respectively (Efizon *et al.*, 2021). This means that tawes fecundity increases with increasing total length and body weight. Fish that have a larger size in addition to having a large visceral cavity to accommodate a larger number of oocytes also have sufficient energy for reproductive activities (Jonsson and Jonsson, 1999). Factors that affect fish fecundity are internal factors such as genetics, age, and size (Hunter *et al.*, 1992), while external factors are food availability and environmental conditions (Bryan *et al.*, 2007).

Conclusion

The length and weight structure of female fish were higher than male fish. The dominant lengths and weights caught were 14.5 cm and 21.2 g. Negative allometric growth pattern and condition factor 1.02; lean growth. The overall ratio of male and female was 1 : 1, while the spawning sex ratio was 1 : 3; that is, one male fish is paired with 3 females in spawning. The first size of gonad maturity of female fish was faster at 18.3 cm and 19.9 cm for males. Fecundity ranged from 253 to 13,398 eggs (mean

2,571 eggs). Variation in fecundity was more strongly influenced by variation in body weight than variation in total length of silver barb.

Acknowledgments

To the Rector of Universitas Muslim Indonesia (UMI) Makassar through the Institute for Research and Resource Development which has supported funds so that this research can be carried out.

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Reproductive biology of silver barb, *Barbonymus gonionotus* (Bleeker, 1850) in Tempe Lake, South Sulawesi, Indonesia

Hasnidar Hasnidar^{1*}; Andi Tamsil¹

Abstract

Information on the reproductive biology of silver barb is needed for conservation and domestication purposes. This study aims to analyze the reproductive biology of silver barb in Tempe Lake. Aspects of reproductive biology analyzed were length-weight structure, sex ratio, length-weight relationship, condition factor, size at first gonad maturity (L_{50}), gonad of maturity and fecundity. This study used primary data, silver barb were caught using gill nets every two weeks from January to July 2023. The total length of fish was measured using an ichthyometer with an accuracy of 0.1 cm, and weight using a digital scale with an accuracy of 0.01 g, gonads were preserved in 4% formalin solution, fecundity was calculated based on the gravimetric method. Length structure of males 8.9 - 22.9 cm and females 8.9 - 28.5 cm; weight of males 21.2 - 183.2 g and females 21.2 - 312.8 g. The overall sex ratio of males and females was 1:1, while the sex ratio during spawning was 1:3 (polygamous). Length-weight relationships between males and females were $W = 0.0234L^{2.7349}$ and $W = 0.0172L^{2.8766}$. The condition factor for males and females was the same at 1.02. The size of first maturing gonads for females was 18.3 cm and 19.9 cm for males. Partial spawning, fecundity ranged from 253-13,398 egg.

Keywords: Reproductive biology, silver barb, Tempe Lake, length, weight

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Introduction

Silver barb, *Barbonymus gonionotus* (Bleeker, 1850) is an economically important freshwater fish in several countries such as Indonesia, Malaysia, Thailand, Myanmar, Bangladesh, India, and China. The taste is good and the price is relatively cheap so it becomes the main consumption of the community, especially some places in the territory of Indonesia. Silver barb production still mainly depends on fishing, so fishing pressure continues to increase.

Tempe Lake has a diversity of fish species consisting of native fish, introduced fish and migratory marine fish. According to Dina *et al.* (2019), the native fishes of Tempe Lake are *Monopterus albus*, *Anabas testudineus*, *Glossogobius aureus*, *Channa striata*. Introduced fish species are *Barbonymus gonionotus*, *Clarias batrachus*, *Trichopodus pectoralis*, *Pangasianodon hypophthalmus*, *Osteochilus vittatus*, *Oreochromis niloticus*, *Helostoma temminckii*, *Cyprinus carpio* (Yanuarita *et al.*, 2020). Migratory marine fish species are *Megalops cyprinoides*, *Stenogobius gymnopomus*, *Anguilla marmorata* and *Caranx sexfasciatus*. Introductions are carried out to increase the production of fishery products to meet increasing demand, optimize water productivity, increase production in a sustainable and increase biodiversity (Yanuarita *et al.*, 2020; FAO, 2022).

Tempe Lake is presently experiencing various environmental problems, including eutrophication (Aisyah and Nomosatryo, 2016). Eutrophication occurs allegedly due to the load of nutrients derived from the activities of humans, plantations and farms that are often found on the shores of the lake. Nitrate and phosphate nutrients are in the range of 0.1063-0.2620 mg/l and 0.0245-0.0655 mg/l respectively in the water (Samuel *et al.*, 2012). These conditions trigger the growth of aquatic weeds such as *Ipomoea aquatic* and *Eichhornia crassipes*. *E. crassipes* is the most dominant of these plants and its population is estimated to have covered the lake surface by about 30 - 40%. According to (Yani *et al.*, 2019), Lake Tempe has experienced moderate to severe pollution in several parameters including turbidity, total suspended solid, biological oxygen demand, nitrate, and phosphate.

Another problem is overfishing and the use of fishing gear that is not environmentally sustainable (Nasution, 2012), and a serious problem is the presence of invasive fish, i.e. *Pterygoplichthys* spp (Hasnidar *et al.*, 2021). The high population of *Pterygoplichthys* spp has caused fishermen's catches of target fish to decline (Hasrianti *et al.*, 2020). The presence of *Pterygoplichthys* spp impacts the lake ecosystem through competition for habitat, diet, and can even be a predator of native and endemic fish, as well as an agent of various diseases. It can change the species composition and structure of fish communities, dominating and excluding native and endemic fish (Syafei and Sudinno, 2018).

Silver barb, *B. gonionotus* was introduced to Lake Tempe in 1937 (Dina *et al.*, 2019; Yanuarita *et al.*, 2020). Although an introduced fish, Tawes (Silver barb) successfully adapted well to the lake environment. The condition of Tempe Lake, which is rich with dominant aquatic plants, enables to survive well. Silver barb are herbivorous, with phytoplankton (Chlorophyceae) as their main food (Ain *et al.*, 2021); aquatic plants (80%), detritus (12%), phytoplankton (8.5%) (Aida, 2018; Pratiwi *et al.*, 2021). Silver barb are considered useful in controlling excessive vegetation in lake waters. Although silver barb successfully lives in Tempe Lake, the declining environmental conditions of Tempe Lake certainly have an impact on the production of these fish.

Silver barb production has fluctuated in recent years, with capture mortality higher than natural mortality due to overfishing (Sukarman, 2022). This condition is thought to be due to the presence of *Pterygoplichthys* spp as an invasive fish (Hasnidar *et al.*, 2021). There are two species that are still caught in large numbers, e.i. silver barb and bloso (*Glossogobius* sp), therefore both fish species are under very high fishing pressure. Conservation and domestication efforts will be carried out, but these efforts require the latest information including aspects of silver barb reproductive biology for the future management. The study aims to analyze the reproductive biology of silver barb including size distribution, sex ratio, length and weight relationship, condition factor, gonad maturity, size of first mature gonad, and fecundity.

Materials and methods

The study was conducted from January to July 2023 in Tempe Lake, Wajo Regency, South Sulawesi Province, Indonesia (Fig. 1). Fish sampling was collected every week for six months, using a gill net response tool. Fish samples caught were cleaned, put in a cooler box and given ice cubes. Sample observations were carried out at the Biota and Environmental Engineering Laboratory, Faculty of Fisheries and Marine Science, Universitas Muslim Indonesia (UMI) Makassar.

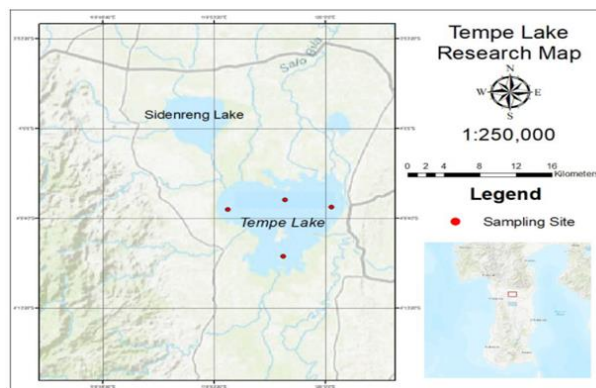


Fig 1. Silver barb fishing sampling points on the site in Tempe Lake, Wajo Regency, South Sulawesi, Indonesia.

The total length (Lt) of silver barb was measured using an ichthymeter (Vernier calipers, Mitutoyo) with an accuracy of 0.1 cm, body weight and gonads (g) were measured using digital scales (Digital elektrik scale, DIGI DS880) with an accuracy of 0.01g. The parameters analyzed were:

Length and weight structure

Length and weight size structures were determined as follows: determining the number of classes; determining the length class interval of 1 cm and weight of 1 g; inserting

each fish sample in the predetermined class. The size structure was determined within the same class interval and then plotted on a graph.

Sex ratio

The sex of silver barb was determined morphologically and anatomically by dissecting the fish to see whether the gonads developed into testes or ovaries. Determination of male and female sex ratio is done by calculating the number of male fish and female fish caught using the formula (Oliveira *et al.*, 2012):

$$N = \frac{\text{number of male or female fish}}{\text{total number of fish observed}} \times 100$$

Next, sex ratio variability was tested using the Chi-square test (Oliveira *et al.*, 2012):

$$X^2 = \frac{\sum (oi - ei)^2}{ei}$$

Description: X^2 = Value for a random variable whose sampling distribution approximates the Chi-square distribution

oi = Observed frequencies of male and female fish

ei = Expected frequencies of male and female fish

Length-weight relationship

The relationship between length and weight was analyzed using the formula (Le Cren, 1951):

$$W = a L^b$$

Description W = Fish body weight (g), L = Total length of fish (cm), a = Coefficient of determination, b = exponent that indicates isometric or allometric.

To obtain the equation, the values of W and L were transformed into logarithms (base 10) as follows:

$$W = \log a + b \log L$$

The b values obtained were used to estimate the two parameters (length and weight) analyzed, with hypotheses: 1) $b = 3$ indicates an isometric growth pattern, 2) $b \neq 3$ indicates an allometric growth pattern, a) $b > 3$: faster weight gain (positive allometric), b) $b < 3$: faster length gain (negative allometric).

Condition factor

Because the growth pattern of tawes in this study is negative allometric ($b \neq 3$), the formulation (Le Cren, 1951) is:

$$Kn = \frac{W}{a L^b}$$

Description Kn = Condition factor, W = Fish body weight (g), L = Total length of fish (cm), a = Intercept, b = slope

Size at first gonadal maturity (L_{50})

The size of the first time the fish matures gonads is obtained by finding the value of L_{50} by plotting the cumulative percentage of gonadal mature fish with the size of the fish body length, so that a standard logistic curve will be obtained and the intersection point between the curve and 50% cumulative frequency is the length when 50% of the fish first matures gonads.

Gonad maturity

The stage of gonadal maturity was observed macroscopically, the observation procedure is when the silver barb was first dissected, and the visceral cavity was opened to observe the morphology of the gonads including: shape, color, size, gonad position in the abdominal cavity and egg diameter. Maturity stages were classified according to Brown-Peterson *et al.* (2011), and modified according to silver barb conditions, i.e. stage I (Immature); II (Developing); III (Maturing); IV (Mature) and V (Spent). Egg diameter was observed by taking samples of stage IV fish gonads then each fish gonad was taken in 3 parts, i.e. posterior, anterior, and middle gonads. Eggs were taken from each part of the gonad sample, with 30 eggs in each part. A total of 90 fish egg samples were measured in diameter using an ocular micrometer (0.01 mm) brand UYCP-12.

Fecundity

Fecundity can be known the procedure that the weight of the total gonads (WG), then take a subpart of the total gonad at each end of the bottom, middle and top then measure its weighed (Ws). The weight of the gonad subpart was then preserved in a 4% formalin solution to facilitate the calculation of the number of eggs (n). Fecundity was observed in maturity stage IV, calculated using the gravimetric method (Hasan *et al.*, 2020):

$$F = \frac{\text{weight of the total gonad (WG)}}{\text{weight subpart gonad (Ws)}} \times \text{number of eggs of the subpart gonad (n)}$$

The relationship between fecundity and total length and body weight using the formulation Hasan *et al.* (2020) is:

$$F = a L^b \quad \text{and} \quad F = a W + b$$

Description F = Fecundity (egg), L = Total length of fish (cm), W = Fish body weight (g), a = Intercept, b = slope

Results*Length and weight structure*

The results of the length structure analysis of male tawes are 8.9 - 22.9 cm and females are 8.9 - 28.5 cm, the largest proportion caught at 14.5 cm both males and females. While the size structure of male weights is 21.2 - 183.2 g and female are 21.2 - 312.8 g; and the largest proportion of males and females caught is the same weight size of 21.2 g (Fig. 2 a and b).

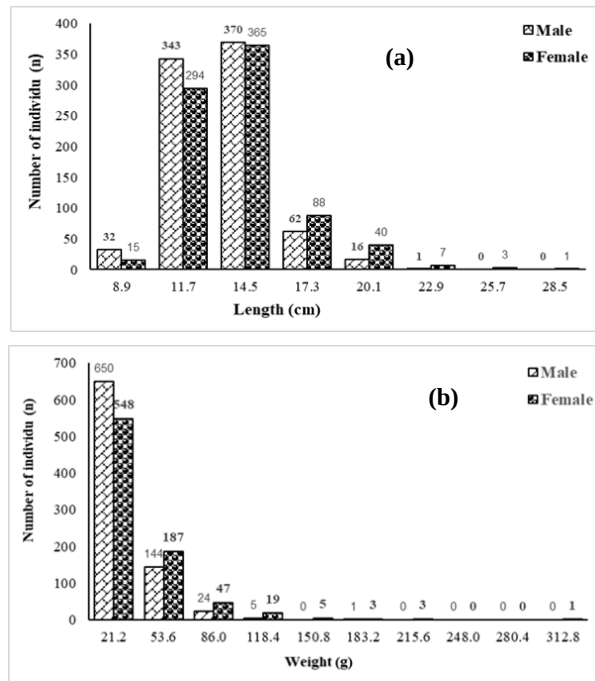


Fig 2. Length (a) and weight (b) structure of silver barb

Sex Ratio

The total sex ratio of males and females was 824 (50%) and 813 (50%), indicating a male-to-female sex ratio of 1:1 (Fig. 3a). The sex ratio of gonadally mature males and females was 27 (25%) and 83 (75%), indicating that 1 male was partnered with 3 females for spawning activities (Fig. 3b).

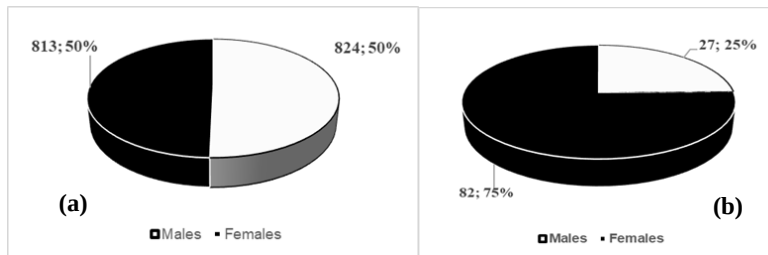


Fig 3. Male-to-female sex ratio of silver barb total fish (a), and gonad of maturity (b)

Length-weight relationship

The results of the analysis of the length-weight relationship of male was $W = 0.0234 L^{2.7349}$ and female $W = 0.0172 L^{2.8766}$ and combined (male and female) $W = 0.0183 L^{2.8415}$ (Fig. 4 a, b, c). The t-test results showed that the b value of male, female and combined (male and female) silver barb is different from 3 ($b \neq 3$) so it can be concluded that the growth pattern is allometric. Because the value of $b < 3$, it is negatively allometric.

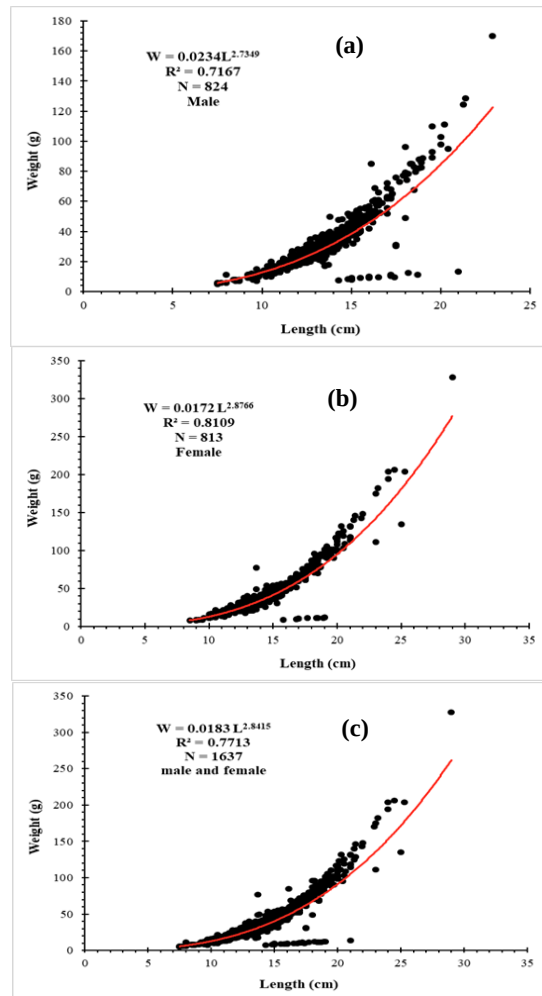


Fig 4. Length-weight relationship of male (a), female (b) and combined (male and female) (c)

Condition Factor

Condition factors for male and female tawes were 1.0243 ± 0.0061 and 1.0181 ± 0.0054 , respectively.

Size at first gonad maturity (L_{50})

The results of the analysis of the size of the first mature gonads (L_{50}) of male fish are different from females. Female fish are faster to mature gonads, i.e. $L_{50} = 18.3$ cm than males $L_{50} = 19.9$ cm.

Gonad maturity

Determination of gonad maturity criteria is macroscopic by observing the morphological shape, size, color and position of the gonads in the abdominal cavity. The development of gonads (ovary and testes) of silver barb is classified into five levels according to the instructions Hasnidar *et al.* (2022) and the condition of silver barb gonads. The gonadal stages are stage I (Immature), II (Developing), III (Maturing), IV (Mature) and V (spent) (Table 1).

Table 1. Gonad maturity of female and male silver barb

Maternity stage	Note	Female	Male
I	Immature	Ovary is small, extending anteriorly to posteriorly in the dorsal abdominal cavity, filled with white and viscous fluid, eggs not yet visible, estimated to fill <15% of the abdominal cavity.	Testes are small and thin, extending from anterior to posterior of the abdominal cavity, filled with clear white fluid
II	Developing I	Ovary is larger than immature ovaries, white in color, egg grains are visible, estimated to fill 20-30% of the abdominal cavity. The average egg diameter is 0.20 – 0.425 mm	Testes are enlarged, larger than stage I (immature) testes; filled with white liquid
III	Maturing	Ovary is enlarged, filled with greenish-white soft granules, egg granules are still difficult to separate. Estimated to fill almost 30%-60% of the abdominal cavity. The average egg diameter is 0.450 - 0.750 mm	Testes are getting bigger and larger than stage II, the surface of the testes appears to be ridged. Contains thick white liquid
IV	Mature	Ovary is getting bigger, filling about 60-80% of the abdominal cavity. ovaries contain yellowish-green egg grains, the average egg diameter is 0.800 - 1.25 mm	Testes are getting bigger larger than stage III, the surface of the testes is grooved. Contains thick milky white liquid
V	Spent	Ovary reduced, creased, ovary wall thick and lobed, yellowish-green color containing unspawned residual eggs	Testes reduced in size, wrinkled edges

Fecundity

The number of gonads mature female (stage IV) was 82 fish with a length range of 7.5-17.5 cm and weights of 7-82 g, gonad weights of 1.25-10.11 g. The fecundity of silver barb obtained in this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The fecundity of silver barb obtained from the results of this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The relationship between fecundity and total length is $F = 4.6297 L^{2.958}$ ($R^2 = 0.3526$), fecundity with body weight is a linear relationship that is $F = 444.66W + 1489.3$ ($R^2 = 0.5145$) (Fig. 5 a, b).

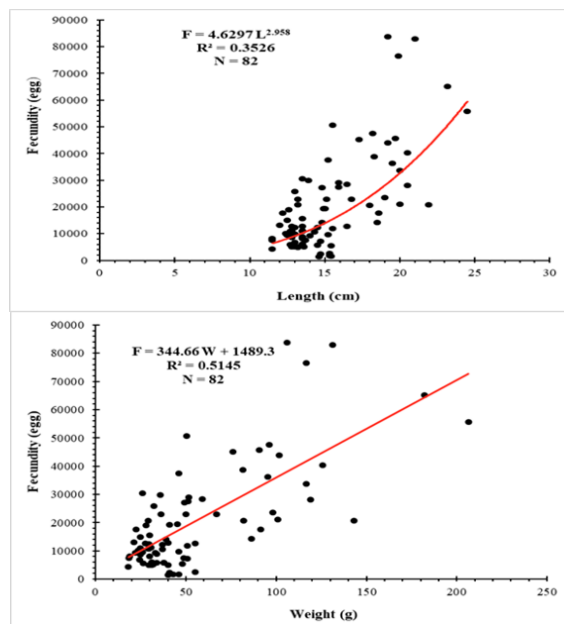


Fig 5. Fecundity-length (a), fecundity-weight (b) relationships of silver barb

Discussion

The length size structure of silver barb is 8.9 - 28.5 cm, with the highest proportion caught size 14.5 cm. Furthermore, the weight size structure is 21.2 - 312.8 g; and the largest proportion caught is 21.2 g in weight size. The data shows that the length and weight of silver barb captured are dominant in small size. The distribution of length and weight of silver barb in several locations is presented in Table 2.

The length and weight structure of silver barb from several waters show low values compared to silver barb caught in Dan Tchang Reservoir, Thailand, which is 45 cm and 2,100 g (Chheng *et al.*, 2004). These data indicate that silver barb fishing, in Lake Tempe in particular, is very intensive and even overexploited (Sukarman, 2022). Silver barb do not have the opportunity to grow large due to intensive fishing. In addition, the less optimal environmental conditions of the lake, the presence of predators or competitors, and the limited ability of swimming larvae to escape from environmental factors are thought to affect the survival and growth. According to (Arevalo *et al.*, 2023), 99% mortality of a large number of fish species occurs in the early phase of fish life. Such high mortality is thought to have influenced variations in silver barb population size.

The total sex ratio of male and female is 1:1, indicating a balanced number of male and female fish. Silver barb with a male and female ratio of 1:1 (Maknuu, 2016), 1:1.27 (Jasmine and Begum, 2016), 1:2 (Ardelia *et al.*, 2023), 4:1 (Efizon *et al.*, 2021). Sex ratios can differ between the same fish species, because sex determination is not only determined by genetic factors but also by the environment (Capel, 2017), a sex ratio of 1:1 is an ideal description because both male and female fish have the same opportunity to maintain their species. Although silver barb experience high exploitation pressure, the sex ratio data shows that silver barb still have a high ability to maintain their population.

Furthermore, the sex ratio of gonads mature males and females is 27 fish (25%) and 83 fish (75%) or 1:3, meaning that 1 male is paired with 3 females for spawning activities (polygamy). The sex ratio in spawning is related to the interaction and synchronization between male and female fish (Mylonas *et al.*, 2010) as well as the

efficient use of the number of male or female fish in spawning. Each fish species has a different optimal male and female sex ratio for spawning, such as climbing perch, *Anabas testudineus* is 1:2 (Hasnidar *et al.*, 2022); sailfin molly, *Poecilia latipinna* is 1:10 (Tamsil and Hasnidar, 2019); silver barb, *Barbonymus* sp. is 6:1 (Efizon *et al.*, 2021).

The results of the analysis of the length-weight relationship of male silver barb obtained relationship model $W = 0.0234 L^{2.7349}$, female $W = 0.0172 L^{2.8766}$, combined (male and female) $W = 0.0183 L^{2.8415}$ (Figure 5). The t test results obtained the value of b silver barb male, female and combined different from 3 ($b \neq 3$) so it can be concluded that the growth pattern is allometric. Because the value of $b < 3$, it is called negative allometric. Some research results on the length-weight relationship of silver barb in several aquatic locations as shown in Table 3.

Differences in tawes growth patterns are due to differences in aquatic conditions. An important factor affecting the growth of fish in the tropics is the availability of food (Froese, 2006). Therefore, the same fish species in different locations will have different growth patterns due to this factor. In addition to food, other factors are the stage of gonad development, water physico-chemistry, fish health conditions, season, time and sampling techniques (Sheridan, 2011; Mehanna and Farouk, 2021). The number of fish caught in this study was 1623 fish, of which only 109 fish or 6.7% were mature gonads (stage IV), which is thought to be the cause of the negative allometric growth pattern.

Condition Factor (CF) is a value that reflects the influence of environmental factors on the physiological condition (Faradonbeh *et al.*, 2015). Good environmental conditions including the availability of food will support good growth so that the weight of the fish is higher and the $CF \geq 1$, on the other hand, environmental conditions are not suitable and limited food availability causes small weight gain and $CF < 1$ (Dirican & Cilek, 2012). The CF value of the results of this study is 1.024 - 1.018; this value indicates the condition of the fish body is thin (compressed), the same as the growth pattern, which is negative allometric, that is length growth is faster than weight.

The condition factor of silver barb from several studies is 0.84 - 1.4 (Buwono *et al.*, 2019), 1.05 – 317 (Sidik *et al.*, 2020), 1.01 – 1.02 (Dwirastina and Marson, 2021), 0.82 – 1.10 (Syaiful *et al.*, 2019), 0.76 – 2.27 (Laila, 2018), 1.145-1.328 (Maknuu, 2016). The varying CF are due to differences in aquatic environment, density, food availability, and physiological conditions such as fish reproductive cycles. The higher the CF value indicates the compatibility of the fish with its environment.

The results of the analysis of the level of maturity of the gonads macroscopically show that in each level of maturity there are differences in size, color, and volume of gonads in the abdominal cavity of the ovary and testes. In the ovary, the higher the level of maturity, the diameter of oocytes tends to increase, but there are variations in the diameter of oocytes at the same maturity stage (Table 1). Similarly, histological observations show that there are different sizes of oocyte diameter in the (Efizon *et al.*, 2021). These data indicate that tawes are gradual spawners, that is, they release their eggs not all at once during spawning. Gradual spawners have a long spawning season. The spawning season of silver barb in Tempe Lake is thought to be throughout the year, it can be seen in every fish sampling from January to June that mature (stage IV) is found every month of observation, with the highest mature in January. In contrast to silver barb in Padma River Bangladesh, the spawning season is April - July and the peak spawning is in June (Jasmine and Begum, 2016).

Length at first maturity (L_{50}) is the value at which 50% of individuals in a group have reproduced at least once (Barzotto and Mateus, 2017). The length at first maturity of male = 19.9 cm, and female = 18.3 cm. The L_{50} value of the results of this study is greater than the L_{50} of silver barb from Nagan river, Aceh Province, Indonesia, e.g. male = 7.3 cm and female = 8.5 cm (Efizon *et al.*, 2021). The length of the first maturing gonads of fish can differ due to competition and predation, fishing pressure and environmental conditions (de Souza *et al.*, 2019). Fish will perform the first maturation with a shorter length to reduce the risk of death before reproduction if environmental conditions are unfavorable (Barzotto and Mateus, 2017). Based on the

L₅₀ value of male and female in relation to the length of the dominant silver barb caught in this study, ± 90% of the fish caught have never reproduced.

Silver barb identified as maturity stage IV in this study were 82 fish, having a length range of 12.2 - 21.28 cm (average ± 15.0 cm) and body weight of 21.0 - 124.4 g (average ± 41 g), producing fecundity with a range of 1,443 - 83,822 eggs (average = 20,239 eggs). Fecundity data of silver barb in several aquatic are presented in Table 4.

The estimated coefficient of determination (R^2) of the relationship between fecundity-length (F-L) and fecundity-weight (F-W) showed that 35.3% of the variation in fecundity occurred due to variation in total fish length and 51.5% of the variation in fecundity due to the influence of variation in body weight. Similar observations on tawes from Nagan river, Aceh Province, Indonesia; the coefficient of determination (R^2) of the relationship between F-L and F-W was 51% and 24.2%, respectively (Efizon *et al.*, 2021). This means that tawes fecundity increases with increasing total length and body weight. Fish that have a larger size in addition to having a large visceral cavity to accommodate a larger number of oocytes also have sufficient energy for reproductive activities (Jonsson and Jonsson, 1999). Factors that affect fish fecundity are internal factors such as genetics, age, and size (Hunter *et al.*, 1992), while external factors are food availability and environmental conditions (Bryan *et al.*, 2007).

Conclusion

The length and weight structure of female fish were higher than male fish. The dominant lengths and weights caught were 14.5 cm and 21.2 g. Negative allometric growth pattern and condition factor 1.02; lean growth. The overall ratio of male and female was 1 : 1, while the spawning sex ratio was 1 : 3; that is, one male fish is paired with 3 females in spawning. The first size of gonad maturity of female fish was faster at 18.3 cm and 19.9 cm for males. Fecundity ranged from 253 to 13,398 eggs (mean

2,571 eggs). Variation in fecundity was more strongly influenced by variation in body weight than variation in total length of silver barb.

Acknowledgments

To the Rector of Universitas Muslim Indonesia (UMI) Makassar through the Institute for Research and Resource Development which has supported funds so that this research can be carried out.

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**Reproductive biology of silver barb, *Barbonymus gonionotus* (Bleeker, 1850)
in Tempe Lake, South Sulawesi, Indonesia**

Abstract

Information on the reproductive biology of silver barb is needed for conservation and domestication purposes. This study aims to analyze the reproductive biology of silver barb in Tempe Lake. Aspects of reproductive biology analyzed were length-weight structure, sex ratio, length-weight relationship, condition factor, size at first gonad maturity (L_{50}), gonad of maturity and fecundity. This study used primary data, silver barb were caught using gill nets every two weeks from January to July 2023. The total length of fish was measured using an ichthyometer with an accuracy of 0.1 cm, and weight using a digital scale with an accuracy of 0.01 g, gonads were preserved in 4% formalin solution, fecundity was calculated based on the gravimetric method. Length structure of males 8.9 - 22.9 cm and females 8.9 - 28.5 cm; weight of males 21.2 - 183.2 g and females 21.2 - 312.8 g. The overall sex ratio of males and females was 1:1, while the sex ratio during spawning was 1:3 (polygamous). Length-weight relationships between males and females were $W = 0.0234L^{2.7349}$ and $W = 0.0172L^{2.8766}$. The condition factor for males and females was the same at 1.02. The size of first maturing gonads for females was 18.3 cm and 19.9 cm for males. Partial spawning, fecundity ranged from 253-13,398 egg.

Keywords: Reproductive biology, silver barb, Tempe Lake, length, weight

Introduction

Silver barb, *Barbonymus gonionotus* (Bleeker, 1850) is an economically important freshwater fish in several countries such as Indonesia, Malaysia, Thailand, Myanmar, Bangladesh, India, and China. The taste is good and the price is relatively cheap so it becomes the main consumption of the community, especially some places in the territory of Indonesia. Silver barb production still mainly depends on fishing, so fishing pressure continues to increase.

Tempe Lake has a diversity of fish species consisting of native fish, introduced fish and migratory marine fish. According to Dina *et al.* (2019), the native fishes of Tempe Lake are *Monopterus albus*, *Anabas testudineus*, *Glossogobius aureus*, *Channa striata*. Introduced fish species are *Barbonymus gonionotus*, *Clarias batrachus*, *Trichopodus pectoralis*, *Pangasianodon hypophthalmus*, *Osteochilus vittatus*, *Oreochromis niloticus*, *Helostoma temminckii*, *Cyprinus carpio* (Yanuarita *et al.*, 2020). Migratory marine fish species are *Megalops cyprinoides*, *Stenogobius gymnopomus*, *Anguilla marmorata* and *Caranx sexfasciatus*. Introductions are carried out to increase the production of fishery products to meet increasing demand, optimize water productivity, increase production in a sustainable and increase biodiversity (Yanuarita *et al.*, 2020; FAO, 2022).

Tempe Lake is presently experiencing various environmental problems, including eutrophication (Aisyah and Nomosatryo, 2016). Eutrophication occurs allegedly due to the load of nutrients derived from the activities of humans, plantations and farms that are often found on the shores of the lake. Nitrate and phosphate nutrients are in the range of 0.1063-0.2620 mg/l and 0.0245-0.0655 mg/l respectively in the water (Samuel *et al.*, 2012). These conditions trigger the growth of aquatic weeds such as *Ipomoea aquatic* and *Eichhornia crassipes*. *E. crassipes* is the most dominant of these plants and its population is estimated to have covered the lake surface by about 30 - 40%. According to (Yani *et al.*, 2019), Lake Tempe has experienced moderate to severe pollution in several parameters including turbidity, total suspended solid, biological oxygen demand, nitrate, and phosphate.

Another problem is overfishing and the use of fishing gear that is not environmentally sustainable (Nasution, 2012), and a serious problem is the presence of invasive fish, i.e. *Pterygoplichthys* spp (Hasnidar *et al.*, 2021). The high population of *Pterygoplichthys* spp has caused fishermen's catches of target fish to decline (Hasrianti *et al.*, 2020). The presence of *Pterygoplichthys* spp impacts the lake ecosystem through competition for habitat, diet, and can even be a predator of native and endemic fish, as well as an agent of various diseases. It can change the species composition and structure of fish communities, dominating and excluding native and endemic fish (Syafei and Sudinno, 2018).

Silver barb, *B. gonionotus* was introduced to Lake Tempe in 1937 (Dina *et al.*, 2019; Yanuarita *et al.*, 2020). Although an introduced fish, Tawes (Silver barb) successfully adapted well to the lake environment. The condition of Tempe Lake, which is rich with dominant aquatic plants, enables to survive well. Silver barb are herbivorous, with phytoplankton (Chlorophyceae) as their main food (Ain *et al.*, 2021); aquatic plants (80%), detritus (12%), phytoplankton (8.5%) (Aida, 2018; Pratiwi *et al.*, 2021). Silver barb are considered useful in controlling excessive vegetation in lake waters. Although silver barb successfully lives in Tempe Lake, the declining environmental conditions of Tempe Lake certainly have an impact on the production of these fish.

Silver barb production has fluctuated in recent years, with capture mortality higher than natural mortality due to overfishing (Sukarman, 2022). This condition is thought to be due to the presence of *Pterygoplichthys* spp as an invasive fish (Hasnidar *et al.*, 2021). There are two species that are still caught in large numbers, e.i. silver barb and bloso (*Glossogobius* sp), therefore both fish species are under very high fishing pressure. Conservation and domestication efforts will be carried out, but these efforts require the latest information including aspects of silver barb reproductive biology for the future management. The study aims to analyze the reproductive biology of silver barb including size distribution, sex ratio, length and weight relationship, condition factor, gonad maturity, size of first mature gonad, and fecundity.

Materials and methods

The study was conducted from January to July 2023 in Tempe Lake, Wajo Regency, South Sulawesi Province, Indonesia (Fig. 1). Fish sampling was collected every week for six months, using a gill net response tool. Fish samples caught were cleaned, put in a cooler box and given ice cubes. Sample observations were carried out at the Biota and Environmental Engineering Laboratory, Faculty of Fisheries and Marine Science, Universitas Muslim Indonesia (UMI) Makassar.

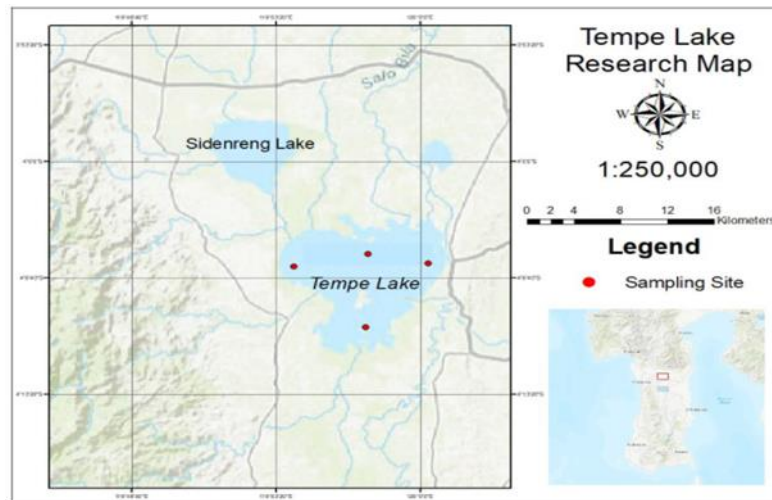


Fig 1. Silver barb fishing sampling points on the site in Tempe Lake, Wajo Regency, South Sulawesi, Indonesia.

The total length (Lt) of silver barb was measured using an ichthymeter (Vernier calipers, Mitutoyo) with an accuracy of 0.1 cm, body weight and gonads (g) were measured using digital scales (Digital elektrik scale, DIGI DS880) with an accuracy of 0.01g. The parameters analyzed were:

Length and weight structure

Length and weight size structures were determined as follows: determining the number of classes; determining the length class interval of 1 cm and weight of 1 g; inserting

each fish sample in the predetermined class. The size structure was determined within the same class interval and then plotted on a graph.

Sex ratio

The sex of silver barb was determined morphologically and anatomically by dissecting the fish to see whether the gonads developed into testes or ovaries. Determination of male and female sex ratio is done by calculating the number of male fish and female fish caught using the formula (Oliveira *et al.*, 2012):

$$N = \frac{\text{number of male or female fish}}{\text{total number of fish observed}} \times 100$$

Next, sex ratio variability was tested using the Chi-square test (Oliveira *et al.*, 2012):

$$X^2 = \frac{\sum (oi - ei)^2}{ei}$$

Description: X^2 = Value for a random variable whose sampling distribution approximates the Chi-square distribution

oi = Observed frequencies of male and female fish

ei = Expected frequencies of male and female fish

Length-weight relationship

The relationship between length and weight was analyzed using the formula (Le Cren, 1951):

$$W = a L^b$$

Description W = Fish body weight (g), L = Total length of fish (cm), a = Coefficient of determination, b = exponent that indicates isometric or allometric.

To obtain the equation, the values of W and L were transformed into logarithms (base 10) as follows:

$$W = \log a + b \log L$$

The b values obtained were used to estimate the two parameters (length and weight) analyzed, with hypotheses: 1) $b = 3$ indicates an isometric growth pattern, 2) $b \neq 3$ indicates an allometric growth pattern, a) $b > 3$: faster weight gain (positive allometric), b) $b < 3$: faster length gain (negative allometric).

Condition factor

Because the growth pattern of tawes in this study is negative allometric ($b \neq 3$), the formulation (Le Cren, 1951) is:

$$Kn = \frac{W}{a L^b}$$

Description Kn = Condition factor, W = Fish body weight (g), L = Total length of fish (cm), a = a = Intercept, b = slope

Size at first gonadal maturity (L_{50})

The size of the first time the fish matures gonads is obtained by finding the value of L_{50} by plotting the cumulative percentage of gonadal mature fish with the size of the fish body length, so that a standard logistic curve will be obtained and the intersection point between the curve and 50% cumulative frequency is the length when 50% of the fish first matures gonads.

Gonad maturity

The stage of gonadal maturity was observed macroscopically, the observation procedure is when the silver barb was first dissected, and the visceral cavity was opened to observe the morphology of the gonads including: shape, color, size, gonad position in the abdominal cavity and egg diameter. Maturity stages were classified according to Brown-Peterson *et al.* (2011), and modified according to silver barb conditions, i.e. stage I (Immature); II (Developing); III (Maturing); IV (Mature) and V (Spent). Egg diameter was observed by taking samples of stage IV fish gonads then each fish gonad was taken in 3 parts, i.e. posterior, anterior, and middle gonads. Eggs were taken from each part of the gonad sample, with 30 eggs in each part. A total of 90 fish egg samples were measured in diameter using an ocular micrometer (0.01 mm) brand UYCP-12.

Fecundity

Fecundity can be known the procedure that the weight of the total gonads (WG), then take a subpart of the total gonad at each end of the bottom, middle and top then measure its weighed (Ws). The weight of the gonad subpart was then preserved in a 4% formalin solution to facilitate the calculation of the number of eggs (n). Fecundity was observed in maturity stage IV, calculated using the gravimetric method (Hasan *et al.*, 2020):

$$F = \frac{\text{weight of the total gonad (WG)}}{\text{weight subpart gonad (Ws)}} \times \text{number of eggs of the subpart gonad (n)}$$

The relationship between fecundity and total length and body weight using the formulation Hasan *et al.* (2020) is:

$$F = a L^b \quad \text{and} \quad F = a W + b$$

Description F = Fecundity (egg), L = Total length of fish (cm), W = Fish body weight (g), a = Intercept, b = slope

Results

Length and weight structure

The results of the length structure analysis of male tawes are 8.9 - 22.9 cm and females are 8.9 - 28.5 cm, the largest proportion caught at 14.5 cm both males and females. While the size structure of male weights is 21.2 - 183.2 g and female are 21.2 - 312.8 g; and the largest proportion of males and females caught is the same weight size of 21.2 g (Fig. 2 a and b).

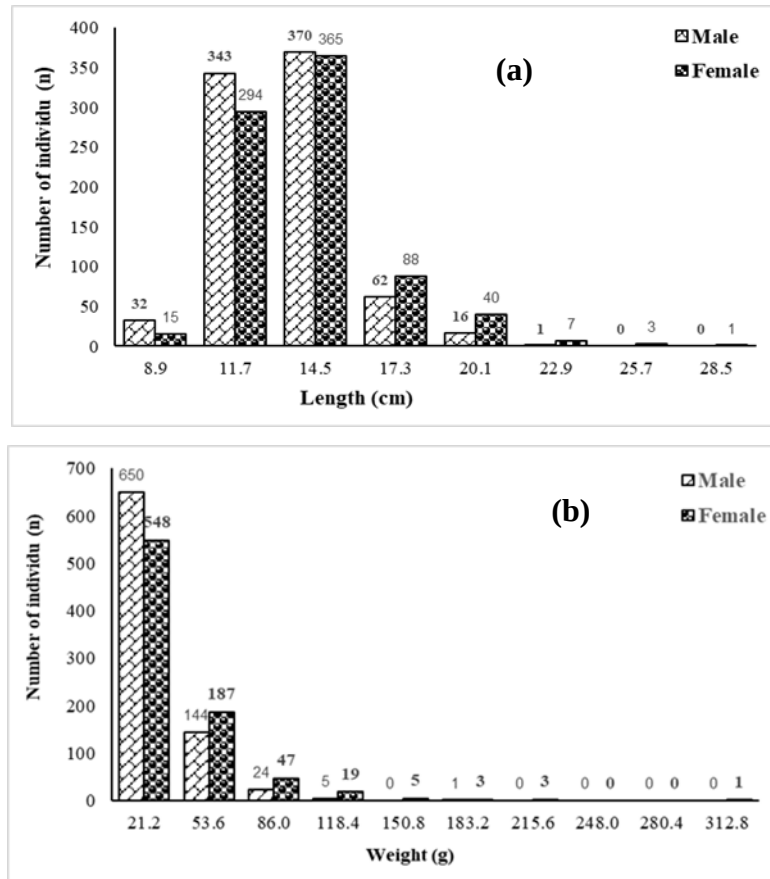


Fig 2. Length (a) and weight (b) structure of silver barb

Sex Ratio

The total sex ratio of males and females was 824 (50%) and 813 (50%), indicating a male-to-female sex ratio of 1:1 (Fig. 3a). The sex ratio of gonadally mature males and females was 27 (25%) and 83 (75%), indicating that 1 male was partnered with 3 females for spawning activities (Fig. 3b).

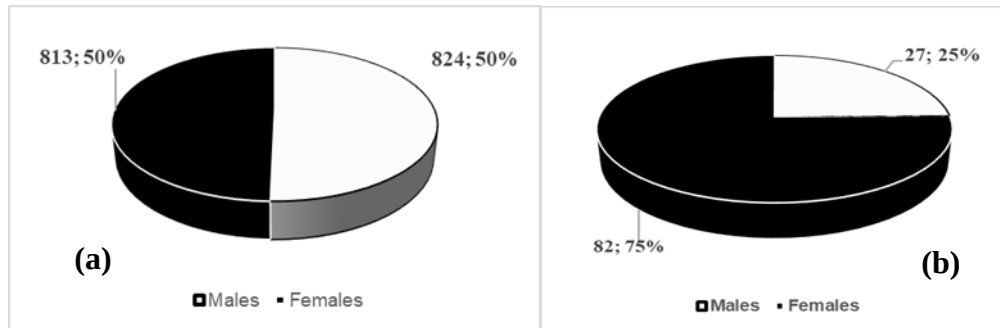


Fig 3. Male-to-female sex ratio of silver barb total fish (a), and gonad of maturity (b)

Length-weight relationship

The results of the analysis of the length-weight relationship of male was $W = 0.0234 L^{2.7349}$ and female $W = 0.0172 L^{2.8766}$ and combined (male and female) $W = 0.0183 L^{2.8415}$ (Fig. 4 a, b, c). The t-test results showed that the b value of male, female and combined (male and female) silver barb is different from 3 ($b \neq 3$) so it can be concluded that the growth pattern is allometric. Because the value of $b < 3$, it is negatively allometric.

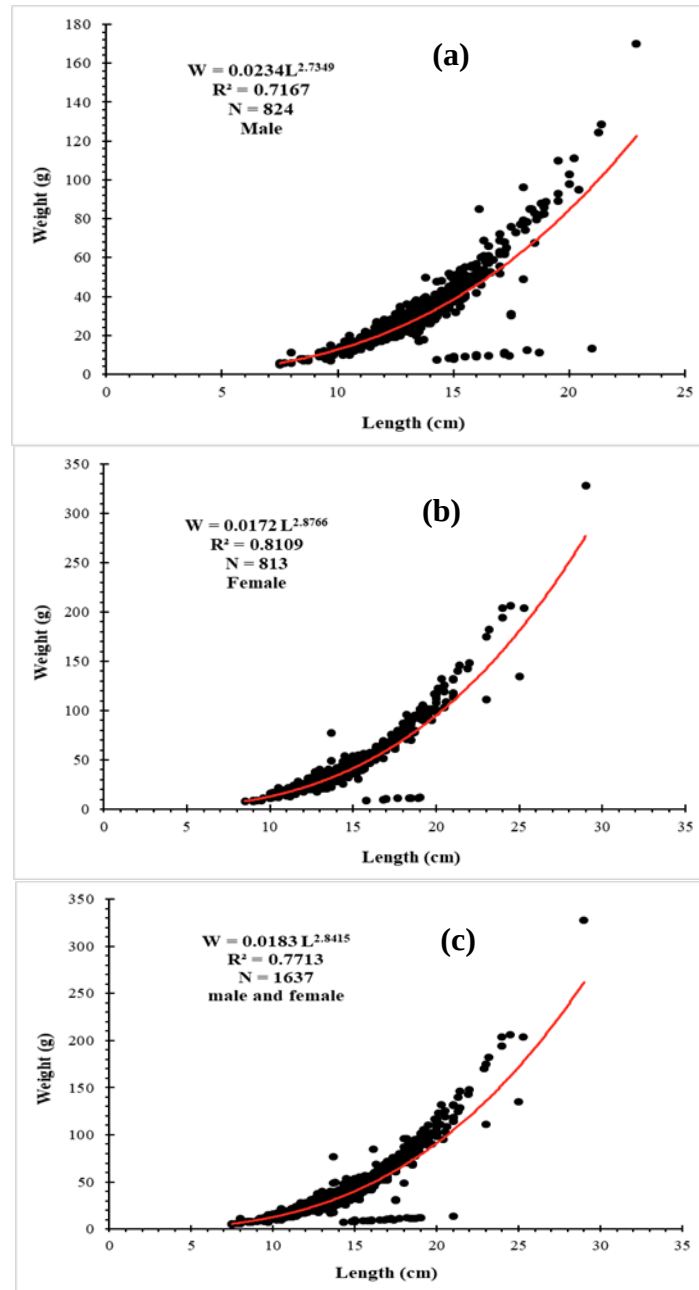


Fig 4. Length-weight relationship of male (a), female (b) and combined (male and female) (c)

Condition Factor

Condition factors for male and female tawes were 1.0243 ± 0.0061 and 1.0181 ± 0.0054 , respectively.

Size at first gonad maturity (L_{50})

The results of the analysis of the size of the first mature gonads (L_{50}) of male fish are different from females. Female fish are faster to mature gonads, i.e. $L_{50} = 18.3$ cm than males $L_{50} = 19.9$ cm.

Gonad maturity

Determination of gonad maturity criteria is macroscopic by observing the morphological shape, size, color and position of the gonads in the abdominal cavity. The development of gonads (ovary and testes) of silver barb is classified into five levels according to the instructions Hasnidar *et al.* (2022) and the condition of silver barb gonads. The gonadal stages are stage I (Immature), II (Developing), III (Maturing), IV (Mature) and V (spent) (Table 1).

Table 1. Gonad maturity of female and male silver barb

Maturity stage	Note	Female	Male
I	Immature	Ovary is small, extending anteriorly to posteriorly in the dorsal abdominal cavity, filled with white and viscous fluid, eggs not yet visible, estimated to fill <15% of the abdominal cavity.	Testes are small and thin, extending from anterior to posterior of the abdominal cavity, filled with clear white fluid
II	Developing I	Ovary is larger than immature ovaries, white in color, egg grains are visible, estimated to fill 20-30% of the abdominal cavity. The average egg diameter is 0.20 – 0.425 mm	Testes are enlarged, larger than stage I (immature) testes; filled with white liquid
III	Maturing	Ovary is enlarged, filled with greenish-white soft granules, egg granules are still difficult to separate. Estimated to fill almost 30%-60% of the abdominal cavity. The average egg diameter is 0.450 - 0.750 mm	Testes are getting bigger and larger than stage II, the surface of the testes appears to be ridged. Contains thick white liquid
IV	Mature	Ovary is getting bigger, filling about 60-80% of the abdominal cavity. ovaries contain yellowish-green egg grains, the average egg diameter is 0.800 - 1.25 mm	Testes are getting bigger larger than stage III, the surface of the testes is grooved. Contains thick milky white liquid
V	Spent	Ovary reduced, creased, ovary wall thick and lobed, yellowish-green color containing unspawned residual eggs	Testes reduced in size, wrinkled edges

Fecundity

The number of gonads mature female (stage IV) was 82 fish with a length range of 7.5-17.5 cm and weights of 7-82 g, gonad weights of 1.25-10.11 g. The fecundity of silver barb obtained in this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The fecundity of silver barb obtained from the results of this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The relationship between fecundity and total length is $F = 4.6297 L^{2.958}$ ($R^2 = 0.3526$), fecundity with body weight is a linear relationship that is $F = 444.66W + 1489.3$ ($R^2 = 0.5145$) (Fig. 5 a, b).

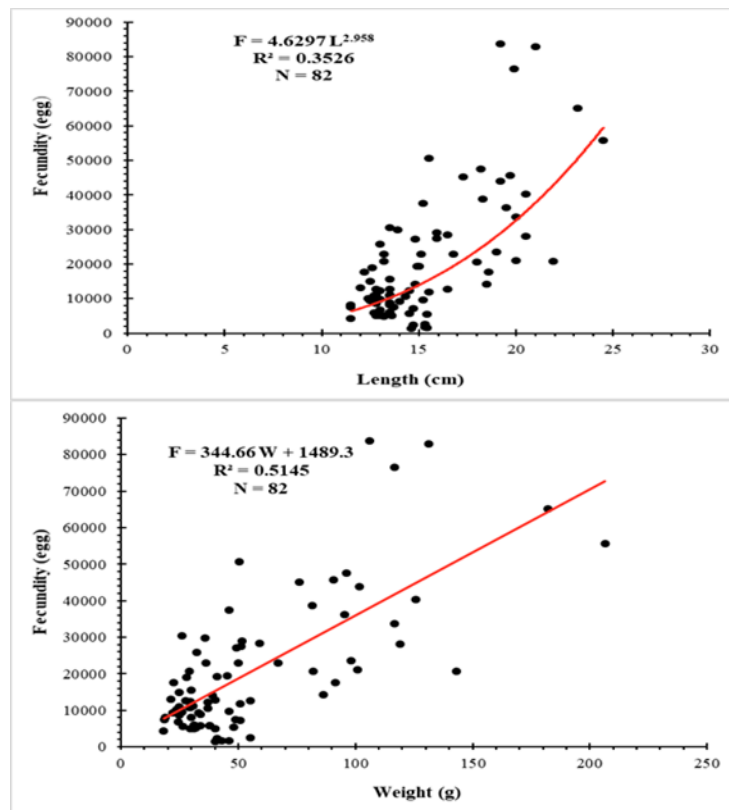


Fig 5. Fecundity-length (a), fecundity-weight (b) relationships of silver barb

Discussion

The length size structure of silver barb is 8.9 - 28.5 cm, with the highest proportion caught size 14.5 cm. Furthermore, the weight size structure is 21.2 - 312.8 g; and the largest proportion caught is 21.2 g in weight size. The data shows that the length and weight of silver barb captured are dominant in small size. The distribution of length and weight of silver barb in several locations is presented in Table 2.

The length and weight structure of silver barb from several waters show low values compared to silver barb caught in Dan Tchang Reservoir, Thailand, which is 45 cm and 2,100 g (Chheng *et al.*, 2004). These data indicate that silver barb fishing, in Lake Tempe in particular, is very intensive and even overexploited (Sukarman, 2022). Silver barb do not have the opportunity to grow large due to intensive fishing. In addition, the less optimal environmental conditions of the lake, the presence of predators or competitors, and the limited ability of swimming larvae to escape from environmental factors are thought to affect the survival and growth. According to (Arevalo *et al.*, 2023), 99% mortality of a large number of fish species occurs in the early phase of fish life. Such high mortality is thought to have influenced variations in silver barb population size.

The total sex ratio of male and female is 1:1, indicating a balanced number of male and female fish. Silver barb with a male and female ratio of 1:1 (Maknuu, 2016), 1:1.27 (Jasmine and Begum, 2016), 1:2 (Ardelia *et al.*, 2023), 4:1 (Efizon *et al.*, 2021). Sex ratios can differ between the same fish species, because sex determination is not only determined by genetic factors but also by the environment (Capel, 2017), a sex ratio of 1:1 is an ideal description because both male and female fish have the same opportunity to maintain their species. Although silver barb experience high exploitation pressure, the sex ratio data shows that silver barb still have a high ability to maintain their population.

Furthermore, the sex ratio of gonads mature males and females is 27 fish (25%) and 83 fish (75%) or 1:3, meaning that 1 male is paired with 3 females for spawning activities (polygamy). The sex ratio in spawning is related to the interaction and synchronization between male and female fish (Mylonas *et al.*, 2010) as well as the

efficient use of the number of male or female fish in spawning. Each fish species has a different optimal male and female sex ratio for spawning, such as climbing perch, *Anabas testudineus* is 1:2 (Hasnidar *et al.*, 2022); sailfin molly, *Poecilia latipinna* is 1:10 (Tamsil and Hasnidar, 2019); silver barb, *Barbonymus* sp. is 6:1 (Efizon *et al.*, 2021).

The results of the analysis of the length-weight relationship of male silver barb obtained relationship model $W = 0.0234 L^{2.7349}$, female $W = 0.0172 L^{2.8766}$, combined (male and female) $W = 0.0183 L^{2.8415}$ (Figure 5). The t test results obtained the value of b silver barb male, female and combined different from 3 ($b \neq 3$) so it can be concluded that the growth pattern is allometric. Because the value of $b < 3$, it is called negative allometric. Some research results on the length-weight relationship of silver barb in several aquatic locations as shown in Table 3.

Differences in tawes growth patterns are due to differences in aquatic conditions. An important factor affecting the growth of fish in the tropics is the availability of food (Froese, 2006). Therefore, the same fish species in different locations will have different growth patterns due to this factor. In addition to food, other factors are the stage of gonad development, water physico-chemistry, fish health conditions, season, time and sampling techniques (Sheridan, 2011; Mehanna and Farouk, 2021). The number of fish caught in this study was 1623 fish, of which only 109 fish or 6.7% were mature gonads (stage IV), which is thought to be the cause of the negative allometric growth pattern.

Condition Factor (CF) is a value that reflects the influence of environmental factors on the physiological condition (Faradonbeh *et al.*, 2015). Good environmental conditions including the availability of food will support good growth so that the weight of the fish is higher and the $CF \geq 1$, on the other hand, environmental conditions are not suitable and limited food availability causes small weight gain and $CF < 1$ (Dirican & Cilek, 2012). The CF value of the results of this study is 1.024 - 1.018; this value indicates the condition of the fish body is thin (compressed), the same as the growth pattern, which is negative allometric, that is length growth is faster than weight.

The condition factor of silver barb from several studies is 0.84 - 1.4 (Buwono *et al.*, 2019), 1.05 – 317 (Sidik *et al.*, 2020), 1.01 – 1.02 (Dwirastina and Marson, 2021), 0.82 – 1.10 (Syaiful *et al.*, 2019), 0.76 – 2.27 (Laila, 2018), 1.145-1.328 (Maknuu, 2016). The varying CF are due to differences in aquatic environment, density, food availability, and physiological conditions such as fish reproductive cycles. The higher the CF value indicates the compatibility of the fish with its environment.

The results of the analysis of the level of maturity of the gonads macroscopically show that in each level of maturity there are differences in size, color, and volume of gonads in the abdominal cavity of the ovary and testes. In the ovary, the higher the level of maturity, the diameter of oocytes tends to increase, but there are variations in the diameter of oocytes at the same maturity stage (Table 1). Similarly, histological observations show that there are different sizes of oocyte diameter in the (Efizon *et al.*, 2021). These data indicate that tawes are gradual spawners, that is, they release their eggs not all at once during spawning. Gradual spawners have a long spawning season. The spawning season of silver barb in Tempe Lake is thought to be throughout the year, it can be seen in every fish sampling from January to June that mature (stage IV) is found every month of observation, with the highest mature in January. In contrast to silver barb in Padma River Bangladesh, the spawning season is April - July and the peak spawning is in June (Jasmine and Begum, 2016).

Length at first maturity (L_{50}) is the value at which 50% of individuals in a group have reproduced at least once (Barzotto and Mateus, 2017). The length at first maturity of male = 19.9 cm, and female = 18.3 cm. The L_{50} value of the results of this study is greater than the L_{50} of silver barb from Nagan river, Aceh Province, Indonesia, e.g. male = 7.3 cm and female = 8.5 cm (Efizon *et al.*, 2021). The length of the first maturing gonads of fish can differ due to competition and predation, fishing pressure and environmental conditions (de Souza *et al.*, 2019). Fish will perform the first maturation with a shorter length to reduce the risk of death before reproduction if environmental conditions are unfavorable (Barzotto and Mateus, 2017). Based on the

L_{50} value of male and female in relation to the length of the dominant silver barb caught in this study, $\pm 90\%$ of the fish caught have never reproduced.

Silver barb identified as maturity stage IV in this study were 82 fish, having a length range of 12.2 - 21.28 cm (average ± 15.0 cm) and body weight of 21.0 - 124.4 g (average ± 41 g), producing fecundity with a range of 1,443 - 83,822 eggs (average = 20,239 eggs). Fecundity data of silver barb in several aquatic are presented in Table 4.

The estimated coefficient of determination (R^2) of the relationship between fecundity-length (F-L) and fecundity-weight (F-W) showed that 35.3% of the variation in fecundity occurred due to variation in total fish length and 51.5% of the variation in fecundity due to the influence of variation in body weight. Similar observations on tawes from Nagan river, Aceh Province, Indonesia; the coefficient of determination (R^2) of the relationship between F-L and F-W was 51% and 24.2%, respectively (Efizon *et al.*, 2021). This means that tawes fecundity increases with increasing total length and body weight. Fish that have a larger size in addition to having a large visceral cavity to accommodate a larger number of oocytes also have sufficient energy for reproductive activities (Jonsson and Jonsson, 1999). Factors that affect fish fecundity are internal factors such as genetics, age, and size (Hunter *et al.*, 1992), while external factors are food availability and environmental conditions (Bryan *et al.*, 2007).

Conclusion

The length and weight structure of female fish were higher than male fish. The dominant lengths and weights caught were 14.5 cm and 21.2 g. Negative allometric growth pattern and condition factor 1.02; lean growth. The overall ratio of male and female was 1 : 1, while the spawning sex ratio was 1 : 3; that is, one male fish is paired with 3 females in spawning. The first size of gonad maturity of female fish was faster at 18.3 cm and 19.9 cm for males. Fecundity ranged from 253 to 13,398 eggs (mean

2,571 eggs). Variation in fecundity was more strongly influenced by variation in body weight than variation in total length of silver barb.

Acknowledgments

To the Rector of Universitas Muslim Indonesia (UMI) Makassar through the Institute for Research and Resource Development which has supported funds so that this research can be carried out.

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Reproductive biology of silver barb, *Barbonymus gonionotus* (Bleeker, 1850), in Tempe Lake, South Sulawesi, Indonesia

Hasnidar Hasnidar^{1*}; Andi Tamsil¹

Abstract

Information on the reproductive biology of silver barb is needed for conservation and domestication purposes. This study aims to analyze the reproductive biology of silver barb in Tempe Lake South Sulawesi, Indonesia. Aspects of reproductive biology analyzed were length-weight structure, sex ratio, length-weight relationship, condition factor, size at first gonad maturity (L_{50}), gonad of maturity and fecundity. This study used primary data, silver barb was caught using gill nets every two weeks from January to July 2023. The total length of fish was measured using an ichthyometer with an accuracy of 0.1 cm, and weight using a digital scale with an accuracy of 0.01 g. The gonads were preserved in 4% formalin solution, fecundity was calculated based on the gravimetric method. Length structure of males 8.9 - 22.9 cm and females

8.9 - 28.5 cm; weight of males 21.2 - 183.2 g and females 21.2 - 312.8 g. The overall sex ratio of males and females was 1:1, while the sex ratio during spawning was 1:3 (polygamous). Length-weight relationships between males and females were $W = 0.0234L^{2.7349}$ and $W = 0.0172L^{2.8766}$ respectively. The condition factor for males and females was the same at 1.02. The size of first maturing gonads for females was

18.3 and 19.9 cm for males. Partial spawning, fecundity ranged from 253-13,398 egg.

Keywords: Reproductive biology, Silver barb, Tempe Lake, Length-weight relation, weight

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Introduction

Silver barb, *Barbonymus gonionotus* (Bleeker, 1850) is an economically important freshwater fish in several countries such as Indonesia, Malaysia, Thailand, Myanmar, Bangladesh, India, and China. The taste is good and the price is relatively cheap so it becomes the main consumption of the community, especially some places in the territory of Indonesia. Silver barb production still mainly depends on fishing, so fishing pressure continues to increase.

Tempe Lake has a diversity of fish species consisting of native fish, introduced fish and migratory marine fish. According to Dina *et al.* (2019), the native fishes of Tempe Lake are *Monopterus albus*, *Anabas testudineus*, *Glossogobius aureus*, *Channa striata*. Introduced fish species are *Barbonymus gonionotus*, *Clarias batrachus*, *Trichopodus pectoralis*, *Pangasianodon hypophthalmus*, *Osteochilus vittatus*, *Oreochromis niloticus*, *Helostoma temminckii*, *Cyprinus carpio* (Yanuarita *et al.*, 2020). Migratory marine fish species are *Megalops cyprinoides*, *Stenogobius gymnopomus*, *Anguilla marmorata* and *Caranx sexfasciatus*. Introductions are carried out to increase the production of fishery products to meet increasing demand, optimize water productivity, increase production in a sustainable and increase biodiversity (Yanuarita *et al.*, 2020; FAO, 2022).

Tempe Lake is presently experiencing various environmental problems, including eutrophication (Aisyah and Nomosatryo, 2016). Eutrophication occurs allegedly due to the load of nutrients derived from the activities of humans, plantations and farms that are often found on the shores of the lake. Nitrate and phosphate nutrients are in the range of 0.1063-0.2620 mg/l and 0.0245-0.0655 mg/l respectively in the water (Samuel *et al.*, 2012). These conditions trigger the growth of aquatic weeds such as *Ipomoea aquatic* and *Eichhornia crassipes*. *E. crassipes* is the most dominant of these plants and its population is estimated to have covered the lake surface by about 30 - 40%. According to (Yani *et al.*, 2019), Lake Tempe has experienced moderate to severe pollution in several parameters including turbidity, total suspended solid, biological oxygen demand, nitrate, and phosphate.

Another problem is overfishing and the use of fishing gear that is not environmentally sustainable (Nasution, 2012), and a serious problem is the presence of invasive fish, i.e. *Pterygoplichthys* spp. (Hasnidar *et al.*, 2021). The high population of *Pterygoplichthys* spp. has caused fishermen's catches of target fish to decline (Hasrianti *et al.*, 2020). The presence of *Pterygoplichthys* spp. impacts the lake ecosystem through competition for habitat, diet, and can even be a predator of native and endemic fish, as well as an agent of various diseases. It can change the species composition and structure of fish communities, dominating and excluding native and endemic fish (Syafei and Sudinno, 2018).

Silver barb, *B. gonionotus* was introduced to Lake Tempe in 1937 (Dina *et al.*, 2019; Yanuarita *et al.*, 2020). Although an introduced fish, Tawes (Silver barb) successfully adapted well to the lake environment. The condition of Tempe Lake, which is rich with dominant aquatic plants, enables to survive well. Silver barb are herbivorous, with phytoplankton (Chlorophyceae) as their main food (Ain *et al.*, 2021); aquatic plants (80%), detritus (12%), phytoplankton (8.5%) (Aida, 2018; Pratiwi *et al.*, 2021). Silver barb are considered useful in controlling excessive vegetation in lake waters. Although silver barb successfully lives in Tempe Lake, the declining environmental conditions of Tempe Lake certainly have an impact on the production of these fish.

Silver barb production has fluctuated in recent years, with capture mortality higher than natural mortality due to overfishing (Sukarman, 2022). This condition is thought to be due to the presence of *Pterygoplichthys* spp. as an invasive fish (Hasnidar *et al.*, 2021). There are two species that are still caught in large numbers, *e.i.* silver barb and bloso (*Glossogobius* sp.), therefore both fish species are under very high fishing pressure. Conservation and domestication efforts will be carried out, but these efforts require the latest information including aspects of silver barb reproductive biology for the future management. The study aims to analyze the reproductive biology of silver barb including size distribution, sex ratio, length and weight relationship, condition factor, gonad maturity, size of first mature gonad, and fecundity.

Materials and methods

The study was conducted from January to July 2023 in Tempe Lake, Wajo Regency, South Sulawesi Province, Indonesia (Fig. 1). Fish sampling was collected every week for six months, using a gill net response tool. Fish samples caught were cleaned, put in a cooler box and given ice cubes. Sample observations were carried out at the Biota and Environmental Engineering Laboratory, Faculty of Fisheries and Marine Science, Universitas Muslim Indonesia (UMI) Makassar.

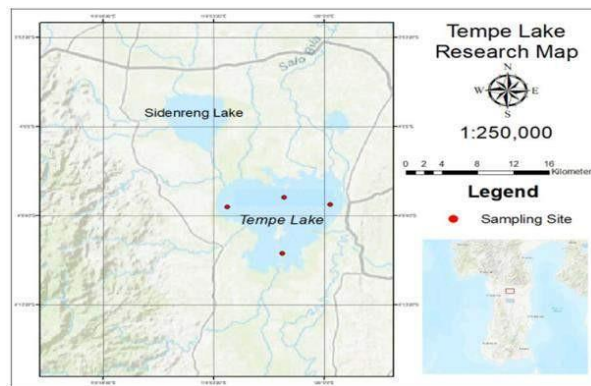


Fig 1:- Silver barb fishing sampling points on the site in Tempe Lake, Wajo Regency, South Sulawesi, Indonesia.

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The total length (Lt) of silver barb was measured using an ichthymeter (Vernier calipers, Mitutoyo) with an accuracy of 0.1 cm, body weight and gonads (g) were measured using digital scales (Digital elektrik scale, DIGI DS880) with an accuracy of 0.01g. The parameters analyzed were:

Length and weight structure

Length and weight size structures were determined as follows: determining the number of classes; determining the length class interval of 1 cm and weight of 1 g; inserting

each fish sample in the predetermined class. The size structure was determined within the same class interval and then plotted on a graph.

Sex ratio

The sex of silver barb was determined morphologically and anatomically by dissecting the fish to see whether the gonads developed into testes or ovaries. Determination of male and female sex ratio is done by calculating the number of male fish and female fish caught using the formula (Oliveira *et al.*, 2012):

$$N = \frac{\text{number of male or female fish}}{\text{total number of fish observed}} \times 100$$

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Next, sex ratio variability was tested using the Chi-square test (Oliveira *et al.*, 2012):

$$X^2 = \frac{\sum (oi - ei)^2}{ei}$$

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Description: X^2 = Value for a random variable whose sampling distribution approximates the Chi-square distribution

oi = Observed frequencies of male and female fish

ei = Expected frequencies of male and female fish

Length-weight relationship

The relationship between length and weight was analyzed using the formula (Le Cren, 1951):

$$W = a L^b$$

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Description W = Fish body weight (g), L = Total length of fish (cm), a = Coefficient of determination, b = exponent that indicates isometric or allometric.

To obtain the equation, the values of W and L were transformed into logarithms (base 10) as follows:

$$W = \log a + b \log L$$

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The b values obtained were used to estimate the two parameters (length and weight) analyzed, with hypotheses: 1) $b = 3$ indicates an isometric growth pattern, 2) $b \neq 3$ indicates an allometric growth pattern, a) $b > 3$: faster weight gain (positive allometric), b) $b < 3$: faster length gain (negative allometric).

Condition factor

Because the growth pattern of **tawes** in this study is negative allometric ($b \neq 3$), the formulation (Le Cren, 1951) is:

$$Kn = \frac{W}{a L^b}$$

Description Kn = Condition factor, W = Fish body weight (g), L = Total length of fish (cm), a = Intercept, b = slope

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Size at first gonadal maturity (L_{50})

The size of the first time the fish matures gonads is obtained by finding the value of L_{50} by plotting the cumulative percentage of gonadal mature fish with the size of the fish body length, so that a standard logistic curve will be obtained and the intersection point between the curve and 50% cumulative frequency is the length when 50% of the fish first matures gonads.

Gonad maturity

The stage of gonadal maturity was observed macroscopically, the observation procedure is when the silver barb was first dissected, and the visceral cavity was opened to observe the morphology of the gonads including: shape, color, size, gonad position in the abdominal cavity and egg diameter. Maturity stages were classified according to Brown-Peterson *et al.* (2011), and modified according to silver barb conditions, i.e. stage I (Immature); II (Developing); III (Maturing); IV (Mature) and V (Spent). Egg diameter was observed by taking samples of stage IV fish gonads then each fish gonad was taken in 3 parts, i.e. posterior, anterior, and middle gonads. Eggs were taken from each part of the gonad sample, with 30 eggs in each part. A total of 90 fish egg samples were measured in diameter using an ocular micrometer (0.01 mm) brand UYCP-12.

Fecundity

Fecundity can be known the procedure that the weight of the total gonads (WG), then take a subpart of the total gonad at each end of the bottom, middle and top then measure its weighed (Ws). The weight of the gonad subpart was then preserved in a 4% formalin solution to facilitate the calculation of the number of eggs (n). Fecundity was observed in maturity stage IV, calculated using the gravimetric method (Hasan *et al.*, 2020):

$$F = \frac{\text{weight of the total gonad (WG)}}{\text{weight subpart gonad (Ws)}} \times \text{number of eggs of the subpart gonad (n)}$$

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The relationship between fecundity and total length and body weight using the formulation Hasan *et al.* (2020) is:

$$F = a L^b \quad \text{and} \quad F = a W + b$$

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Description F = Fecundity (egg), L = Total length of fish (cm), W = Fish body weight (g), a = Intercept, b = slope

Results

Length and weight structure

The results of the length structure analysis of male tawes are 8.9 - 22.9 cm and females are 8.9 - 28.5 cm, the largest proportion caught at 14.5 cm both males and females. While the size structure of male weights is 21.2 - 183.2 g and female are 21.2 - 312.8 g; and the largest proportion of males and females caught is the same weight size of 21.2 g (Figs. 2 a and b).

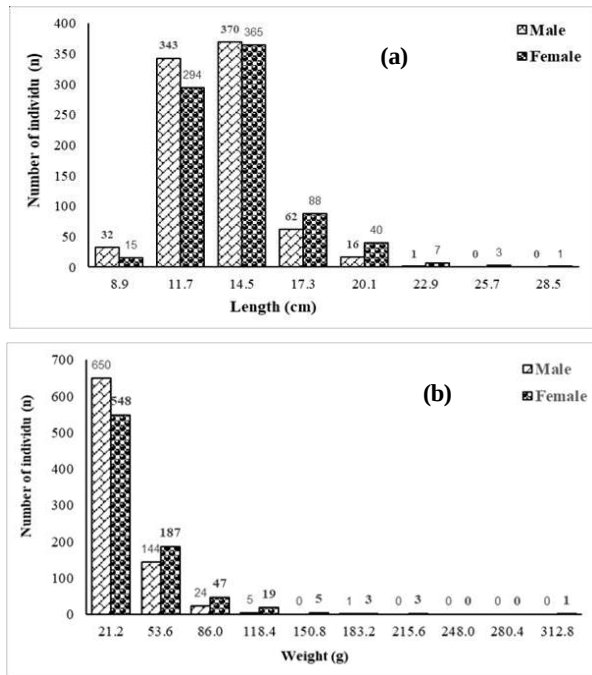


Fig 2: Length (a) and weight (b) structure of silver barb

Sex Ratio

The total sex ratio of males and females was 824 (50%) and 813 (50%), indicating a male-to-female sex ratio of 1:1 (Fig. 3a). The sex ratio of gonadally mature males and females was 27 (25%) and 83 (75%), indicating that 1 male was partnered with 3 females for spawning activities (Fig. 3b).

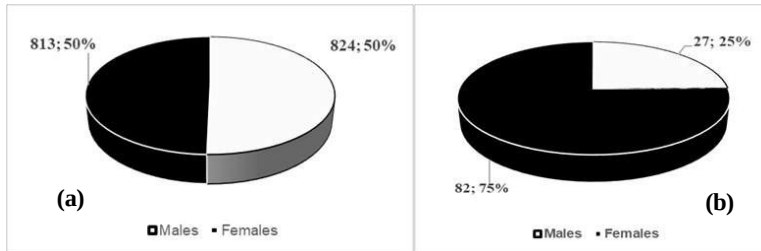


Fig 3: Male-to-female sex ratio of silver barb total fish (a), and gonad of maturity (b)

Length-weight relationship

The results of the analysis of the length-weight relationship of male were $W = 0.0234 L^{2.7349}$ and female $W = 0.0172 L^{2.8766}$ and combined (male and female) $W = 0.0183 L^{2.8415}$ (Fig. 4 a, b, c). The t-test results showed that the b value of male, female and combined (male and female) silver barb is different from 3 ($b \neq 3$) so it can be concluded that the growth pattern is allometric. Because the value of $b < 3$, it is negatively allometric.

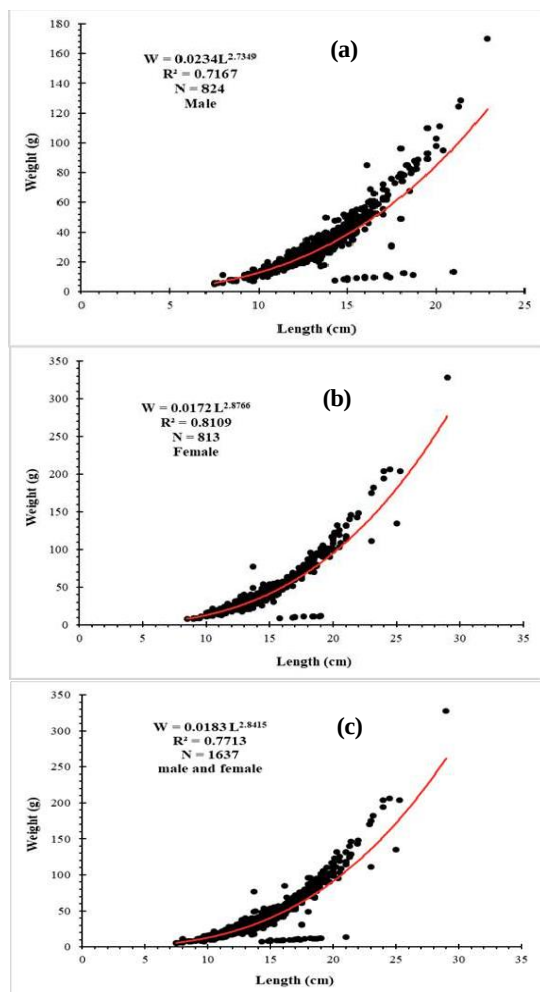


Fig 4: Length-weight relationship of male (a), female (b) and combined (male and female) (c)

Condition Factor

Condition factors for male and female **tawes** were 1.0243 ± 0.0061 and 1.0181 ± 0.0054 , respectively.

Size at first gonad maturity (L_{50})

The results of the analysis of the size of the first mature gonads (L_{50}) of male fish are different from females. Female fish are faster to mature gonads, i.e. $L_{50} = 18.3$ cm than males $L_{50} = 19.9$ cm.

Gonad maturity

Determination of gonad maturity criteria is macroscopic by observing the morphological shape, size, color and position of the gonads in the abdominal cavity. The development of gonads (ovary and testes) of silver barb is classified into five levels according to the instructions Hasnidar *et al.* (2022) and the condition of silver barb gonads. The gonadal stages are stage I (Immature), II (Developing), III (Maturing), IV (Mature) and V (spent) (Table 1).

Table 1. Gonad maturity of female and male silver barb

Maturity stage	Note	Female	Male
I	Immature	Ovary is small, extending anteriorly to posteriorly in the dorsal abdominal cavity, filled with white and viscous fluid, eggs not yet visible, estimated to fill <15% of the abdominal cavity.	Testes are small and thin, extending from anterior to posterior of the abdominal cavity, filled with clear white fluid
II	Developing	Ovary is larger than immature ovaries, white in color, egg grains are visible, estimated to fill 20-30% of the abdominal cavity. The average egg diameter is 0.20 – 0.425 mm	Testes are enlarged, larger than stage I (immature) testes; filled with white liquid
III	Maturing	Ovary is enlarged, filled with greenish-white soft granules, egg granules are still difficult to separate. Estimated to fill almost 30%-60% of the abdominal cavity. The average egg diameter is 0.450 - 0.750 mm	Testes are getting bigger and larger than stage II, the surface of the testes appears to be ridged. Contains thick white liquid
IV	Mature	Ovary is getting bigger, filling about 60-80% of the abdominal cavity. ovaries contain yellowish-green egg grains, the average egg diameter is 0.800 - 1.25 mm	Testes are getting bigger larger than stage III, the surface of the testes is grooved. Contains thick milky white liquid
V	Spent	Ovary reduced, creased, ovary wall thick and lobed, yellowish-green color containing unspawned residual eggs	Testes reduced in size, wrinkled edges

Fecundity

The number of gonads mature female (stage IV) was 82 fish with a length range of 7.5-17.5 cm and weights of 7-82 g, gonad weights of 1.25-10.11 g. The fecundity of silver barb obtained in this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The fecundity of silver barb obtained from the results of this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The relationship between fecundity and total length is $F = 4.6297 L^{2.958}$ ($R^2 = 0.3526$), fecundity with body weight is a linear relationship that is $F = 444.66W + 1489.3$ ($R^2 = 0.5145$) (Fig. 5 a, b).

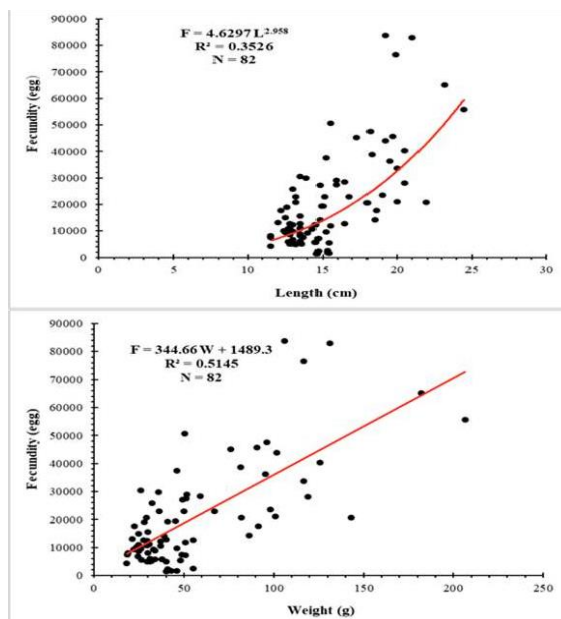


Fig 5: Fecundity-length (a), fecundity-weight (b) relationships of silver barb

Discussion

The length size structure of silver barb is 8.9 - 28.5 cm, with the highest ~~proportion~~ caught size of 14.5 cm. Furthermore, the weight size structure is 21.2 - 312.8 g; and the largest proportion caught is 21.2 g in weight size. The data shows that the length and weight of silver barb captured are dominant in small size. The distribution of length and weight of silver barb in several locations is presented in Table 2.

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The length and weight structure of silver barb from several waters show low values compared to silver barb caught in Dan Tchang Reservoir, Thailand, which is 45 cm and 2,100 g (Chheng *et al.*, 2004). These data indicate that silver barb fishing, in Lake Tempe in particular, is very intensive and even overexploited (Sukarman, 2022). Silver barb do not have the opportunity to grow large due to intensive fishing. In addition, the less optimal environmental conditions of the lake, the presence of predators or competitors, and the limited ability of swimming larvae to escape from environmental factors are thought to affect the survival and growth. According to (Arevalo *et al.*, 2023), 99% mortality of a large number of fish species occurs in the early phase of fish life. Such high mortality is thought to have influenced variations in silver barb population size.

The total sex ratio of male and female is 1:1, indicating a balanced number of male and female fish. Silver barb with a male and female ratio of 1:1 (Maknuu, 2016), 1:1.27 (Jasmine and Begum, 2016), 1:2 (Ardelia *et al.*, 2023), 4:1 (Efizon *et al.*, 2021). Sex ratios can differ between the same fish species, because sex determination is not only determined by genetic factors but also by the environment (Capel, 2017), a sex ratio of 1:1 is an ideal description because both male and female fish have the same opportunity to maintain their species. Although silver barb experience high exploitation pressure, the sex ratio data shows that silver barb still have a high ability to maintain their population.

Furthermore, the sex ratio of gonads mature males and females is 27 fish (25%) and 83 fish (75%) or 1:3, meaning that 1 male is paired with 3 females for spawning activities (polygamy). The sex ratio in spawning is related to the interaction and synchronization between male and female fish (Mylonas *et al.*, 2010) as well as the

efficient use of the number of male or female fish in spawning. Each fish species has a different optimal male and female sex ratio for spawning, such as climbing perch, *Anabas testudineus* is 1:2 (Hasnidar *et al.*, 2022); sailfin molly, *Poecilia latipinna* is 1:10 (Tamsil and Hasnidar, 2019); silver barb, *Barbonymus* sp. is 6:1 (Efizon *et al.*, 2021).

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The results of the analysis of the length-weight relationship of male silver barb obtained relationship model $W = 0.0234 L^{2.7349}$, female $W = 0.0172 L^{2.8766}$, combined (male and female) $W = 0.0183 L^{2.8415}$ (Figure 5). The t test results obtained the value of b silver barb male, female and combined different from 3 ($b \neq 3$) so it can be concluded that the growth pattern is allometric. Because the value of $b < 3$, it is called negative allometric. Some research results on the length-weight relationship of silver barb in several aquatic locations as shown in Table 3.

Differences in tawes growth patterns are due to differences in aquatic conditions. An important factor affecting the growth of fish in the tropics is the availability of food (Froese, 2006). Therefore, the same fish species in different locations will have different growth patterns due to this factor. In addition to food, other factors are the stage of gonad development, water physico-chemistry, fish health conditions, season, time and sampling techniques (Sheridan, 2011; Mehanna and Farouk, 2021). The number of fish caught in this study was 1623 fish, of which only 109 fish or 6.7% were mature gonads (stage IV), which is thought to be the cause of the negative allometric growth pattern.

Condition Factor (CF) is a value that reflects the influence of environmental factors on the physiological condition (Faradonbeh *et al.*, 2015). Good environmental conditions including the availability of food will support good growth so that the weight of the fish is higher and the $CF \geq 1$, on the other hand, environmental conditions are not suitable and limited food availability causes small weight gain and $CF < 1$ (Dirican & Cilek, 2012). The CF value of the results of this study is 1.024 - 1.018; this value indicates the condition of the fish body is thin (compressed), the same as the growth pattern, which is negative allometric, that is length growth is faster than weight.

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The condition factor of silver barb from several studies is 0.84 - 1.4 (Buwono *et al.*, 2019), 1.05 – 317 (Sidik *et al.*, 2020), 1.01 – 1.02 (Dwirastina and Marson, 2021), 0.82 – 1.10 (Syaiful *et al.*, 2019), 0.76 – 2.27 (Laila, 2018), 1.145-1.328 (Maknuu, 2016).

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The varying CF are due to differences in aquatic environment, density, food availability, and physiological conditions such as fish reproductive cycles. The higher the CF value indicates the compatibility of the fish with its environment.

The results of the analysis of the level of maturity of the gonads macroscopically show that in each level of maturity there are differences in size, color, and volume of gonads in the abdominal cavity of the ovary and testes. In the ovary, the higher the level of maturity, the diameter of oocytes tends to increase, but there are variations in the diameter of oocytes at the same maturity stage (Table 1). Similarly, histological observations show that there are different sizes of oocyte diameter in the (Efizon *et al.*, 2021). These data indicate that tawes are gradual spawners, that is, they release their eggs not all at once during spawning. Gradual spawners have a long spawning season. The spawning season of silver barb in Tempe Lake is thought to be throughout the year, it can be seen in every fish sampling from January to June that mature (stage IV) is found every month of observation, with the highest mature in January. In contrast to silver barb in Padma River Bangladesh, the spawning season is April - July and the peak spawning is in June (Jasmine and Begum, 2016).

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Length at first maturity (L_{50}) is the value at which 50% of individuals in a group have reproduced at least once (Barzotto and Mateus, 2017). The length at first maturity of male = 19.9 cm, and female = 18.3 cm. The L_{50} value of the results of this study is greater than the L_{50} of silver barb from Nagan river, Aceh Province, Indonesia, e.g. male = 7.3 cm and female = 8.5 cm (Efizon *et al.*, 2021). The length of the first maturing gonads of fish can differ due to competition and predation, fishing pressure and environmental conditions (de Souza *et al.*, 2019). Fish will perform the first maturation with a shorter length to reduce the risk of death before reproduction if environmental conditions are unfavorable (Barzotto and Mateus, 2017). Based on the

L₅₀ value of male and female in relation to the length of the dominant silver barb caught in this study, ± 90% of the fish caught have never reproduced.

Silver barb identified as maturity stage IV in this study were 82 fish, having a length range of 12.2 - 21.28 cm (average ± 15.0 cm) and body weight of 21.0 - 124.4 g (average ± 41 g), producing fecundity with a range of 1,443 - 83,822 eggs (average = 20,239 eggs). Fecundity data of silver barb in several aquatic are presented in Table 4.

The estimated coefficient of determination (R^2) of the relationship between fecundity-length (F-L) and fecundity-weight (F-W) showed that 35.3% of the variation in fecundity occurred due to variation in total fish length and 51.5% of the variation in fecundity due to the influence of variation in body weight. Similar observations on tawes from Nagan river, Aceh Province, Indonesia; the coefficient of determination (R^2) of the relationship between F-L and F-W was 51% and 24.2%, respectively (Efizon *et al.*, 2021). This means that tawes fecundity increases with increasing total length and body weight. Fish that have a larger size in addition to having a large visceral cavity to accommodate a larger number of oocytes also have sufficient energy for reproductive activities (Jonsson and Jonsson, 1999). Factors that affect fish fecundity are internal factors such as genetics, age, and size (Hunter *et al.*, 1992), while external factors are food availability and environmental conditions (Bryan *et al.*, 2007).

Conclusions

The length and weight structure of female fish were higher than male fish. The dominant lengths and weights caught were 14.5 cm and 21.2 g. Negative allometric growth pattern and condition factor 1.02; lean growth. The overall ratio of male and female was 1-: 1, while the spawning sex ratio was 1 : 3; that is, one male fish is paired with 3 females in spawning. The first size of gonad maturity of female fish was faster at 18.3 cm and 19.9 cm for males. Fecundity ranged from 253 to 13,398 eggs (mean

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2,571 eggs). Variation in fecundity was more strongly influenced by variation in body weight than variation in total length of silver barb.

Acknowledgments

To the Rector of Universitas Muslim Indonesia (UMI) Makassar through the Institute for Research and Resource Development which has supported funds so that this research can be carried out.

Conflicts of interest

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Reproductive biology of silver barb, *Barbonymus gonionotus* (Bleeker, 1850), in Tempe Lake, Indonesia

Hasnidar Hasnidar^{1*}; Andi Tamsil¹

Abstract

Information on the reproductive biology of silver barb is needed for conservation and domestication purposes. This study aims to analyze the reproductive biology of silver barb in Tempe Lake South Sulawesi, Indonesia. Aspects of reproductive biology analyzed were length-weight structure, sex ratio, length-weight relationship, condition factor, size at first gonad maturity (L_{50}), gonad of maturity and fecundity. This study used primary data, silver barb were caught using gill nets every two weeks from January to July 2023. The total length of fish was measured using an ichthyometer with an accuracy of 0.1 cm, and weight using a digital scale with an accuracy of 0.01 g. The gonads were preserved in 4% formalin solution, fecundity was calculated based on the gravimetric method. Male structures respectively are 8.9 - 22.9 cm long, while females respectively are 8.9 - 28.5 cm long; males weigh between respectively 21.2 - 183.2 g, and females weigh between respectively 21.2 - 312.8 g. The overall sex ratio of males and females was 1:1, while the sex ratio during spawning was 1:3 (polygamous). Length-weight relationships between males and females were $W = 0.0234L^{2.7349}$ and $W = 0.0172L^{2.8766}$ respectively. The condition factor for males and females was the same at 1.02. The size of first maturing gonads for females was 18.3 cm and 19.9 cm for males. Partial spawning, with fecundity ranging from 253 to 13,398 eggs.

Keywords: Reproductive biology, Silver barb, Tempe Lake, Length-weight relation

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Introduction

Silver barb, *Barbonymus gonionotus* (Bleeker, 1850) is an economically important freshwater fish in several countries such as Indonesia, Malaysia, Thailand, Myanmar, Bangladesh, India, and China. The taste is good and the price is relatively cheap so it becomes the main consumption of the community, especially some places in the territory of Indonesia. Silver barb production still mainly depends on fishing, so fishing pressure continues to increase.

Tempe Lake has a diversity of fish species consisting of native fish, introduced fish and migratory marine fish. According to Dina *et al.* (2019), the native fishes of Tempe Lake are *Monopterus albus*, *Anabas testudineus*, *Glossogobius aureus*, *Channa striata*. Introduced fish species are *Barbonymus gonionotus*, *Clarias batrachus*, *Trichopodus pectoralis*, *Pangasianodon hypophthalmus*, *Osteochilus vittatus*, *Oreochromis niloticus*, *Helostoma temminckii*, *Cyprinus carpio* (Yanuarita *et al.*, 2020). Migratory marine fish species are *Megalops cyprinoides*, *Stenogobius gymnopomus*, *Anguilla marmorata* and *Caranx sexfasciatus*. Introductions are carried out to increase the production of fishery products to meet increasing demand, optimize water productivity, increase production in a sustainable and increase biodiversity (Yanuarita *et al.*, 2020; FAO, 2022).

Tempe Lake is presently experiencing various environmental problems, including eutrophication (Aisyah and Nomosatryo, 2016). Eutrophication occurs allegedly due to the load of nutrients derived from the activities of humans, plantations and farms that are often found on the shores of the lake. Nitrate and phosphate nutrients are in the range of 0.1063-0.2620 mg/l and 0.0245-0.0655 mg/l respectively in the water (Samuel *et al.*, 2012). These conditions trigger the growth of aquatic weeds such as *Ipomoea aquatic* and *Eichhornia crassipes*. *E. crassipes* is the most dominant of these plants and its population is estimated to have covered the lake surface by about 30 - 40%. According to (Yani *et al.*, 2019), Lake Tempe has experienced moderate to severe pollution in several parameters including turbidity, total suspended solid, biological oxygen demand, nitrate, and phosphate.

Another problem is overfishing and the use of fishing gear that is not environmentally sustainable (Nasution, 2012), and a serious problem is the presence of invasive fish, i.e. *Pterygoplichthys* spp (Hasnidar *et al.*, 2021). The high population of *Pterygoplichthys* spp has caused fishermen's catches of target fish to decline (Hasrianti *et al.*, 2020). The presence of *Pterygoplichthys* spp impacts the lake ecosystem through competition for habitat, diet, and can even be a predator of native and endemic fish, as well as an agent of various diseases. It can change the species composition and structure of fish communities, dominating and excluding native and endemic fish (Syafei and Sudinno, 2018).

Silver barb, *B. gonionotus* was introduced to Lake Tempe in 1937 (Dina *et al.*, 2019; Yanuarita *et al.*, 2020). Although an introduced fish, Tawes (Silver barb) successfully adapted well to the lake environment. The condition of Tempe Lake, which is rich with dominant aquatic plants, enables to survive well. Silver barb are herbivorous, with phytoplankton (Chlorophyceae) as their main food (Ain *et al.*, 2021); aquatic plants (80%), detritus (12%), phytoplankton (8.5%) (Aida, 2018; Pratiwi *et al.*, 2021). Silver barb are considered useful in controlling excessive vegetation in lake waters. Although silver barb successfully lives in Tempe Lake, the declining environmental conditions of Tempe Lake certainly have an impact on the production of these fish.

Silver barb production has fluctuated in recent years, with capture mortality higher than natural mortality due to overfishing (Sukarman, 2022). This condition is thought to be due to the presence of *Pterygoplichthys* spp as an invasive fish (Hasnidar *et al.*, 2021). There are two species that are still caught in large numbers, e.i. silver barb and bloso (*Glossogobius* sp), therefore both fish species are under very high fishing pressure. Conservation and domestication efforts will be carried out, but these efforts require the latest information including aspects of silver barb reproductive biology for the future management. The study aims to analyze the reproductive biology of silver barb including size distribution, sex ratio, length and weight relationship, condition factor, gonad maturity, size of first mature gonad, and fecundity.

Materials and methods

The study was conducted from January to July 2023 in Tempe Lake, Wajo Regency, South Sulawesi Province, Indonesia (Fig. 1). Fish sampling was collected every week for six months, using a gill net response tool. Fish samples caught were cleaned, put in a cooler box and given ice cubes. Sample observations were carried out at the Biota and Environmental Engineering Laboratory, Faculty of Fisheries and Marine Science, Universitas Muslim Indonesia (UMI) Makassar.

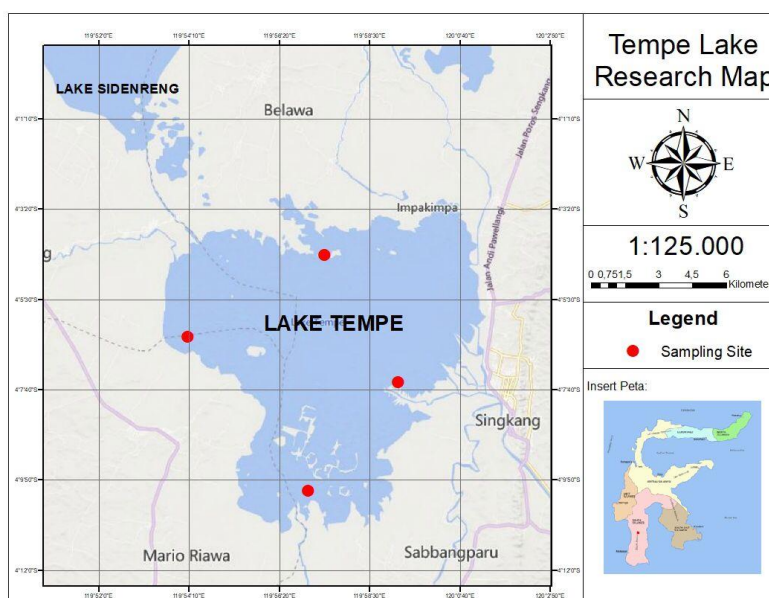


Fig 1. Silver barb fishing sampling points on the site in Tempe Lake, Wajo Regency, South Sulawesi, Indonesia.

The total length (Lt) of silver barb was measured using an ichthymeter (Vernier calipers, Mitutoyo) with an accuracy of 0.1 cm, body weight and gonads (g) were measured using digital scales (Digital elektrik scale, DIGI DS880) with an accuracy of 0.01g. The parameters analyzed were:

Length and weight structure

Length and weight size structures were determined as follows: determining the number of classes; determining the length class interval of 1 cm and weight of 1 g; inserting

each fish sample in the predetermined class. The size structure was determined within the same class interval and then plotted on a graph.

Sex ratio

The sex of silver barb was determined morphologically and anatomically by dissecting the fish to see whether the gonads developed into testes or ovaries. Determination of male and female sex ratio is done by calculating the number of male fish and female fish caught using the formula (Oliveira *et al.*, 2012):

$$N = \frac{\text{number of male of female}}{\text{total number of fish observed}} \times 100$$

Next, sex ratio variability was tested using the Chi-square test (Oliveira *et al.*, 2012):

$$X^2 = \frac{\sum(o_i - e_i)^2}{e_i}$$

Description: X^2 = Value for a random variable whose sampling distribution approximates the Chi-square distribution

o_i = Observed frequencies of male and female fish

e_i = Expected frequencies of male and female fish

Length-weight relationship

The relationship between length and weight was analyzed using the formula (Le Cren, 1951):

$$W = aL^b$$

Description W = Fish body weight (g), L = Total length of fish (cm), a = Coefficient of determination, b = exponent that indicates isometric or allometric.

To obtain the equation, the values of W and L were transformed into logarithms (base 10) as follows:

$$W = \log a + b \log L$$

The b values obtained were used to estimate the two parameters (length and weight) analyzed, with hypotheses: 1) $b = 3$ indicates an isometric growth pattern, 2) $b \neq 3$ indicates an allometric growth pattern, a) $b > 3$: faster weight gain (positive allometric), b) $b < 3$: faster length gain (negative allometric).

Condition factor

Because the growth pattern of silver barb in this study is negative allometric ($b \neq 3$),

the formulation (Le Cren, 1951) is:

$$Kn = \frac{W}{a L^b}$$

Description Kn = Condition factor, W = Fish body weight (g), L = Total length of fish (cm), a = a = Intercept, b = slope

Size at first gonadal maturity (L_{50})

The size of the first time the fish matures gonads is obtained by finding the value of L_{50} by plotting the cumulative percentage of gonadal mature fish with the size of the fish body length, so that a standard logistic curve will be obtained and the intersection point between the curve and 50% cumulative frequency is the length when 50% of the fish first matures gonads.

Gonad maturity

The stage of gonadal maturity was observed macroscopically, the observation procedure is when the silver barb was first dissected, and the visceral cavity was opened to observe the morphology of the gonads including: shape, color, size, gonad position in the abdominal cavity and egg diameter. Maturity stages were classified according to Brown-Peterson *et al.* (2011), and modified according to silver barb conditions, i.e. stage I (Immature); II (Developing); III (Maturing); IV (Mature) and V (Spent). Egg diameter was observed by taking samples of stage IV fish gonads then each fish gonad was taken in 3 parts, i.e. posterior, anterior, and middle gonads. Eggs were taken from each part of the gonad sample, with 30 eggs in each part. A total of 90 fish egg samples were measured in diameter using an ocular micrometer (0.01 mm) brand UYCP-12.

Fecundity

Fecundity can be known the procedure that the weight of the total gonads (WG), then take a subpart of the total gonad at each end of the bottom, middle and top then measure its weighed (Ws). The weight of the gonad subpart was then preserved in a 4% formalin solution to facilitate the calculation of the number of eggs (n). Fecundity was observed in maturity stage IV, calculated using the gravimetric method (Hasan *et al.*, 2020):

$$F = \frac{\text{Weight of the total gonad (WG)}}{\text{Weight subpart gonad (Ws)}} \times \text{number of eggs of the subpart gonad (n)}$$

The relationship between fecundity and total length and body weight using the formulation Hasan *et al.* (2020) is:

$$F = a L^b \quad \text{and} \quad F = a W + b$$

Description F = Fecundity (egg), L = Total length of fish (cm), W = Fish body weight (g), a = Intercept, b = slope

Results

Length and weight structure

The results of the length structure analysis of male tawes are 8.9 - 22.9 cm and females are 8.9 - 28.5 cm, the largest proportion caught at 14.5 cm both males and females. While the size structure of male weights is 21.2 - 183.2 g and female are 21.2 - 312.8 g; and the largest proportion of males and females caught is the same weight size of 21.2 g (Fig. 2 a and b).

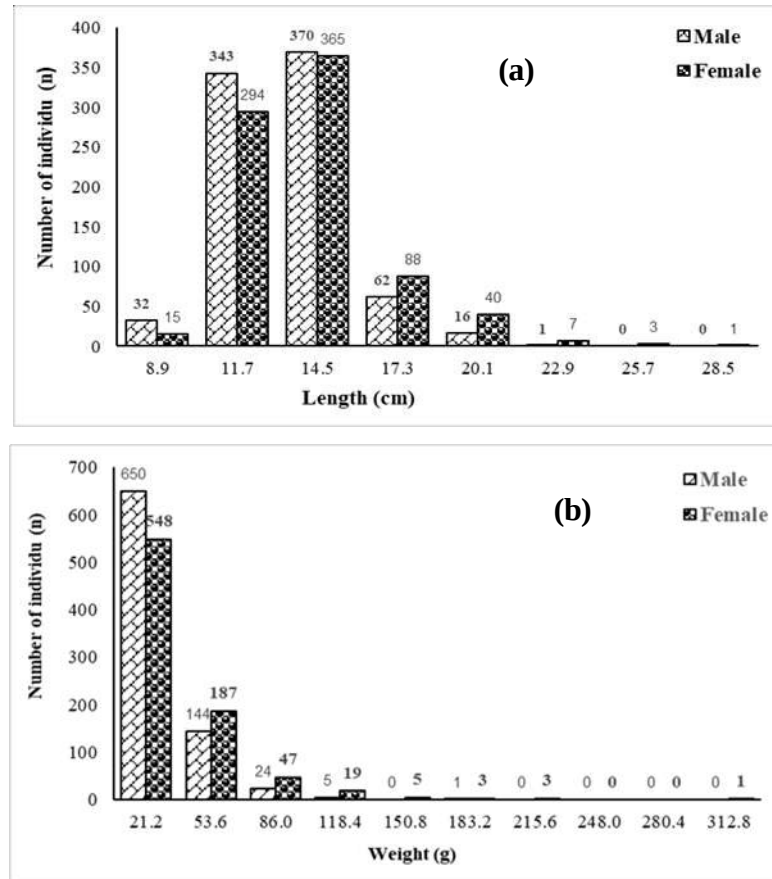


Fig 2. Length (a) and weight (b) structure of silver barb

Sex Ratio

The total sex ratio of males and females was 824 (50%) and 813 (50%), indicating a male-to-female sex ratio of 1:1 (Fig. 3a). The sex ratio of gonadally mature males and females was 27 (25%) and 83 (75%), indicating that 1 male was partnered with 3 females for spawning activities (Fig. 3b).

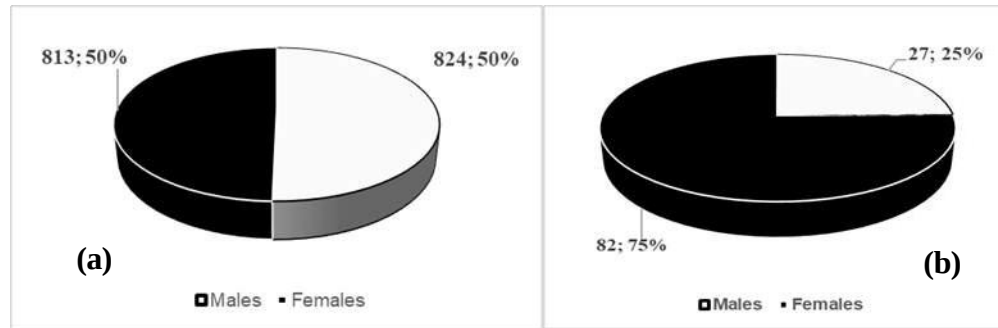


Fig 3. Male-to-female sex ratio of silver barb total fish (a), and gonad of maturity (b)

Length-weight relationship

The results of the analysis of the length-weight relationship of male was $W = 0.0234 L^{2.7349}$ and female $W = 0.0172 L^{2.8766}$ and combined (male and female) $W = 0.0183 L^{2.8415}$ (Fig. 4 a, b, c). The t-test results showed that the b value of male, female and combined (male and female) silver barb is different from 3 ($b \neq 3$) so it can be concluded that the growth pattern is allometric. Because the value of $b < 3$, it is negatively allometric.

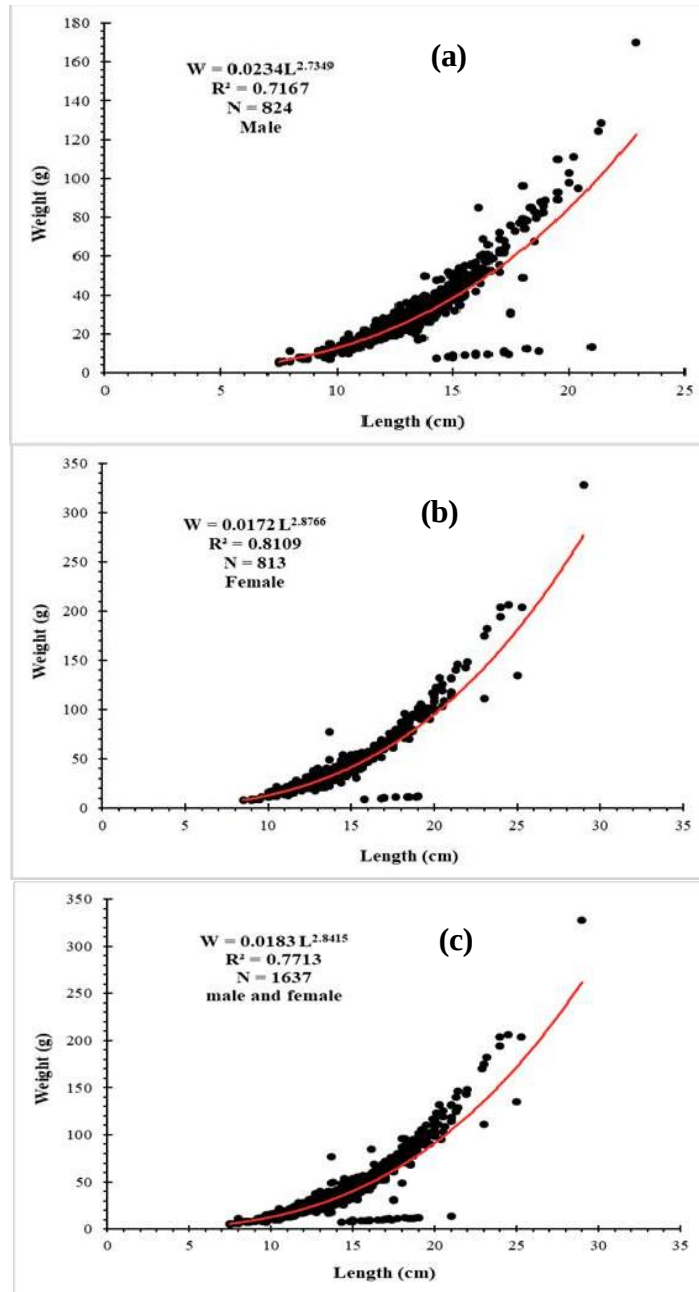


Fig 4. Length-weight relationship of male (a), female (b) and combined (male and female) (c)

Condition Factor

Condition factors for male and female silver barb were 1.0243 ± 0.0061 and 1.0181 ± 0.0054 , respectively.

Size at first gonad maturity (L_{50})

The results of the analysis of the size of the first mature gonads (L_{50}) of male fish are different from females. Female fish are faster to mature gonads, i.e. $L_{50} = 18.3$ cm than males $L_{50} = 19.9$ cm.

Gonad maturity

Determination of gonad maturity criteria is macroscopic by observing the morphological shape, size, color and position of the gonads in the abdominal cavity. The development of gonads (ovary and testes) of silver barb is classified into five levels according to the instructions Hasnidar *et al.* (2022) and the condition of silver barb gonads. The gonadal stages are stage I (Immature), II (Developing), III (Maturing), IV (Mature) and V (spent) (Table 1).

Table 1. Gonad maturity of female and male silver barb

Maturity stage	Note	Female	Male
I	Immature	Ovary is small, extending anteriorly to posteriorly in the dorsal abdominal cavity, filled with white and viscous fluid, eggs not yet visible, estimated to fill <15% of the abdominal cavity.	Testes are small and thin, extending from anterior to posterior of the abdominal cavity, filled with clear white fluid
II	Developing I	Ovary is larger than immature ovaries, white in color, egg grains are visible, estimated to fill 20-30% of the abdominal cavity. The average egg diameter is 0.20 – 0.425 mm	Testes are enlarged, larger than stage I (immature) testes; filled with white liquid
III	Maturing	Ovary is enlarged, filled with greenish-white soft granules, egg granules are still difficult to separate. Estimated to fill almost 30%-60% of the abdominal cavity. The average egg diameter is 0.450 - 0.750 mm	Testes are getting bigger and larger than stage II, the surface of the testes appears to be ridged. Contains thick white liquid
IV	Mature	Ovary is getting bigger, filling about 60-80% of the abdominal cavity. ovaries contain yellowish-green egg grains, the average egg diameter is 0.800 - 1.25 mm	Testes are getting bigger larger than stage III, the surface of the testes is grooved. Contains thick milky white liquid
V	Spent	Ovary reduced, creased, ovary wall thick and lobed, yellowish-green color containing	Testes reduced in size, wrinkled edges
		unspawned residual eggs	

Fecundity

The number of gonads mature female (stage IV) was 82 fish with a length range of 7.5-17.5 cm and weights of 7-82 g, gonad weights of 1.25-10.11 g. The fecundity of silver barb obtained in this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The fecundity of silver barb obtained from the results of this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The relationship between fecundity and total length is $F = 4.6297 L^{2.958}$ ($R^2 = 0.3526$), fecundity with body weight is a linear relationship that is $F = 444.66W + 1489.3$ ($R^2 = 0.5145$) (Fig. 5 a, b).

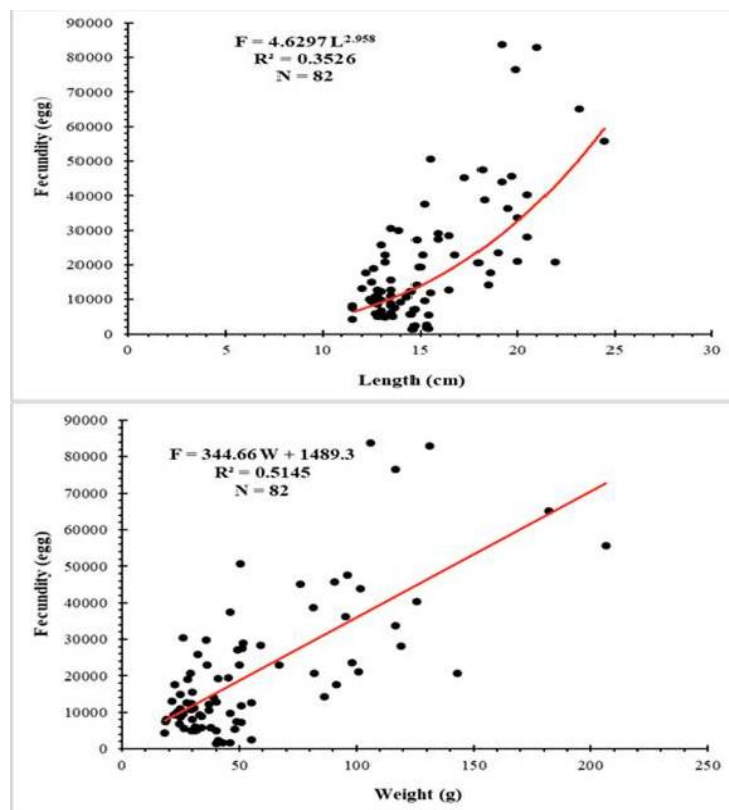


Fig 5. Fecundity-length (a), fecundity-weight (b) relationships of silver barb

Discussion

The length size structure of silver barb is 8.9 - 28.5 cm, with the highest caught size of 14.5 cm. Furthermore, the weight size structure is 21.2 - 312.8 g; and the largest proportion caught is 21.2 g in weight size. The data shows that the length and weight of silver barb captured are dominant in small size.

The length and weight structure of silver barb from several waters show low values compared to silver barb caught in Dan Tchang Reservoir, Thailand, which is 45 cm and 2,100 g (Chheng *et al.*, 2004). These data indicate that silver barb fishing, in Lake Tempe in particular, is very intensive and even overexploited (Sukarman, 2022). Silver barb do not have the opportunity to grow large due to intensive fishing. In addition, the less optimal environmental conditions of the lake, the presence of predators or competitors, and the limited ability of swimming larvae to escape from environmental factors are thought to affect the survival and growth. According to (Arevalo *et al.*, 2023), 99% mortality of a large number of fish species occurs in the early phase of fish life. Such high mortality is thought to have influenced variations in silver barb population size.

The total sex ratio of male and female is 1:1, indicating a balanced number of male and female fish. Silver barb with a male and female ratio of 1:1 (Maknuu, 2016), 1:1.27 (Jasmine and Begum, 2016), 1:2 (Ardelia *et al.*, 2023), 4:1 (Efizon *et al.*, 2021). Sex ratios can differ between the same fish species, because sex determination is not only determined by genetic factors but also by the environment (Capel, 2017), a sex ratio of 1:1 is an ideal description because both male and female fish have the same opportunity to maintain their species. Although silver barb experience high exploitation pressure, the sex ratio data shows that silver barb still have a high ability to maintain their population.

Furthermore, the sex ratio of gonads mature males and females is 27 fish (25%) and 83 fish (75%) or 1:3, meaning that 1 male is paired with 3 females for spawning activities (polygamy). The sex ratio in spawning is related to the interaction and synchronization between male and female fish (Mylonas *et al.*, 2010) as well as the

efficient use of the number of male or female fish in spawning. Each fish species has an optimal sex ratio of males to females for spawning, for example climbing perch, *Anabas testudineus* is 1:2 (Hasnidar et al., 2022); Sailfin molly, *Poecilia latipinna* is 1:10 (Tamsil and Hasnidar, 2019); silver barb, *Barbonymus sp.* is 6:1 (Efizon *et al.*, 2021).

The results of the analysis of the length-weight relationship of male silver barb obtained relationship model $W = 0.0234 L^{2.7349}$, female $W = 0.0172 L^{2.8766}$, combined (male and female) $W = 0.0183 L^{2.8415}$. The t test results obtained the value of b silver barb male, female and combined different from 3 ($b \neq 3$) so it can be concluded that the growth pattern is allometric. Because the value of $b < 3$, it is called negative allometric. Some research results on the length-weight relationship of silver barb in several aquatic locations.

Differences in tawes growth patterns are due to differences in aquatic conditions. An important factor affecting the growth of fish in the tropics is the availability of food (Froese, 2006). Therefore, the same fish species in different locations will have different growth patterns due to this factor. In addition to food, other factors are the stage of gonad development, water physico-chemistry, fish health conditions, season, time and sampling techniques (Sheridan, 2011; Mehanna and Farouk, 2021). The number of fish caught in this study was 1623 fish, of which only 109 fish or 6.7% were mature gonads (stage IV), which is thought to be the cause of the negative allometric growth pattern.

Condition Factor (CF) is a value that reflects the influence of environmental factors on the physiological condition (Faradonbeh *et al.*, 2015). Good environmental conditions including the availability of food will support good growth so that the weight of the fish is higher and the $CF \geq 1$, on the other hand, environmental conditions are not suitable and limited food availability causes small weight gain and $CF < 1$ (Dirican and Cilek, 2012). The CF value of the results of this study is 1.024 - 1.018; this value indicates the condition of the fish body is thin (compressed), the same as the growth pattern, which is negative allometric, that is length growth is faster than weight.

The condition factor of silver barb from several studies is 0.84 - 1.4 (Buwono *et al.*, 2019), 1.05 – 317 (Sidik *et al.*, 2020), 1.01 – 1.02 (Dwirastina and Marson, 2021), 0.82 – 1.10 (Syaiful *et al.*, 2019), 0.76 – 2.27 (Laila, 2018), 1.145-1.328 (Maknuu, 2016). The varying CF are due to differences in aquatic environment, density, food availability, and physiological conditions such as fish reproductive cycles. The higher the CF value indicates the compatibility of the fish with its environment.

The results of the analysis of the level of maturity of the gonads macroscopically show that in each level of maturity there are differences in size, color, and volume of gonads in the abdominal cavity of the ovary and testes. In the ovary, the higher the level of maturity, the diameter of oocytes tends to increase, but there are variations in the diameter of oocytes at the same maturity stage. Similarly, histological observations show that there are different sizes of oocyte diameter in the (Efizon *et al.*, 2021). These data indicate that tawes are gradual spawners, that is, they release their eggs not all at once during spawning. Gradual spawners have a long spawning season. The spawning season of silver barb in Tempe Lake is thought to be throughout the year, it can be seen in every fish sampling from January to June that mature (stage IV) is found every month of observation, with the highest mature in January. In contrast to silver barb in Padma River Bangladesh, the spawning season is April - July and the peak spawning is in June (Jasmine and Begum, 2016).

Length at first maturity (L_{50}) is the value at which 50% of individuals in a group have reproduced at least once (Barzotto and Mateus, 2017). The length at first maturity of male = 19.9 cm, and female = 18.3 cm. The L_{50} value of the results of this study is greater than the L_{50} of silver barb from Nagan river, Aceh Province, Indonesia, e.g. male = 7.3 cm and female = 8.5 cm (Efizon *et al.*, 2021). The length of the first maturing gonads of fish can differ due to competition and predation, fishing pressure and environmental conditions (de Souza *et al.*, 2019). Fish will perform the first maturation with a shorter length to reduce the risk of death before reproduction if environmental conditions are unfavorable (Barzotto and Mateus, 2017). Based on the

L_{50} value of male and female in relation to the length of the dominant silver barb caught in this study, $\pm 90\%$ of the fish caught have never reproduced.

Silver barb identified as maturity stage IV in this study were 82 fish, having a length range of 12.2 - 21.28 cm (average ± 15.0 cm) and body weight of 21.0 - 124.4 g (average ± 41 g), producing fecundity with a range of 1,443 - 83,822 eggs (average = 20,239 eggs). Fecundity data of silver barb in several aquatic are presented in Table 4.

The estimated coefficient of determination (R^2) of the relationship between fecundity-length (F-L) and fecundity-weight (F-W) showed that 35.3% of the variation in fecundity occurred due to variation in total fish length and 51.5% of the variation in fecundity due to the influence of variation in body weight. Similar observations on tawes from Nagan river, Aceh Province, Indonesia; the coefficient of determination (R^2) of the relationship between F-L and F-W was 51% and 24.2%, respectively (Efizon *et al.*, 2021). This means that tawes fecundity increases with increasing total length and body weight. Fish that have a larger size in addition to having a large visceral cavity to accommodate a larger number of oocytes also have sufficient energy for reproductive activities (Jonsson and Jonsson, 1999). Factors that affect fish fecundity are internal factors such as genetics, age, and size (Hunter *et al.*, 1992), while external factors are food availability and environmental conditions (Bryan *et al.*, 2007).

Conclusions

The length and weight structure of female fish were higher than male fish. The dominant lengths and weights caught were 14.5 cm and 21.2 g. Negative allometric growth pattern and condition factor 1.02; lean growth. The overall ratio of male and female was 1 : 1, while the spawning sex ratio was 1 : 3; that is, one male fish is paired with 3 females in spawning. The first size of gonad maturity of female fish was faster at 18.3 cm and 19.9 cm for males. Fecundity ranged from 253 to 13,398 eggs (mean

2,571 eggs). Variation in fecundity was more strongly influenced by variation in body weight than variation in total length of silver barb.

Acknowledgments

To the Rector of Universitas Muslim Indonesia (UMI) Makassar through the Institute for Research and Resource Development which has supported funds so that this research can be carried out.

Conflicts of interest

We declare that this research was conducted without any conflict of interest with any party.

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Reproductive biology of silver barb, *Barbonymus gonionotus* (Bleeker, 1850), in Tempe Lake, Indonesia

Andi Tamsil¹; Hasnidar Hasnidar^{1*}; Andi Tamsil²

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Abstract

Information on the reproductive biology of silver barb is needed for conservation and domestication purposes. This study aims to analyze the reproductive biology of silver barb in Tempe Lake South Sulawesi, Indonesia. Aspects of reproductive biology analyzed were length-weight structure, sex ratio, length-weight relationship, condition factor, size at first gonad maturity (L_{50}), gonad of maturity, and fecundity. This study used primary data, silver barb were caught using gill nets every two weeks from January to July 2023. The total length of fish was measured using an ichthyometer with an accuracy of 0.1 cm, and weight using a digital scale with an accuracy of 0.01 g. [The gonads were preserved in 4% formalin solution, fecundity was calculated based on the gravimetric method. Male structures ~~respectively are were~~ 8.9 - 22.9 cm long, while females respectively ~~we are~~ 8.9 - 28.5 cm long; males weigh between respectively 21.2 - 183.2 g, and females weigh between respectively 21.2 - 312.8 g. The overall sex ratio of males and females was 1:1, while the sex ratio during spawning was 1:3 (polygamous). Length-weight relationships between males and females were $W = 0.0234L^{2.7349}$ and $W = 0.0172L^{2.8766}$ respectively. The condition factor for males and females was the same at 1.02. The size of first maturing gonads for females was 18.3 cm and 19.9 cm for males. Partial spawning, with fecundity ranging from 253 to 13,398 eggs.

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Keywords: Reproductive biology, Silver barb, Tempe Lake, Length-weight relation

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Introduction

Silver barb, *Barbonymus gonionotus* (Bleeker, 1850) is an economically important freshwater fish in several countries such as Indonesia, Malaysia, Thailand, Myanmar, Bangladesh, India, and China. The taste is good and the price is relatively cheap so it becomes the main consumption of the community, especially some places in the territory of Indonesia. Silver barb production still mainly depends on fishing, so fishing pressure continues to increase.

Tempe Lake has a diversity of fish species consisting of native fish, introduced fish and migratory marine fish. According to Dina *et al.* (2019), the native fishes of Tempe Lake are *Monopterus albus*, *Anabas testudineus*, *Glossogobius aureus*, *Channa striata*. Introduced fish species are *Barbonymus gonionotus*, *Clarias batrachus*, *Trichopodus pectoralis*, *Pangasianodon hypophthalmus*, *Osteochilus vittatus*, *Oreochromis niloticus*, *Helostoma temminckii*, *Cyprinus carpio* (Yanuarita *et al.*, 2020). Migratory marine fish species are *Megalops cyprinoides*, *Stenogobius gymnopomus*, *Anguilla marmorata* and *Caranx sexfasciatus*. Introductions are carried out to increase the production of fishery products to meet increasing demand, optimize water productivity, increase production in a sustainable and increase biodiversity (Yanuarita *et al.*, 2020; FAO, 2022).

Tempe Lake is presently experiencing various environmental problems, including eutrophication (Aisyah and Nomosatryo, 2016). Eutrophication occurs allegedly due to the load of nutrients derived from the activities of humans, plantations and farms that are often found on the shores of the lake. Nitrate and phosphate nutrients are in the range of 0.1063-0.2620 mg/l and 0.0245-0.0655 mg/l respectively in the water (Samuel *et al.*, 2012). These conditions trigger the growth of aquatic weeds such as *Ipomoea aquatic* and *Eichhornia crassipes*. *E. crassipes* is the most dominant of these plants and its population is estimated to have covered the lake surface by about 30 - 40%. According to (Yani *et al.*, 2019), Lake Tempe has experienced moderate to severe pollution in several parameters including turbidity, total suspended solids, biological oxygen demand, nitrate, and phosphate.

Another problem is overfishing and the use of fishing gear that is not environmentally sustainable (Nasution, 2012), and a serious problem is the presence of invasive fish, i.e. *Pterygoplichthys* spp (Hasnidar *et al.*, 2021). The high population of *Pterygoplichthys* spp has caused fishermen's catches of target fish to decline (Hasrianti *et al.*, 2020). The presence of *Pterygoplichthys* spp impacts the lake ecosystem through competition for habitat, diet, and can even be a predator of native and endemic fish, as well as an agent of various diseases. It can change the species composition and structure of fish communities, dominating and excluding native and endemic fish (Syafei and Sudinno, 2018).

Silver barb or Java barb, *B. gonionotus* was introduced to Lake Tempe in 1937 (Dina *et al.*, 2019; Yanuarita *et al.*, 2020). Although an introduced fish, Tawes (Silver barb) successfully adapted well to the lake environment. The condition of Tempe Lake, which is rich with dominant aquatic plants, enables it to survive well. Silver barb are herbivorous, with phytoplankton (Chlorophyceae) as their main food (Ain *et al.*, 2021); aquatic plants (80%), detritus (12%), phytoplankton (8.5%) (Aida, 2018; Pratiwi *et al.*, 2021). Silver barb are considered useful in controlling excessive vegetation in lake waters. Although silver barb successfully lives in Tempe Lake, the declining environmental conditions of Tempe Lake certainly have an impact on the production of these fish.

Silver barb production has fluctuated in recent years, with capture mortality higher than natural mortality due to overfishing (Sukarman, 2022). This condition is thought to be due to the presence of *Pterygoplichthys* spp as an invasive fish (Hasnidar *et al.*, 2021). There are two species that are still caught in large numbers, ~~e.i.e~~ silver barb and bloso (*Glossogobius* sp), therefore both fish species are under very high fishing pressure. Conservation and domestication efforts will be carried out, but these efforts require the latest information including aspects of silver barb reproductive biology for the future management. The study aims to analyze the reproductive biology of silver barb including size distribution, sex ratio, length and weight relationship, condition factor, gonad maturity, size of first mature gonad, and fecundity.

Materials and methods

The study was conducted from January to July 2023 in Tempe Lake, Wajo Regency, South Sulawesi Province, Indonesia (Fig. 1). Fish sampling was collected every week for six months, using a gill net response tool. Fish samples caught were cleaned, put in a cooler box and given ice cubes. Sample observations were carried out at the Biota and Environmental Engineering Laboratory, Faculty of Fisheries and Marine Science, Universitas Muslim Indonesia (UMI) Makassar.

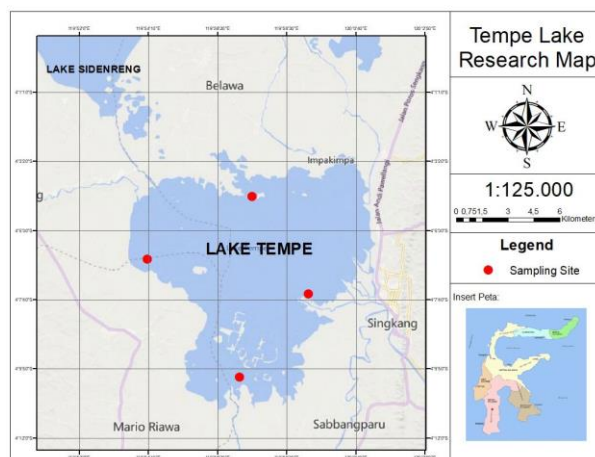


Fig 1. Silver barb fishing sampling points on the site in Tempe Lake, Wajo Regency, South Sulawesi, Indonesia.

The total length (Lt) of silver barb was measured using an ichthymeter (Vernier calipers, Mitutoyo) with an accuracy of 0.1 cm, body weight and gonads (g) were measured using digital scales (Digital elektrik scale, DIGI DS880) with an accuracy of 0.01g. The parameters analyzed were:

Length and weight structure

Length and weight size structures were determined as follows: determining the number of classes; determining the length class interval of 1 cm and weight of 1 g; inserting

Each fish sample in the predetermined class. The size structure was determined within the same class interval and then plotted on a graph.

Sex ratio

The sex of silver barb was determined morphologically and anatomically by dissecting the fish to see whether the gonads developed into testes or ovaries. Determination of male and female sex ratio is done by calculating the number of male fish and female fish caught using the formula (Oliveira *et al.*, 2012):

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$$N = \frac{\text{number of male of female}}{\text{total number of fish observed}} \times 100$$

Next, sex ratio variability was tested using the Chi-square test (Oliveira *et al.*, 2012):

$$X^2 = \frac{\sum (oi - ei)^2}{ei}$$

Description: X^2 = Value for a random variable whose sampling distribution approximates the Chi-square distribution

oi = Observed frequencies of male and female fish

ei = Expected frequencies of male and female fish

Length-weight relationship

The relationship between length and weight was analyzed using the formula (Le Cren, 1951):

$$W = aL^b$$

Description W = Fish body weight (g), L = Total length of fish (cm), a = Coefficient of determination, b = exponent that indicates isometric or allometric.

To obtain the equation, the values of W and L were transformed into logarithms (base 10) as follows:

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$$W = \log a + b \log L$$

The b values obtained were used to estimate the two parameters (length and weight) analyzed, with hypotheses: 1) $b = 3$ indicates an isometric growth pattern, 2) $b \neq 3$ indicates an allometric growth pattern, a) $b > 3$: faster weight gain (positive allometric), b) $b < 3$: faster length gain (negative allometric).

Condition factor

Because the growth pattern of silver barb in this study is negative allometric ($b \neq 3$),

the formulation (Le Cren, 1951) is:

$$Kn = \frac{W}{a L^b}$$

Description Kn = Condition factor, W = Fish body weight (g), L = Total length of fish (cm), a = Intercept, b = slope

Size at first gonadal maturity (L_{50})

The size of the first time the fish matures gonads is obtained by finding the value of L_{50} by plotting the cumulative percentage of gonadal mature fish with the size of the fish body length, so that a standard logistic curve will be obtained and the intersection point between the curve and 50% cumulative frequency is the length when 50% of the fish first matures gonads.

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Gonad maturity

The stage of gonadal maturity was observed macroscopically, the observation procedure is when the silver barb was first dissected, and the visceral cavity was opened to observe the morphology of the gonads including: shape, color, size, gonad position in the abdominal cavity and egg diameter. Maturity stages were classified according to Brown-Peterson *et al.* (2011), and modified according to silver barb conditions, i.e. stage I (Immature); II (Developing); III (Maturing); IV (Mature) and V (Spent). Egg diameter was observed by taking samples of stage IV fish gonads then each fish gonad was taken in 3 parts, i.e. posterior, anterior, and middle gonads. Eggs were taken from each part of the gonad sample, with 30 eggs in each part. A total of 90 fish egg samples were measured in diameter using an ocular micrometer (0.01 mm) brand UYCP-12.

Fecundity

Fecundity can be known the procedure that the weight of the total gonads (WG), then take a subpart of the total gonad at each end of the bottom, middle and top then measure its weighed (Ws). The weight of the gonad subpart was then preserved in a 4% formalin solution to facilitate the calculation of the number of eggs (n). Fecundity was observed in maturity stage IV, calculated using the gravimetric method (Hasan *et al.*, 2020):

$$F = \frac{\text{Weight of the total gonad (WG)}}{\text{Weight subpart gonad (Ws)}} \times \text{number of eggs of the subpart gonad (n)}$$

The relationship between fecundity and total length and body weight using the formulation Hasan *et al.* (2020) is:

$$F = a L^b \quad \text{and} \quad F = a W + b$$

Description F = Fecundity (egg), L = Total length of fish (cm), W = Fish body weight (g), a = Intercept, b = slope

Results

Length and weight structure

The results of the length structure analysis of male **tawes** are 8.9 - 22.9 cm and females are 8.9 - 28.5 cm, the largest proportion caught at 14.5 cm both males and females. While the size structure of male weights is 21.2 - 183.2 g and female are 21.2 - 312.8 g; and the largest proportion of males and females caught is the same weight size of 21.2 g (Fig. 2 a and b).

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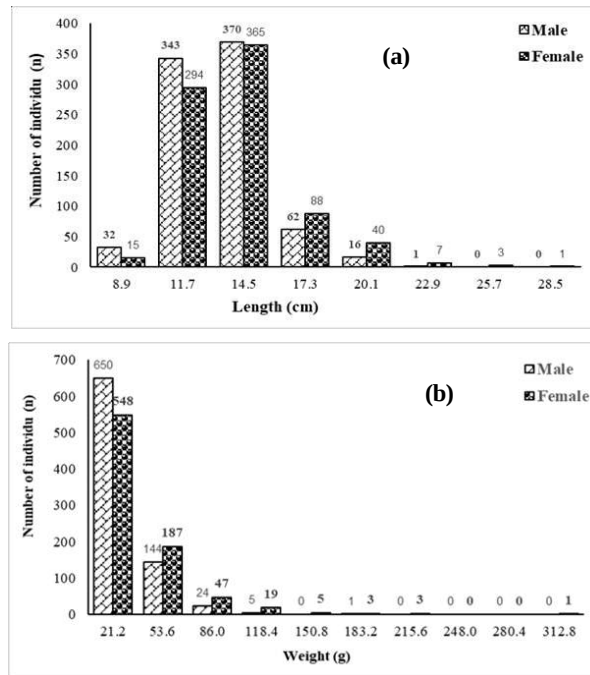


Fig 2. Length (a) and weight (b) structure of silver barb

Sex Ratio

The total sex ratio of males and females was 824 (50%) and 813 (50%), indicating a male-to-female sex ratio of 1:1 (Fig. 3a). The sex ratio of gonadally mature males and females was 27 (25%) and 83 (75%), indicating that 1 male was partnered with 3 females for spawning activities (Fig. 3b).

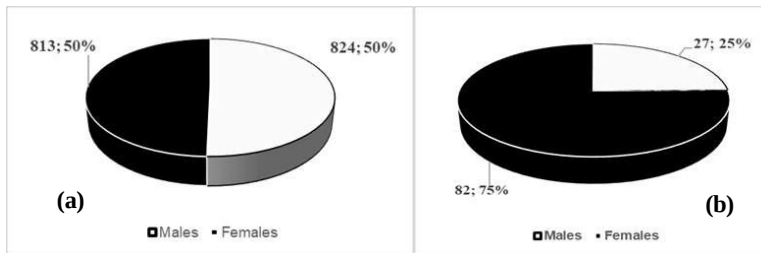


Fig 3. Male-to-female sex ratio of silver barb total fish (a), and gonad of maturity (b)

Length-weight relationship

The results of the analysis of the length-weight relationship of male was $W = 0.0234 L^{2.7349}$ and female $W = 0.0172 L^{2.8766}$ and combined (male and female) $W = 0.0183 L^{2.8415}$ (Fig. 4 a, b, c). The t-test results showed that the b value of male, female and combined (male and female) silver barb is different from 3 ($b \neq 3$) so it can be concluded that the growth pattern is allometric. Because the value of $b < 3$, it is negatively allometric.

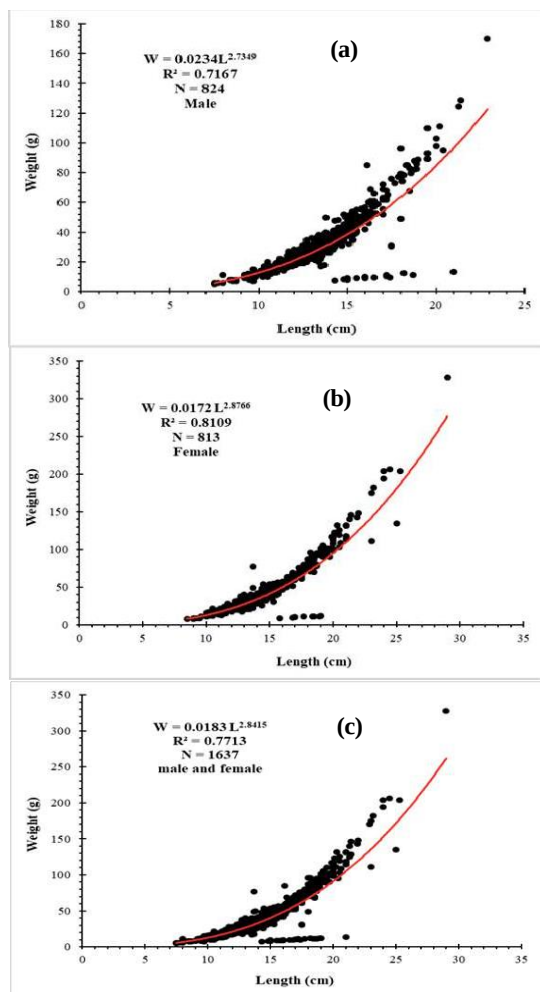


Fig 4. Length-weight relationship of male (a), female (b) and combined (male and female) (c)

Condition Factor

Condition factors for male and female silver barb were 1.0243 ± 0.0061 and 1.0181 ± 0.0054 , respectively.

Size at first gonad maturity (L_{50})

The results of the analysis of the size of the first mature gonads (L_{50}) of male fish are different from females. Female fish are faster to mature gonads, i.e. $L_{50} = 18.3$ cm than males $L_{50} = 19.9$ cm.

Gonad maturity

Determination of gonad maturity criteria is macroscopic by observing the morphological shape, size, color and position of the gonads in the abdominal cavity. The development of gonads (ovary and testes) of silver barb is classified into five levels according to the instructions Hasnidar *et al.* (2022) and the condition of silver barb gonads. The gonadal stages are stage I (Immature), II (Developing), III (Maturing), IV (Mature) and V (spent) (Table 1).

Table 1. Gonad maturity of female and male silver barb

Maturity stage	Note	Female	Male
I	Immature	Ovary is small, extending anteriorly to posteriorly in the dorsal abdominal cavity, filled with white and viscous fluid, eggs not yet visible, estimated to fill <15% of the abdominal cavity.	Testes are small and thin, extending from anterior to posterior of the abdominal cavity, filled with clear white fluid
II	Developing	Ovary is larger than immature ovaries, white in color, egg grains are visible, estimated to fill 20-30% of the abdominal cavity. The average egg diameter is 0.20 – 0.425 mm	Testes are enlarged, larger than stage I (immature) testes; filled with white liquid
III	Maturing	Ovary is enlarged, filled with greenish-white soft granules, egg granules are still difficult to separate. Estimated to fill almost 30%-60% of the abdominal cavity. The average egg diameter is 0.450 - 0.750 mm	Testes are getting bigger and larger than stage II, the surface of the testes appears to be ridged. Contains thick white liquid
IV	Mature	Ovary is getting bigger, filling about 60-80% of the abdominal cavity. ovaries contain yellowish-green egg grains, the average egg diameter is 0.800 - 1.25 mm	Testes are getting bigger larger than stage III, the surface of the testes is grooved. Contains thick milky white liquid
V	Spent	Ovary reduced, creased, ovary wall thick and lobed, yellowish-green color containing unspawned residual eggs	Testes reduced in size, wrinkled edges

Fecundity

The number of gonads mature female (stage IV) was 82 fish with a length range of 7.5-17.5 cm and weights of 7-82 g, gonad weights of 1.25-10.11 g. The fecundity of silver barb obtained in this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The fecundity of silver barb obtained from the results of this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The relationship between fecundity and total length is $F = 4.6297 L^{2.958}$ ($R^2 = 0.3526$), fecundity with body weight is a linear relationship that is $F = 444.66W + 1489.3$ ($R^2 = 0.5145$) (Fig. 5 a, b).

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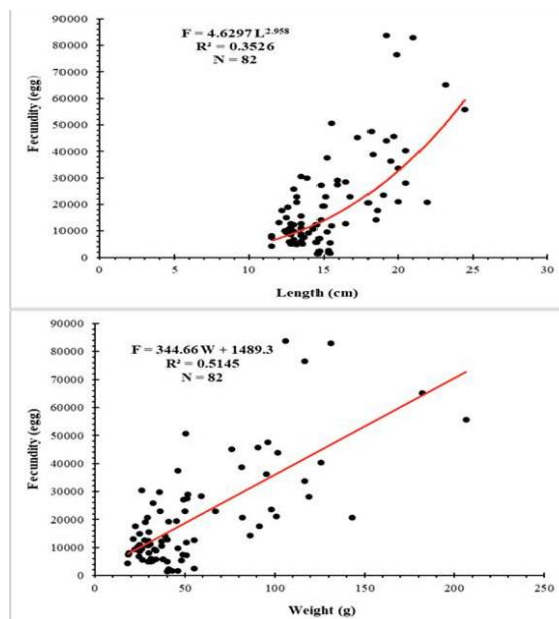


Fig 5. Fecundity-length (a), fecundity-weight (b) relationships of silver barb

Discussion

The length size structure of silver barb is 8.9 - 28.5 cm, with the highest caught size of 14.5 cm. Furthermore, the weight size structure is 21.2 - 312.8 g; and the largest proportion caught is 21.2 g in weight size. The data shows that the length and weight of silver barb captured are dominant in small size.

The length and weight structure of silver barb from several waters show low values compared to silver barb caught in Dan Tchang Reservoir, Thailand, which is 45 cm and 2,100 g (Chheng *et al.*, 2004). These data indicate that silver barb fishing, in Lake Tempe in particular, is very intensive and even overexploited (Sukarman, 2022). Silver barb do not have the opportunity to grow large due to intensive fishing. In addition, the less optimal environmental conditions of the lake, the presence of predators or competitors, and the limited ability of swimming larvae to escape from environmental factors are thought to affect the survival and growth. According to (Arevalo *et al.*, 2023), 99% mortality of a large number of fish species occurs in the early phase of fish life. Such high mortality is thought to have influenced variations in silver barb population size.

The total sex ratio of male and female is 1:1, indicating a balanced number of male and female fish. Silver barb with a male and female ratio of 1:1 (Maknuu, 2016), 1:1.27 (Jasmine and Begum, 2016), 1:2 (Ardelia *et al.*, 2023), 4:1 (Efizon *et al.*, 2021). Sex ratios can differ between the same fish species, because sex determination is not only determined by genetic factors but also by the environment (Capel, 2017), a sex ratio of 1:1 is an ideal description because both male and female fish have the same opportunity to maintain their species. Although silver barb experience high exploitation pressure, the sex ratio data shows that silver barb still have a high ability to maintain their population.

Furthermore, the sex ratio of gonads mature males and females is 27 fish (25%) and 83 fish (75%) or 1:3, meaning that 1 male is paired with 3 females for spawning activities (polygamy). The sex ratio in spawning is related to the interaction and synchronization between male and female fish (Mylonas *et al.*, 2010) as well as the

Efficient use of the number of male or female fish in spawning. Each fish species has an optimal sex ratio of males to females for spawning, for example climbing perch, *Anabas testudineus* is 1:2 (Hasnidar et al., 2022); Sailfin molly, *Poecilia latipinna* is 1:10 (Tamsil and Hasnidar, 2019); silver barb, *Barbonymus sp.* is 6:1 (Efizon et al., 2021).

The results of the analysis of the length-weight relationship of male silver barb obtained relationship model $W = 0.0234 L^{2.7349}$, female $W = 0.0172 L^{2.8766}$, combined (male and female) $W = 0.0183 L^{2.8415}$. The t test results obtained the value of b silver barb male, female and combined different from 3 ($b \neq 3$) so it can be concluded that the growth pattern is allometric. Because the value of $b < 3$, it is called negative allometric. Some research results on the length-weight relationship of silver barb in several aquatic locations.

Differences in silver barb ~~growth~~ growth patterns are due to differences in aquatic conditions. An important factor affecting the growth of fish in the tropics is the availability of food (Froese, 2006). Therefore, the same fish species in different locations will have different growth patterns due to this factor. In addition to food, other factors are the stage of gonad development, water physico-chemistry, fish health conditions, season, time and sampling techniques (Sheridan, 2011; Mehanna and Farouk, 2021). The number of fish caught in this study was 1623 fish, of which only 109 fish or 6.7% were mature gonads (stage IV), which is thought to be the cause of the negative allometric growth pattern.

Condition Factor (CF) is a value that reflects the influence of environmental factors on the physiological condition (Faradonbeh et al., 2015). Good environmental conditions including the availability of food will support good growth so that the weight of the fish is higher and the $CF \geq 1$, on the other hand, environmental conditions are not suitable and limited food availability causes small weight gain and $CF < 1$ (Dirican and Cilek, 2012). The CF value of the results of this study is 1.024 - 1.018; this value indicates the condition of the fish body is thin (compressed), the same as the growth pattern, which is negative allometric, that is length growth is faster than weight.

The condition factor of silver barb from several studies is 0.84 - 1.4 (Buwono *et al.*, 2019), 1.05 – 317 (Sidik *et al.*, 2020), 1.01 – 1.02 (Dwirastina and Marson, 2021), 0.82 – 1.10 (Syaiful *et al.*, 2019), 0.76 – 2.27 (Laila, 2018), 1.145-1.328 (Maknuu, 2016). The varying CF are due to differences in aquatic environment, density, food availability, and physiological conditions such as fish reproductive cycles. The higher the CF value indicates the compatibility of the fish with its environment.

The results of the analysis of the level of maturity of the gonads macroscopically show that in each level of maturity there are differences in size, color, and volume of gonads in the abdominal cavity of the ovary and testes. In the ovary, the higher the level of maturity, the diameter of oocytes tends to increase, but there are variations in the diameter of oocytes at the same maturity stage. Similarly, histological observations show that there are different sizes of oocyte diameter in the (Efizon *et al.*, 2021). These data indicate that silver barb ~~tawes~~ are gradual spawners, ~~that is, they release their eggs~~ not all at once during spawning. Gradual spawners have a long spawning season. The spawning season of silver barb in Tempe Lake is thought to be throughout the year, it can be seen in every fish sampling from January to June that mature (stage IV) is found every month of observation, with the highest mature in January. In contrast to silver barb in Padma River Bangladesh, the spawning season is April - July and the peak spawning is in June (Jasmine and Begum, 2016).

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Length at first maturity (L_{50}) is the value at which 50% of individuals in a group have reproduced at least once (Barzotto and Mateus, 2017). The length at first maturity of male = 19.9 cm, and female = 18.3 cm. The L_{50} value of the results of this study is greater than the L_{50} of silver barb from Nagan river, Aceh Province, Indonesia, e.g. male = 7.3 cm and female = 8.5 cm (Efizon *et al.*, 2021). The length of the first maturing gonads of fish can differ due to competition and predation, fishing pressure and environmental conditions (de Souza *et al.*, 2019). Fish will perform the first maturation with a shorter length to reduce the risk of death before reproduction if environmental conditions are unfavorable (Barzotto and Mateus, 2017). Based on the

L₅₀ value of male and female in relation to the length of the dominant silver barb caught in this study, ± 90% of the fish caught have never reproduced.

Silver barb identified as maturity stage IV in this study were 82 fish, having a length range of 12.2 - 21.28 cm (average ± 15.0 cm) and body weight of 21.0 - 124.4 g (average ± 41 g), producing fecundity with a range of 1,443 - 83,822 eggs (average = 20,239 eggs). Fecundity data of silver barb in several aquatic are presented in Table 4.

The estimated coefficient of determination (R^2) of the relationship between fecundity-length (F-L) and fecundity-weight (F-W) showed that 35.3% of the variation in fecundity occurred due to variation in total fish length and 51.5% of the variation in fecundity due to the influence of variation in body weight. Similar observations on tawes from Nagan river, Aceh Province, Indonesia; the coefficient of determination (R^2) of the relationship between F-L and F-W was 51% and 24.2%, respectively (Efizon *et al.*, 2021). This means that tawes fecundity increases with increasing total length and body weight. Fish that have a larger size in addition to having a large visceral cavity to accommodate a larger number of oocytes also have sufficient energy for reproductive activities (Jonsson and Jonsson, 1999). Factors that affect fish fecundity are internal factors such as genetics, age, and size (Hunter *et al.*, 1992), while external factors are food availability and environmental conditions (Bryan *et al.*, 2007).

Conclusions

The length and weight structure of female fish were higher than male fish. The dominant lengths and weights caught were 14.5 cm and 21.2 g. Negative allometric growth pattern and condition factor 1.02; lean growth. The overall ratio of male and female was 1 : 1, while the spawning sex ratio was 1 : 3; that is, one male fish is paired with 3 females in spawning. The first size of gonad maturity of female fish was faster at 18.3 cm and 19.9 cm for males. Fecundity ranged from 253 to 13,398 eggs (mean

2,571 eggs). Variation in fecundity was more strongly influenced by variation in body weight than variation in total length of silver barb.

Acknowledgments

To the Rector of Universitas Muslim Indonesia (UMI) Makassar through the Institute for Research and Resource Development which has supported funds so that this research can be carried out.

Conflicts of interest

We declare that this research was conducted without any conflict of interest with any party.

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Reproductive biology of silver barb, *Barbonymus gonionotus* (Bleeker, 1850), in Tempe Lake, Indonesia

Andi Tamsil¹, Hasnidar Hasnidar^{1*}, Andi Tamsil²

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Abstract

Information on the reproductive biology of silver barb is needed for conservation and domestication purposes. This study aims to analyze the reproductive biology of silver barb in Tempe Lake South Sulawesi, Indonesia. Aspects of reproductive biology analyzed were length-weight structure, sex ratio, length-weight relationship, condition factor, size at first gonad maturity (L_{50}), gonad of maturity, and fecundity. This study used primary data, silver barb were caught using gill nets every two weeks from January to July 2023. The total length of fish was measured using an ichthyometer with an accuracy of 0.1 cm, and weight using a digital scale with an accuracy of 0.01 g. [The gonads were preserved in 4% formalin solution, fecundity was calculated based on the gravimetric method. Male structures ~~respectively are were~~ 8.9 - 22.9 cm long, while females respectively ~~we are~~ 8.9 - 28.5 cm long; males weigh between respectively 21.2 - 183.2 g, and females weigh between respectively 21.2 - 312.8 g. [The overall sex ratio of males and females was 1:1, while the sex ratio during spawning was 1:3 (polygamous). Length-weight relationships between males and females were $W = 0.0234L^{2.7349}$ and $W = 0.0172L^{2.8766}$ respectively. The condition factor for males and females was the same at 1.02. The size of first maturing gonads for females was 18.3 cm and 19.9 cm for males. Partial spawning, with fecundity ranging from 253 to 13,398 eggs.

Keywords: Reproductive biology, Silver barb, Tempe Lake, Length-weight relation

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Commented [SS2R1]: Silver barb is one of the highly economical fish that comes from Lake Tempe and has experienced a population decline. Data on its reproductive biology is needed for conservation and cultivation efforts. This research aims to analyze aspects of the reproductive biology of silver barb in Lake Tempe, South Sulawesi, Indonesia. Aspects of reproductive biology analyzed include length and weight structure, sex ratio, length-weight relationship, condition factors, size of first mature gonad (L_{50}), gonad maturity stage and fecundity. This research uses primary data, silver barb are caught using gill nets every two weeks from January to July 2023. The total length of the fish is measured using an ichthyometer with an accuracy of 0.1 cm, and weight using a digital scale with an accuracy of 0.01 g. Gonads were removed from the visceral cavity and preserved in 4% formalin solution to facilitate fecundity calculations. Fecundity is calculated using the gravimetric method. The length and weight structure of male fish is 8.9 – 22.9 cm and 21.2 – 183.2 g; female 8.9 - 28.5 cm and 21.2 - 312.8 g. The overall male to female sex ratio is 1:1, while the sex ratio during spawning is 1:3 (polygamy). The length-weight relationship for male is $W = 0.0234L^{2.7349}$ and female $W = 0.0172L^{2.8766}$. The condition factor for males and females is the same, namely 1.02. The first size of mature gonads (L_{50}) in males is 19.9 cm and in females 18.3 cm. Spawning is partial and fecundity ranges from 253 to 13,398 eggs.

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Introduction

Silver barb, *Barbonymus gonionotus* (Bleeker, 1850) is an economically important freshwater fish in several countries such as Indonesia, Malaysia, Thailand, Myanmar, Bangladesh, India, and China. The taste is good and the price is relatively cheap so it becomes the main consumption of the community, especially some places in the territory of Indonesia. Silver barb production still mainly depends on fishing, so fishing pressure continues to increase.

Tempe Lake has a diversity of fish species consisting of native fish, introduced fish and migratory marine fish. According to Dina *et al.* (2019), the native fishes of Tempe Lake are *Monopterus albus*, *Anabas testudineus*, *Glossogobius aureus*, *Channa striata*. Introduced fish species are *Barbonymus gonionotus*, *Clarias batrachus*, *Trichopodus pectoralis*, *Pangasianodon hypophthalmus*, *Osteochilus vittatus*, *Oreochromis niloticus*, *Helostoma temminckii*, *Cyprinus carpio* (Yanuarita *et al.*, 2020). Migratory marine fish species are *Megalops cyprinoides*, *Stenogobius gymnopomus*, *Anguilla marmorata* and *Caranx sexfasciatus*. Introductions are carried out to increase the production of fishery products to meet increasing demand, optimize water productivity, increase production in a sustainable and increase biodiversity (Yanuarita *et al.*, 2020; FAO, 2022).

Tempe Lake is presently experiencing various environmental problems, including eutrophication (Aisyah and Nomosatryo, 2016). Eutrophication occurs allegedly due to the load of nutrients derived from the activities of humans, plantations and farms that are often found on the shores of the lake. Nitrate and phosphate nutrients are in the range of 0.1063-0.2620 mg/l and 0.0245-0.0655 mg/l respectively in the water (Samuel *et al.*, 2012). These conditions trigger the growth of aquatic weeds such as *Ipomoea aquatic* and *Eichhornia crassipes*. *E. crassipes* is the most dominant of these plants and its population is estimated to have covered the lake surface by about 30 - 40%. According to (Yani *et al.*, 2019), Lake Tempe has experienced moderate to severe pollution in several parameters including turbidity, total suspended solids, biological oxygen demand, nitrate, and phosphate.

Another problem is overfishing and the use of fishing gear that is not environmentally sustainable (Nasution, 2012), and a serious problem is the presence of invasive fish, i.e. *Pterygoplichthys* spp (Hasnidar *et al.*, 2021). The high population of *Pterygoplichthys* spp has caused fishermen's catches of target fish to decline (Hasrianti *et al.*, 2020). The presence of *Pterygoplichthys* spp impacts the lake ecosystem through competition for habitat, diet, and can even be a predator of native and endemic fish, as well as an agent of various diseases. It can change the species composition and structure of fish communities, dominating and excluding native and endemic fish (Syafei and Sudinno, 2018).

Silver barb or Java barb, *B. gonionotus* was introduced to Lake Tempe in 1937 (Dina *et al.*, 2019; Yanuarita *et al.*, 2020). Although an introduced fish, Tawes (Silver barb) successfully adapted well to the lake environment. The condition of Tempe Lake, which is rich with dominant aquatic plants, enables it to survive well. Silver barb are herbivorous, with phytoplankton (Chlorophyceae) as their main food (Ain *et al.*, 2021); aquatic plants (80%), detritus (12%), phytoplankton (8.5%) (Aida, 2018; Pratiwi *et al.*, 2021). Silver barb are considered useful in controlling excessive vegetation in lake waters. Although silver barb successfully lives in Tempe Lake, the declining environmental conditions of Tempe Lake certainly have an impact on the production of these fish.

Silver barb production has fluctuated in recent years, with capture mortality higher than natural mortality due to overfishing (Sukarman, 2022). This condition is thought to be due to the presence of *Pterygoplichthys* spp as an invasive fish (Hasnidar *et al.*, 2021). There are two species that are still caught in large numbers, ~~e.i.e~~ silver barb and bloso (*Glossogobius* sp), therefore both fish species are under very high fishing pressure. Conservation and domestication efforts will be carried out, but these efforts require the latest information including aspects of silver barb reproductive biology for the future management. The study aims to analyze the reproductive biology of silver barb including size distribution, sex ratio, length and weight relationship, condition factor, gonad maturity, size of first mature gonad, and fecundity.

Materials and methods

The study was conducted from January to July 2023 in Tempe Lake, Wajo Regency, South Sulawesi Province, Indonesia (Fig. 1). Fish sampling was collected every week for six months, using a gill net response tool. Fish samples caught were cleaned, put in a cooler box and given ice cubes. Sample observations were carried out at the Biota and Environmental Engineering Laboratory, Faculty of Fisheries and Marine Science, Universitas Muslim Indonesia (UMI) Makassar.

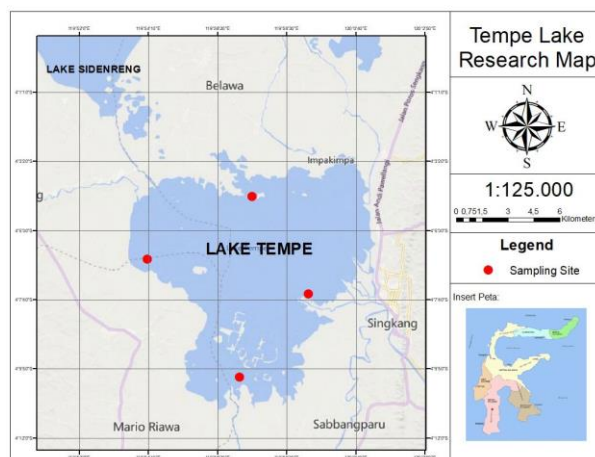


Fig 1. Silver barb fishing sampling points on the site in Tempe Lake, Wajo Regency, South Sulawesi, Indonesia.

The total length (Lt) of silver barb was measured using an ichthymeter (Vernier calipers, Mitutoyo) with an accuracy of 0.1 cm, body weight and gonads (g) were measured using digital scales (Digital elektrik scale, DIGI DS880) with an accuracy of 0.01g. The parameters analyzed were:

Length and weight structure

Length and weight size structures were determined as follows: determining the number of classes; determining the length class interval of 1 cm and weight of 1 g; inserting

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Each fish sample in the predetermined class. The size structure was determined within the same class interval and then plotted on a graph.

Sex ratio

The sex of silver barb was determined morphologically and anatomically by dissecting the fish to see whether the gonads developed into testes or ovaries. Determination of male and female sex ratio is done by calculating the number of male fish and female fish caught using the formula (Oliveira *et al.*, 2012):

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$$N = \frac{\text{number of male of female}}{\text{total number of fish observed}} \times 100$$

Next, sex ratio variability was tested using the Chi-square test (Oliveira *et al.*, 2012):

$$X^2 = \frac{\sum (oi - ei)^2}{ei}$$

Description: X^2 = Value for a random variable whose sampling distribution approximates the Chi-square distribution

oi = Observed frequencies of male and female fish

ei = Expected frequencies of male and female fish

Length-weight relationship

The relationship between length and weight was analyzed using the formula (Le Cren, 1951):

$$W = aL^b$$

Description W = Fish body weight (g), L = Total length of fish (cm), a = Coefficient of determination, b = exponent that indicates isometric or allometric.

To obtain the equation, the values of W and L were transformed into logarithms (base 10) as follows:

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$$W = \log a + b \log L$$

The b values obtained were used to estimate the two parameters (length and weight) analyzed, with hypotheses: 1) $b = 3$ indicates an isometric growth pattern, 2) $b \neq 3$ indicates an allometric growth pattern, a) $b > 3$: faster weight gain (positive allometric), b) $b < 3$: faster length gain (negative allometric).

Condition factor

Because the growth pattern of silver barb in this study is negative allometric ($b \neq 3$),

the formulation (Le Cren, 1951) is:

$$Kn = \frac{W}{a L^b}$$

Description Kn = Condition factor, W = Fish body weight (g), L = Total length of fish (cm), a = Intercept, b = slope

Size at first gonadal maturity (L_{50})

The size of the first time the fish matures gonads is obtained by finding the value of L_{50} by plotting the cumulative percentage of gonadal mature fish with the size of the fish body length, so that a standard logistic curve will be obtained and the intersection point between the curve and 50% cumulative frequency is the length when 50% of the fish first matures gonads.

Gonad maturity

The stage of gonadal maturity was observed macroscopically, the observation procedure is when the silver barb was first dissected, and the visceral cavity was opened to observe the morphology of the gonads including shape, color, size, gonad position in the abdominal cavity and egg diameter. Maturity stages were classified according to Brown-Peterson *et al.* (2011), and modified according to silver barb conditions, i.e. stage I (Immature); II (Developing); III (Maturing); IV (Mature) and V (Spent). Egg diameter was observed by taking samples of stage IV fish gonads then each fish gonad was taken in 3 parts, i.e. posterior, anterior, and middle gonads. Eggs were taken from each part of the gonad sample, with 30 eggs in each part. A total of 90 fish egg samples were measured in diameter using an ocular micrometer (0.01 mm) brand UYCP-12.

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Commented [SS10R9]: Measure the total length of the fish, check the gonads to determine whether the fish have mature gonads or not. Classify the fish into size groups, calculating the proportion of gonad mature fish in each size group. Use regression analysis to determine the relationship between fish size and the probability of gonad maturity. Determine L_{50} with the regression equation:

$$P(x) = \frac{1}{1 + e^{-(a+bx)}}$$

where $P(x)$ is the probability of maturity at size x , and a and b are the parameters to be estimated. Parameters a and b was estimated using SPSS statistical software.

Fecundity

Fecundity can be known the procedure that the weight of the total gonads (WG), then take a subpart of the total gonad at each end of the bottom, middle and top then measure its weighed (Ws). The weight of the gonad subpart was then preserved in a 4% formalin solution to facilitate the calculation of the number of eggs (n). Fecundity was observed in maturity stage IV, calculated using the gravimetric method (Hasan *et al.*, 2020):

$$F = \frac{\text{Weight of the total gonad (WG)}}{\text{Weight subpart gonad (Ws)}} \times \text{number of eggs of the subpart gonad (n)}$$

The relationship between fecundity and total length and body weight using the formulation Hasan *et al.* (2020) is:

$$F = a L^b \quad \text{and} \quad F = a W + b$$

Description F = Fecundity (egg), L = Total length of fish (cm), W = Fish body weight (g), a = Intercept, b = slope

Results

Length and weight structure

The results of the length structure analysis of male **tawes** are 8.9 - 22.9 cm and females are 8.9 - 28.5 cm, the largest proportion caught at 14.5 cm both males and females. While the size structure of male weights is 21.2 - 183.2 g and female are 21.2 - 312.8 g; and the largest proportion of males and females caught is the same weight size of 21.2 g (Fig. 2 a and b).

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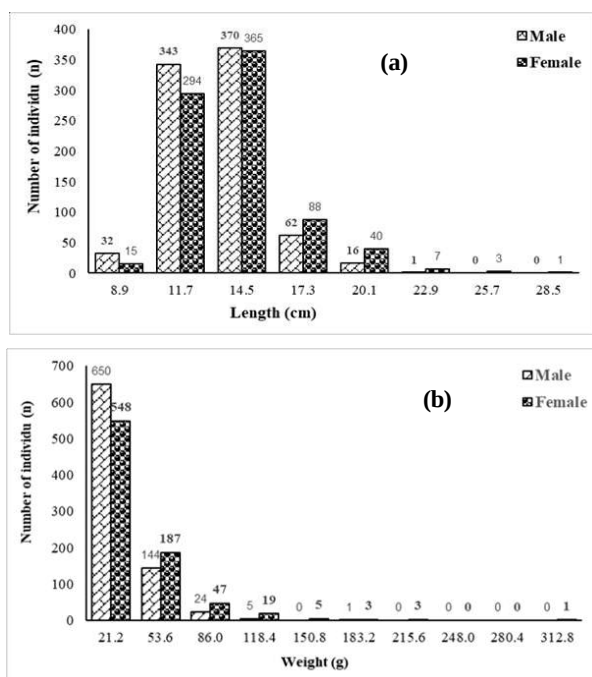


Fig 2. Length (a) and weight (b) structure of silver barb

Sex Ratio

The total sex ratio of males and females was 824 (50%) and 813 (50%), indicating a male-to-female sex ratio of 1:1 (Fig. 3a). The sex ratio of gonadally mature males and females was 27 (25%) and 83 (75%), indicating that 1 male was partnered with 3 females for spawning activities (Fig. 3b).

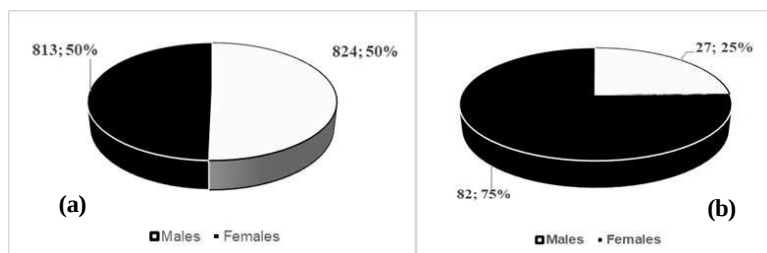


Fig 3. Male-to-female sex ratio of silver barb total fish (a), and gonad of maturity (b)

Length-weight relationship

The results of the analysis of the length-weight relationship of male was $W = 0.0234 L^{2.7349}$ and female $W = 0.0172 L^{2.8766}$ and combined (male and female) $W = 0.0183 L^{2.8415}$ (Fig. 4 a, b, c). The t-test results showed that the b value of male, female and combined (male and female) silver barb is different from 3 ($b \neq 3$) so it can be concluded that the growth pattern is allometric. Because the value of $b < 3$, it is negatively allometric.

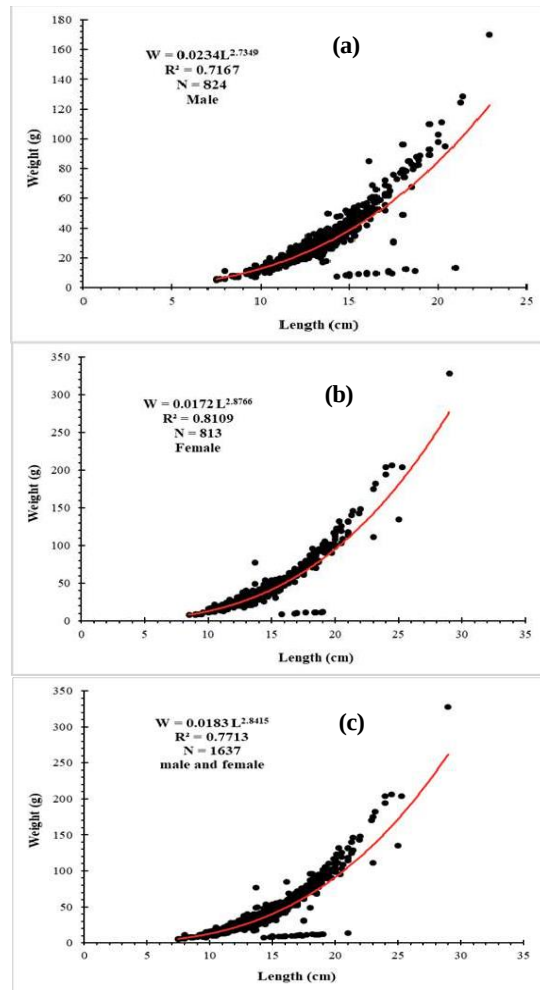


Fig 4. Length-weight relationship of male (a), female (b) and combined (male and female) (c)

Condition Factor

Condition factors for male and female silver barb were 1.0243 ± 0.0061 and 1.0181 ± 0.0054 , respectively.

Size at first gonad maturity (L_{50})

The results of the analysis of the size of the first mature gonads (L_{50}) of male fish are different from females. Female fish are faster to mature gonads, i.e. $L_{50} = 18.3$ cm than males $L_{50} = 19.9$ cm.

Gonad maturity

Determination of gonad maturity criteria is macroscopic by observing the morphological shape, size, color and position of the gonads in the abdominal cavity. The development of gonads (ovary and testes) of silver barb is classified into five levels according to the instructions Hasnidar *et al.* (2022) and the condition of silver barb gonads. The gonadal stages are stage I (Immature), II (Developing), III (Maturing), IV (Mature) and V (spent) (Table 1).

Table 1. Gonad maturity of female and male silver barb

Maturity stage	Note	Female	Male
I	Immature	Ovary is small, extending anteriorly to posteriorly in the dorsal abdominal cavity, filled with white and viscous fluid, eggs not yet visible, estimated to fill <15% of the abdominal cavity.	Testes are small and thin, extending from anterior to posterior of the abdominal cavity, filled with clear white fluid
II	Developing	Ovary is larger than immature ovaries, white in color, egg grains are visible, estimated to fill 20-30% of the abdominal cavity. The average egg diameter is 0.20 – 0.425 mm	Testes are enlarged, larger than stage I (immature) testes; filled with white liquid
III	Maturing	Ovary is enlarged, filled with greenish-white soft granules, egg granules are still difficult to separate. Estimated to fill almost 30%-60% of the abdominal cavity. The average egg diameter is 0.450 - 0.750 mm	Testes are getting bigger and larger than stage II, the surface of the testes appears to be ridged. Contains thick white liquid
IV	Mature	Ovary is getting bigger, filling about 60-80% of the abdominal cavity. ovaries contain yellowish-green egg grains, the average egg diameter is 0.800 - 1.25 mm	Testes are getting bigger larger than stage III, the surface of the testes is grooved. Contains thick milky white liquid
V	Spent	Ovary reduced, creased, ovary wall thick and lobed, yellowish-green color containing unspawned residual eggs	Testes reduced in size, wrinkled edges

Fecundity

The number of gonads mature female (stage IV) was 82 fish with a length range of 7.5-17.5 cm and weights of 7-82 g, gonad weights of 1.25-10.11 g. The fecundity of silver barb obtained in this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The fecundity of silver barb obtained from the results of this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The relationship between fecundity and total length is $F = 4.6297 L^{2.958}$ ($R^2 = 0.3526$), fecundity with body weight is a linear relationship that is $F = 444.66W + 1489.3$ ($R^2 = 0.5145$) (Fig. 5 a, b).

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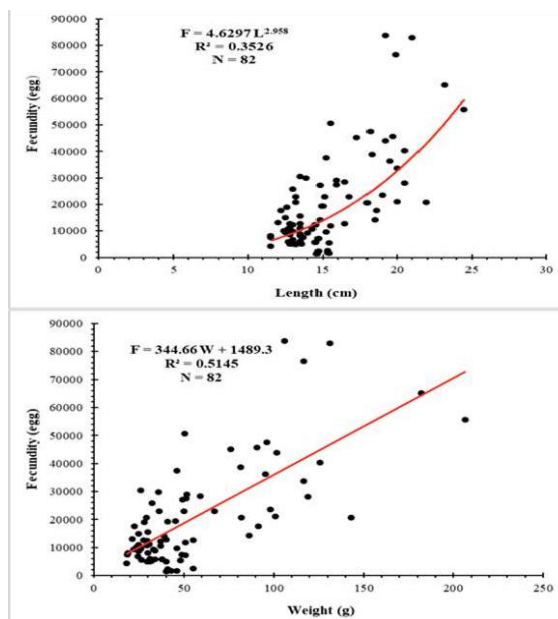


Fig 5. Fecundity-length (a), fecundity-weight (b) relationships of silver barb

Discussion

The length size structure of silver barb is 8.9 - 28.5 cm, with the highest caught size of 14.5 cm. Furthermore, the weight size structure is 21.2 - 312.8 g; and the largest proportion caught is 21.2 g in weight size. The data shows that the length and weight of silver barb captured are dominant in small size.

The length and weight structure of silver barb from several waters show low values compared to silver barb caught in Dan Tchang Reservoir, Thailand, which is 45 cm and 2,100 g (Chheng *et al.*, 2004). These data indicate that silver barb fishing, in Lake Tempe in particular, is very intensive and even overexploited (Sukarman, 2022). Silver barb do not have the opportunity to grow large due to intensive fishing. In addition, the less optimal environmental conditions of the lake, the presence of predators or competitors, and the limited ability of swimming larvae to escape from environmental factors are thought to affect the survival and growth. According to (Arevalo *et al.*, 2023), 99% mortality of a large number of fish species occurs in the early phase of fish life. Such high mortality is thought to have influenced variations in silver barb population size.

The total sex ratio of male and female is 1:1, indicating a balanced number of male and female fish. Silver barb with a male and female ratio of 1:1 (Maknuu, 2016), 1:1.27 (Jasmine and Begum, 2016), 1:2 (Ardelia *et al.*, 2023), 4:1 (Efizon *et al.*, 2021). Sex ratios can differ between the same fish species, because sex determination is not only determined by genetic factors but also by the environment (Capel, 2017), a sex ratio of 1:1 is an ideal description because both male and female fish have the same opportunity to maintain their species. Although silver barb experience high exploitation pressure, the sex ratio data shows that silver barb still have a high ability to maintain their population.

Furthermore, the sex ratio of gonads mature males and females is 27 fish (25%) and 83 fish (75%) or 1:3, meaning that 1 male is paired with 3 females for spawning activities (polygamy). The sex ratio in spawning is related to the interaction and synchronization between male and female fish (Mylonas *et al.*, 2010) as well as the

Efficient use of the number of male or female fish in spawning. Each fish species has an optimal sex ratio of males to females for spawning, for example climbing perch, *Anabas testudineus* is 1:2 (Hasnidar et al., 2022); Sailfin molly, *Poecilia latipinna* is 1:10 (Tamsil and Hasnidar, 2019); silver barb, *Barbonymus sp.* is 6:1 (Efizon et al., 2021).

The results of the analysis of the length-weight relationship of male silver barb obtained relationship model $W = 0.0234 L^{2.7349}$, female $W = 0.0172 L^{2.8766}$, combined (male and female) $W = 0.0183 L^{2.8415}$. The t test results obtained the value of b silver barb male, female and combined different from 3 ($b \neq 3$) so it can be concluded that the growth pattern is allometric. Because the value of $b < 3$, it is called negative allometric. Some research results on the length-weight relationship of silver barb in several aquatic locations.

Differences in silver barb ~~growth~~ growth patterns are due to differences in aquatic conditions. An important factor affecting the growth of fish in the tropics is the availability of food (Froese, 2006). Therefore, the same fish species in different locations will have different growth patterns due to this factor. In addition to food, other factors are the stage of gonad development, water physico-chemistry, fish health conditions, season, time and sampling techniques (Sheridan, 2011; Mehanna and Farouk, 2021). The number of fish caught in this study was 1623 fish, of which only 109 fish or 6.7% were mature gonads (stage IV), which is thought to be the cause of the negative allometric growth pattern.

Condition Factor (CF) is a value that reflects the influence of environmental factors on the physiological condition (Faradonbeh et al., 2015). Good environmental conditions including the availability of food will support good growth so that the weight of the fish is higher and the $CF \geq 1$, on the other hand, environmental conditions are not suitable and limited food availability causes small weight gain and $CF < 1$ (Dirican and Cilek, 2012). The CF value of the results of this study is 1.024 - 1.018; this value indicates the condition of the fish body is thin (compressed), the same as the growth pattern, which is negative allometric, that is length growth is faster than weight.

The condition factor of silver barb from several studies is 0.84 - 1.4 (Buwono *et al.*, 2019), 1.05 – 317 (Sidik *et al.*, 2020), 1.01 – 1.02 (Dwirastina and Marson, 2021), 0.82 – 1.10 (Syaiful *et al.*, 2019), 0.76 – 2.27 (Laila, 2018), 1.145-1.328 (Maknuu, 2016). The varying CF are due to differences in aquatic environment, density, food availability, and physiological conditions such as fish reproductive cycles. The higher the CF value indicates the compatibility of the fish with its environment.

The results of the analysis of the level of maturity of the gonads macroscopically show that in each level of maturity there are differences in size, color, and volume of gonads in the abdominal cavity of the ovary and testes. In the ovary, the higher the level of maturity, the diameter of oocytes tends to increase, but there are variations in the diameter of oocytes at the same maturity stage. Similarly, histological observations show that there are different sizes of oocyte diameter in the (Efizon *et al.*, 2021). These data indicate that silver barb ~~tawes~~ are gradual spawners, that is, they release their eggs not all at once during spawning. Gradual spawners have a long spawning season. The spawning season of silver barb in Tempe Lake is thought to be throughout the year, it can be seen in every fish sampling from January to June that mature (stage IV) is found every month of observation, with the highest mature in January. In contrast to silver barb in Padma River Bangladesh, the spawning season is April - July and the peak spawning is in June (Jasmine and Begum, 2016).

Length at first maturity (L_{50}) is the value at which 50% of individuals in a group have reproduced at least once (Barzotto and Mateus, 2017). The length at first maturity of male = 19.9 cm, and female = 18.3 cm. The L_{50} value of the results of this study is greater than the L_{50} of silver barb from Nagan river, Aceh Province, Indonesia, e.g. male = 7.3 cm and female = 8.5 cm (Efizon *et al.*, 2021). The length of the first maturing gonads of fish can differ due to competition and predation, fishing pressure and environmental conditions (de Souza *et al.*, 2019). Fish will perform the first maturation with a shorter length to reduce the risk of death before reproduction if environmental conditions are unfavorable (Barzotto and Mateus, 2017). Based on the

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L₅₀ value of male and female in relation to the length of the dominant silver barb caught in this study, ± 90% of the fish caught have never reproduced.

Silver barb identified as maturity stage IV in this study were 82 fish, having a length range of 12.2 - 21.28 cm (average ± 15.0 cm) and body weight of 21.0 - 124.4 g (average ± 41 g), producing fecundity with a range of 1,443 - 83,822 eggs (average = 20,239 eggs). Fecundity data of silver barb in several aquatic are presented in Table 4.

The estimated coefficient of determination (R^2) of the relationship between fecundity-length (F-L) and fecundity-weight (F-W) showed that 35.3% of the variation in fecundity occurred due to variation in total fish length and 51.5% of the variation in fecundity due to the influence of variation in body weight. Similar observations on tawes from Nagan river, Aceh Province, Indonesia; the coefficient of determination (R^2) of the relationship between F-L and F-W was 51% and 24.2%, respectively (Efizon *et al.*, 2021). This means that tawes fecundity increases with increasing total length and body weight. Fish that have a larger size in addition to having a large visceral cavity to accommodate a larger number of oocytes also have sufficient energy for reproductive activities (Jonsson and Jonsson, 1999). Factors that affect fish fecundity are internal factors such as genetics, age, and size (Hunter *et al.*, 1992), while external factors are food availability and environmental conditions (Bryan *et al.*, 2007).

Conclusions

The length and weight structure of female fish were higher than male fish. The dominant lengths and weights caught were 14.5 cm and 21.2 g. Negative allometric growth pattern and condition factor 1.02; lean growth. The overall ratio of male and female was 1 : 1, while the spawning sex ratio was 1 : 3; that is, one male fish is paired with 3 females in spawning. The first size of gonad maturity of female fish was faster at 18.3 cm and 19.9 cm for males. Fecundity ranged from 253 to 13,398 eggs (mean

2,571 eggs). Variation in fecundity was more strongly influenced by variation in body weight than variation in total length of silver barb.

Acknowledgments

To the Rector of Universitas Muslim Indonesia (UMI) Makassar through the Institute for Research and Resource Development which has supported funds so that this research can be carried out.

Conflicts of interest

We declare that this research was conducted without any conflict of interest with any party.

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10 Agustus 2024 pukul 15.22

Kepada: Hasnidar Yasin <hasnidar.yasin@umi.ac.id>

Dear author

Please correct your article completely. If you don't do it, we won't publish it.

With best regards

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Reproductive biology of silver barb, *Barbonymus gonionotus* (Bleeker, 1850), in Tempe Lake, Indonesia

Andi Tamsil¹; Hasnidar Hasnidar^{1*}; Andi Tamsil²

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Abstract

Information on the reproductive biology of silver barb is needed for conservation and domestication purposes. This study aims to analyze the reproductive biology of silver barb in Tempe Lake South Sulawesi, Indonesia. Aspects of reproductive biology analyzed were length-weight structure, sex ratio, length-weight relationship, condition factor, size at first gonad maturity (L_{50}), gonad of maturity, and fecundity. This study used primary data, silver barb were caught using gill nets every two weeks from January to July 2023. The total length of fish was measured using an ichthyometer with an accuracy of 0.1 cm, and weight using a digital scale with an accuracy of 0.01 g. The gonads were preserved in 4% formalin solution and the fecundity was calculated based on the gravimetric method. The Male structures respectively are were 8.9 - 22.9 cm long, while the females respectively are 8.9 - 28.5 cm long; males weigh between respectively 21.2 - 183.2 g, and females weigh between respectively 21.2 - 312.8 g. The overall sex ratio of males and females was 1:1, while the sex ratio during spawning was 1:3 (polygamous). Length-weight relationships between males and females were $W = 0.0234L^{2.7349}$ and $W = 0.0172L^{2.8766}$ respectively. The condition factor for the males and females was the same at 1.02. The size of first maturing gonads for females was 18.3 cm and 19.9 cm for males. Partial spawning, with fecundity ranging from 253 to 13,398 eggs.

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Keywords: Reproductive biology, Silver barb, Tempe Lake, Length-weight relation

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Therefore, it is highly recommended to send your manuscript to an English institute or a native editor to improve/revise the English language.

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Introduction

Silver barb, *Barbonymus gonionotus* (Bleeker, 1850) is an economically important freshwater fish in several countries such as Indonesia, Malaysia, Thailand, Myanmar, Bangladesh, India, and China. The taste is good and the price is relatively cheap so it becomes the main consumption of the community, especially some places in the territory of Indonesia. Silver barb production still mainly depends on fishing, so fishing pressure continues to increase.

Tempe Lake has a diversity of fish species consisting of native fish, introduced fish and migratory marine fish. According to Dina *et al.* (2019), the native fishes of Tempe Lake are *Monopterus albus*, *Anabas testudineus*, *Glossogobius aureus*, *Channa striata*. Introduced fish species are *Barbonymus gonionotus*, *Clarias batrachus*, *Trichopodus pectoralis*, *Pangasianodon hypophthalmus*, *Osteochilus vittatus*, *Oreochromis niloticus*, *Helostoma temminckii*, *Cyprinus carpio* (Yanuarita *et al.*, 2020). Migratory marine fish species are *Megalops cyprinoides*, *Stenogobius gymnopomus*, *Anguilla marmorata* and *Caranx sexfasciatus*. Introductions are carried out to increase the production of fishery products to meet increasing demand, optimize water productivity, increase production in a sustainable and increase biodiversity (Yanuarita *et al.*, 2020; FAO, 2022).

Tempe Lake is presently experiencing various environmental problems, including eutrophication (Aisyah and Nomosatryo, 2016). Eutrophication occurs allegedly due to the load of nutrients derived from the activities of humans, plantations and farms that are often found on the shores of the lake. Nitrate and phosphate nutrients are in the range of 0.1063-0.2620 mg/l and 0.0245-0.0655 mg/l respectively in the water (Samuel *et al.*, 2012). These conditions trigger the growth of aquatic weeds such as *Ipomoea aquatic* and *Eichhornia crassipes*. *E. crassipes* is the most dominant of these plants and its population is estimated to have covered the lake surface by about 30 - 40%. According to (Yani *et al.*, 2019), Lake Tempe has experienced moderate to severe pollution in several parameters including turbidity, total suspended solids, biological oxygen demand, nitrate, and phosphate.

Another problem is overfishing and the use of fishing gear that is not environmentally sustainable (Nasution, 2012), and a serious problem is the presence of invasive fish, i.e. *Pterygoplichthys* spp (Hasnidar *et al.*, 2021). The high population of *Pterygoplichthys* spp has caused fishermen's catches of target fish to decline (Hasrianti *et al.*, 2020). The presence of *Pterygoplichthys* spp impacts the lake ecosystem through competition for habitat, diet, and can even be a predator of native and endemic fish, as well as an agent of various diseases. It can change the species composition and structure of fish communities, dominating and excluding native and endemic fish (Syafei and Sudinno, 2018).

Silver barb or Java barb, *B. gonionotus* was introduced to Lake Tempe in 1937 (Dina *et al.*, 2019; Yanuarita *et al.*, 2020). Although an introduced fish, Tawes (Silver barb) successfully adapted well to the lake environment. The condition of Tempe Lake, which is rich with dominant aquatic plants, enables it to survive well. Silver barb are herbivorous, with phytoplankton (Chlorophyceae) as their main food (Ain *et al.*, 2021); aquatic plants (80%), detritus (12%), phytoplankton (8.5%) (Aida, 2018; Pratiwi *et al.*, 2021). Silver barb are considered useful in controlling excessive vegetation in lake waters. Although silver barb successfully lives in Tempe Lake, the declining environmental conditions of Tempe Lake certainly have an impact on the production of these fish.

Silver barb production has fluctuated in recent years, with capture mortality higher than natural mortality due to overfishing (Sukarman, 2022). This condition is thought to be due to the presence of *Pterygoplichthys* spp as an invasive fish (Hasnidar *et al.*, 2021). There are two species that are still caught in large numbers, ~~e.i.e~~ silver barb and bloso (*Glossogobius* sp), therefore both fish species are under very high fishing pressure. Conservation and domestication efforts will be carried out, but these efforts require the latest information including aspects of silver barb reproductive biology for the future management. The study aims to analyze the reproductive biology of silver barb including size distribution, sex ratio, length and weight relationship, condition factor, gonad maturity, size of first mature gonad, and fecundity.

Materials and methods

The study was conducted from January to July 2023 in Tempe Lake, Wajo Regency, South Sulawesi Province, Indonesia (Fig. 1). Fish sampling was collected every week for six months, using a gill net response tool. Fish samples caught were cleaned, put in a cooler box and given ice cubes. Sample observations were carried out at the Biota and Environmental Engineering Laboratory, Faculty of Fisheries and Marine Science, Universitas Muslim Indonesia (UMI) Makassar.

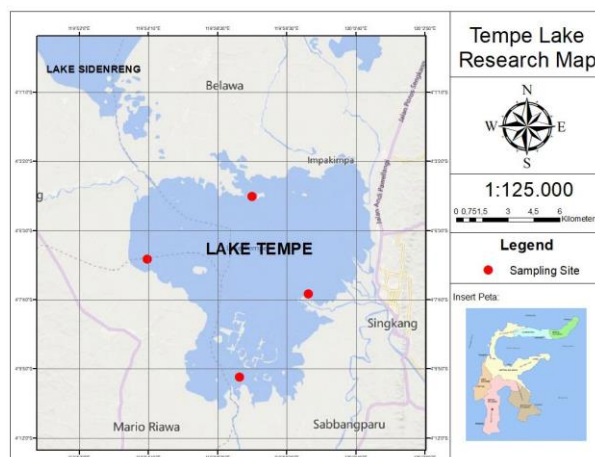


Fig 1. Silver barb fishing sampling points on the site in Tempe Lake, Wajo Regency, South Sulawesi, Indonesia.

The total length (Lt) of silver barb was measured using an ichthymeter (Vernier calipers, Mitutoyo) with an accuracy of 0.1 cm, body weight and gonads (g) were measured using digital scales (Digital elektrik scale, DIGI DS880) with an accuracy of 0.01g. The parameters analyzed were:

Length and weight structure

Length and weight size structures were determined as follows: determining the number of classes; determining the length class interval of 1 cm and weight of 1 g; inserting

Each fish sample in the predetermined class. The size structure was determined within the same class interval and then plotted on a graph.

Sex ratio

The sex of silver barb was determined morphologically and anatomically by dissecting the fish to see ~~whetherewhether~~ the gonads developed into testes or ovaries. Determination of male and female sex ratio is done by calculating the number of male fish and female fish caught using the formula (Oliveira *et al.*, 2012):

$$N = \frac{\text{number of male of female}}{\text{total number of fish observed}} \times 100$$

Next, sex ratio variability was tested using the Chi-square test (Oliveira *et al.*, 2012):

$$X^2 = \frac{\sum(o_i - e_i)^2}{e_i}$$

Description: X^2 = Value for a random variable whose sampling distribution approximates the Chi-square distribution

o_i = Observed frequencies of male and female fish

e_i = Expected frequencies of male and female fish

Length-weight relationship

The relationship between length and weight was analyzed using the formula (Le Cren, 1951):

$$W = aL^b$$

Description W = Fish body weight (g), L = Total length of fish (cm), a = Coefficient of determination, b = exponent that indicates isometric or allometric.

To ~~obtain-make~~ the equation, the values of W and L were transformed into logarithms (base 10) as follows:

$$W = \log a + b \log L$$

The b values obtained were used to estimate the two parameters (length and weight) analyzed, with hypotheses: 1) $b = 3$ indicates an isometric growth pattern, 2) $b \neq 3$ indicates an allometric growth pattern, a) $b > 3$: faster weight gain (positive allometric), b) $b < 3$: faster length gain (negative allometric).

Condition factor

Because the growth pattern of silver barb in this study is negative allometric ($b \neq 3$),

the formulation (Le Cren, 1951) is:

$$Kn = \frac{W}{a L^b}$$

Description Kn = Condition factor, W = Fish body weight (g), L = Total length of fish (cm), a = Intercept, b = slope

Size at first gonadal maturity (L_{50})

The size of the first time the fish matures gonads is obtained by finding the value of L_{50} by plotting the cumulative percentage of gonadal mature fish with the size of the fish body length, so that a standard logistic curve will be obtained and the intersection point between the curve and 50% cumulative frequency is the length when 50% of the fish first matures gonads.

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Gonad maturity

The stage of gonadal maturity was observed macroscopically, the observation procedure is when the silver barb was first dissected, and the visceral cavity was opened to observe the morphology of the gonads including shape, color, size, gonad position in the abdominal cavity and egg diameter. Maturity stages were classified according to Brown-Peterson *et al.* (2011), and modified according to silver barb conditions, i.e. stage I (Immature); II (Developing); III (Maturing); IV (Mature) and V (Spent). Egg diameter was observed by taking samples of stage IV fish gonads then each fish gonad was taken in 3 parts, i.e. posterior, anterior, and middle gonads. Eggs were taken from each part of the gonad sample, with 30 eggs in each part. A total of 90 fish egg samples were measured in diameter using an ocular micrometer (0.01 mm) brand UYCP-12.

Fecundity

Fecundity can be known the procedure that the weight of the total gonads (WG), then take a subpart of the total gonad at each end of the bottom, middle and top then measure its weighed (Ws). The weight of the gonad subpart was then preserved in a 4% formalin solution to facilitate the calculation of the number of eggs (n). Fecundity was observed in maturity stage IV, calculated using the gravimetric method (Hasan *et al.*, 2020):

$$F = \frac{\text{Weight of the total gonad (WG)}}{\text{Weight subpart gonad (Ws)}} \times \text{number of eggs of the subpart gonad (n)}$$

The relationship between fecundity and total length and body weight using the formulation Hasan *et al.* (2020) is:

$$F = a L^b \quad \text{and} \quad F = a W + b$$

Description F = Fecundity (egg), L = Total length of fish (cm), W = Fish body weight (g), a = Intercept, b = slope

Results*Length and weight structure*

The results of the length structure analysis of male ~~tawes-Silver barb~~ are 8.9 - 22.9 cm and females are 8.9 - 28.5 cm, the largest proportion caught at 14.5 cm both males and females. While the size structure of male weights is 21.2 - 183.2 g and female are 21.2

- 312.8 g; and the largest proportion of males and females caught is the same weight size of 21.2 g (Fig. 2 a and b).

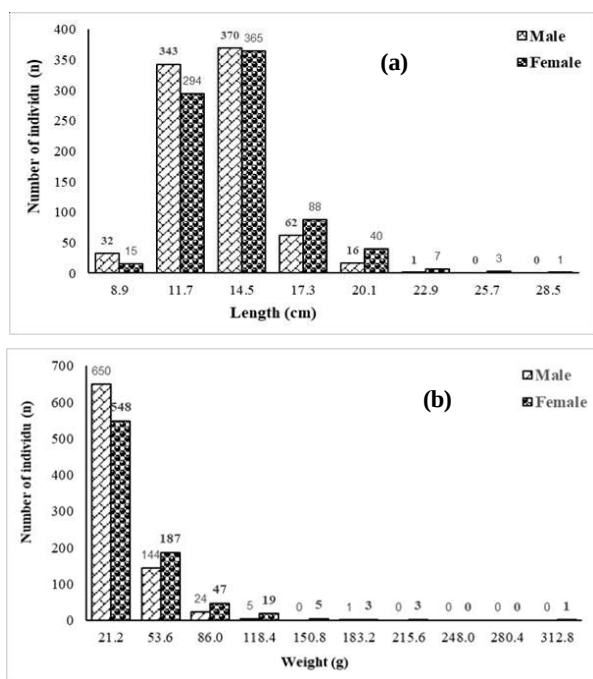


Fig 2. Length (a) and weight (b) structure of silver barb

Sex Ratio

The total sex ratio of males and females was 824 (50%) and 813 (50%), indicating a male-to-female sex ratio of 1:1 (Fig. 3a). The sex ratio of gonadally mature males and females was 27 (25%) and 83 (75%), indicating that 1 male was partnered with 3 females for spawning activities (Fig. 3b).

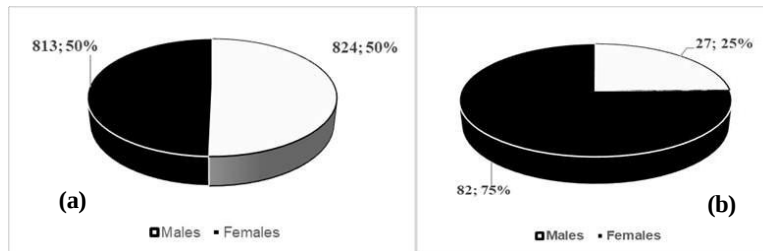


Fig 3. Male-to-female sex ratio of silver barb total fish (a), and gonad of maturity (b)

Length-weight relationship

The results of the analysis of the length-weight relationship of male was $W = 0.0234 L^{2.7349}$ and female $W = 0.0172 L^{2.8766}$ and combined (male and female) $W = 0.0183 L^{2.8415}$ (Fig. 4 a, b, c). The t-test results showed that the b value of male, female and combined (male and female) silver barb is different from 3 ($b \neq 3$) so it can be concluded that the growth pattern is allometric. Because the value of $b < 3$, it is negatively allometric.

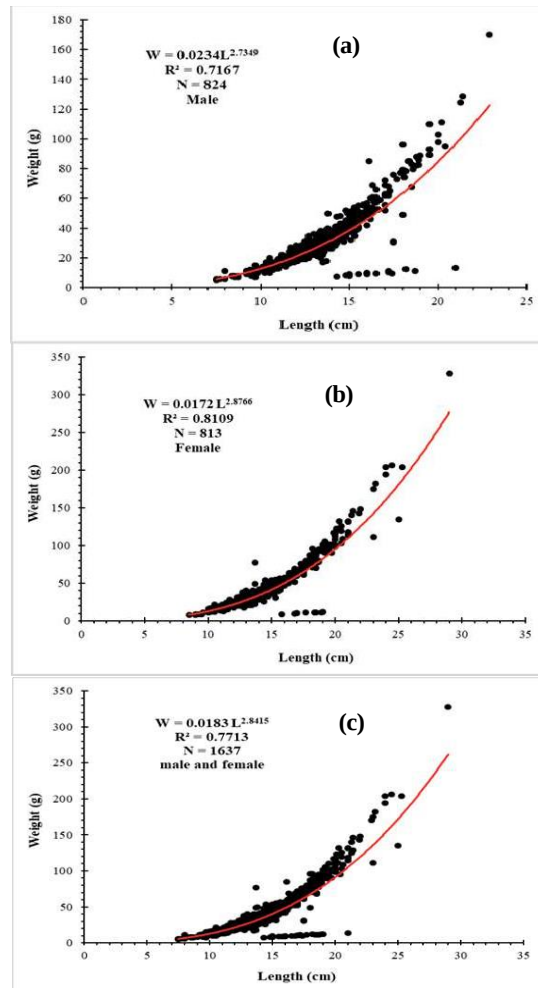


Fig 4. Length-weight relationship of male (a), female (b) and combined (male and female) (c)

Condition Factor

Condition factors for male and female silver barb were 1.0243 ± 0.0061 and 1.0181 ± 0.0054 , respectively.

Size at first gonad maturity (L_{50})

The results of the analysis of the size of the first mature gonads (L_{50}) of male fish are different from females. Female fish are faster to mature gonads, i.e. $L_{50} = 18.3$ cm than males $L_{50} = 19.9$ cm.

Gonad maturity

Determination of gonad maturity criteria is macroscopic by observing the morphological shape, size, color and position of the gonads in the abdominal cavity. The development of gonads (ovary and testes) of silver barb is classified into five levels according to the instructions Hasnidar *et al.* (2022) and the condition of silver barb gonads. The gonadal stages are stage I (Immature), II (Developing), III (Maturing), IV (Mature) and V (spent) (Table 1).

Table 1. Gonad maturity of female and male silver barb

Maturity stage	Note	Female	Male
I	Immature	Ovary is small, extending anteriorly to posteriorly in the dorsal abdominal cavity, filled with white and viscous fluid, eggs not yet visible, estimated to fill <15% of the abdominal cavity.	Testes are small and thin, extending from anterior to posterior of the abdominal cavity, filled with clear white fluid
II	Developing	Ovary is larger than immature ovaries, white in color, egg grains are visible, estimated to fill 20-30% of the abdominal cavity. The average egg diameter is 0.20 – 0.425 mm	Testes are enlarged, larger than stage I (immature) testes; filled with white liquid
III	Maturing	Ovary is enlarged, filled with greenish-white soft granules, egg granules are still difficult to separate. Estimated to fill almost 30%-60% of the abdominal cavity. The average egg diameter is 0.450 - 0.750 mm	Testes are getting bigger and larger than stage II, the surface of the testes appears to be ridged. Contains thick white liquid
IV	Mature	Ovary is getting bigger, filling about 60-80% of the abdominal cavity. ovaries contain yellowish-green egg grains, the average egg diameter is 0.800 - 1.25 mm	Testes are getting bigger larger than stage III, the surface of the testes is grooved. Contains thick milky white liquid
V	Spent	Ovary reduced, creased, ovary wall thick and lobed, yellowish-green color containing unspawned residual eggs	Testes reduced in size, wrinkled edges

Fecundity

The number of gonads mature female (stage IV) was 82 fish with a length range of 7.5-17.5 cm and weights of 7-82 g, gonad weights of 1.25-10.11 g. The fecundity of silver barb obtained in this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The fecundity of silver barb obtained from the results of this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The relationship between fecundity and total length is $F = 4.6297 L^{2.958}$ ($R^2 = 0.3526$), fecundity with body weight is a linear relationship that is $F = 444.66W + 1489.3$ ($R^2 = 0.5145$) (Fig. 5 a, b).

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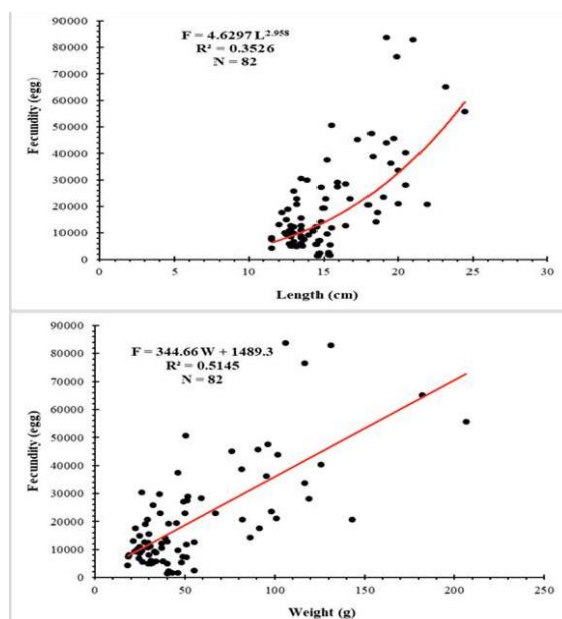


Fig 5. Fecundity-length (a), fecundity-weight (b) relationships of silver barb

Discussion

The length size structure of silver barb is 8.9 - 28.5 cm, with the highest caught size of 14.5 cm. Furthermore, the weight size structure is 21.2 - 312.8 g; and the largest proportion caught is 21.2 g in weight size. The data shows that the length and weight of silver barb captured are dominant in small size.

The length and weight structure of silver barb from several waters show low values compared to silver barb caught in Dan Tchang Reservoir, Thailand, which is 45 cm and 2,100 g (Chheng *et al.*, 2004). These data indicate that silver barb fishing, in Lake Tempe in particular, is very intensive and even overexploited (Sukarman, 2022). Silver barb do not have the opportunity to grow large due to intensive fishing. In addition, the less optimal environmental conditions of the lake, the presence of predators or competitors, and the limited ability of swimming larvae to escape from environmental factors are thought to affect the survival and growth. According to (Arevalo *et al.*, 2023), 99% mortality of a large number of fish species occurs in the early phase of fish life. Such high mortality is thought to have influenced variations in silver barb population size.

The total sex ratio of male and female is 1:1, indicating a balanced number of male and female fish. Silver barb with a male and female ratio of 1:1 (Maknuu, 2016), 1:1.27 (Jasmine and Begum, 2016), 1:2 (Ardelia *et al.*, 2023), 4:1 (Efizon *et al.*, 2021). Sex ratios can differ between the same fish species, because sex determination is not only determined by genetic factors but also by the environment (Capel, 2017), a sex ratio of 1:1 is an ideal description because both male and female fish have the same opportunity to maintain their species. Although silver barb experience high exploitation pressure, the sex ratio data shows that silver barb still have a high ability to maintain their population.

Furthermore, the sex ratio of gonads mature males and females is 27 fish (25%) and 83 fish (75%) or 1:3, meaning that 1 male is paired with 3 females for spawning activities (polygamy). The sex ratio in spawning is related to the interaction and synchronization between male and female fish (Mylonas *et al.*, 2010) as well as the

Efficient use of the number of male or female fish in spawning. Each fish species has an optimal sex ratio of males to females for spawning, for example climbing perch, *Anabas testudineus* is 1:2 (Hasnidar et al., 2022); Sailfin molly, *Poecilia latipinna* is 1:10 (Tamsil and Hasnidar, 2019); silver barb, *Barbonymus sp.* is 6:1 (Efizon et al., 2021).

The results of the analysis of the length-weight relationship of male silver barb obtained relationship model $W = 0.0234 L^{2.7349}$, female $W = 0.0172 L^{2.8766}$, combined (male and female) $W = 0.0183 L^{2.8415}$. The t test results obtained the value of b silver barb male, female and combined different from 3 ($b \neq 3$) so it can be concluded that the growth pattern is allometric. Because the value of $b < 3$, it is called negative allometric. Some research results on the length-weight relationship of silver barb in several aquatic locations.

Differences in silver barb ~~growth~~ growth patterns are due to differences in aquatic conditions. An important factor affecting the growth of fish in the tropics is the availability of food (Froese, 2006). Therefore, the same fish species in different locations will have different growth patterns due to this factor. In addition to food, other factors are the stage of gonad development, water physico-chemistry, fish health conditions, season, time and sampling techniques (Sheridan, 2011; Mehanna and Farouk, 2021). The number of fish caught in this study was 1623 fish, of which only 109 fish or 6.7% were mature gonads (stage IV), which is thought to be the cause of the negative allometric growth pattern.

Condition Factor (CF) is a value that reflects the influence of environmental factors on the physiological condition (Faradonbeh et al., 2015). Good environmental conditions including the availability of food will support good growth so that the weight of the fish is higher and the $CF \geq 1$, on the other hand, environmental conditions are not suitable and limited food availability causes small weight gain and $CF < 1$ (Dirican and Cilek, 2012). The CF value of the results of this study is 1.024 - 1.018; this value indicates the condition of the fish body is thin (compressed), the same as the growth pattern, which is negative allometric, that is length growth is faster than weight.

The condition factor of silver barb from several studies is 0.84 - 1.4 (Buwono *et al.*, 2019), 1.05 – 317 (Sidik *et al.*, 2020), 1.01 – 1.02 (Dwirastina and Marson, 2021), 0.82 – 1.10 (Syaiful *et al.*, 2019), 0.76 – 2.27 (Laila, 2018), 1.145-1.328 (Maknuu, 2016). The varying CF are due to differences in aquatic environment, density, food availability, and physiological conditions such as fish reproductive cycles. The higher the CF value indicates the compatibility of the fish with its environment.

The results of the analysis of the level of maturity of the gonads macroscopically show that in each level of maturity there are differences in size, color, and volume of gonads in the abdominal cavity of the ovary and testes. In the ovary, the higher the level of maturity, the diameter of oocytes tends to increase, but there are variations in the diameter of oocytes at the same maturity stage. Similarly, histological observations show that there are different sizes of oocyte diameter in the (Efizon *et al.*, 2021). These data indicate that silver barb ~~tawes~~ are gradual spawners, ~~that is, they release their eggs~~ not all at once during spawning. Gradual spawners have a long spawning season. The spawning season of silver barb in Tempe Lake is thought to be throughout the year, it can be seen in every fish sampling from January to June that mature (stage IV) is found every month of observation, with the highest mature in January. In contrast to silver barb in Padma River Bangladesh, the spawning season is April - July and the peak spawning is in June (Jasmine and Begum, 2016).

Length at first maturity (L_{50}) is the value at which 50% of individuals in a group have reproduced at least once (Barzotto and Mateus, 2017). The length at first maturity of male = 19.9 cm, and female = 18.3 cm. The L_{50} value of the results of this study is greater than the L_{50} of silver barb from Nagan river, Aceh Province, Indonesia, e.g. male = 7.3 cm and female = 8.5 cm (Efizon *et al.*, 2021). The length of the first maturing gonads of fish can differ due to competition and predation, fishing pressure and environmental conditions (de Souza *et al.*, 2019). Fish will perform the first maturation with a shorter length to reduce the risk of death before reproduction if environmental conditions are unfavorable (Barzotto and Mateus, 2017). Based on the

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L₅₀ value of male and female in relation to the length of the dominant silver barb caught in this study, ± 90% of the fish caught have never reproduced.

Silver barb identified as maturity stage IV in this study were 82 fish, having a length range of 12.2 - 21.28 cm (average ± 15.0 cm) and body weight of 21.0 - 124.4 g (average ± 41 g), producing fecundity with a range of 1,443 - 83,822 eggs (average = 20,239 eggs). Fecundity data of silver barb in several aquatic are presented in Table 4.

The estimated coefficient of determination (R^2) of the relationship between fecundity-length (F-L) and fecundity-weight (F-W) showed that 35.3% of the variation in fecundity occurred due to variation in total fish length and 51.5% of the variation in fecundity due to the influence of variation in body weight. Similar observations on tawes from Nagan river, Aceh Province, Indonesia; the coefficient of determination (R^2) of the relationship between F-L and F-W was 51% and 24.2%, respectively (Efizon *et al.*, 2021). This means that tawes fecundity increases with increasing total length and body weight. Fish that have a larger size in addition to having a large visceral cavity to accommodate a larger number of oocytes also have sufficient energy for reproductive activities (Jonsson and Jonsson, 1999). Factors that affect fish fecundity are internal factors such as genetics, age, and size (Hunter *et al.*, 1992), while external factors are food availability and environmental conditions (Bryan *et al.*, 2007).

Conclusions

The length and weight structure of female fish were higher than male fish. The dominant lengths and weights caught were 14.5 cm and 21.2 g. Negative allometric growth pattern and condition factor 1.02; lean growth. The overall ratio of male and female was 1 : 1, while the spawning sex ratio was 1 : 3; that is, one male fish is paired with 3 females in spawning. The first size of gonad maturity of female fish was faster at 18.3 cm and 19.9 cm for males. Fecundity ranged from 253 to 13,398 eggs (mean

2,571 eggs). Variation in fecundity was more strongly influenced by variation in body weight than variation in total length of silver barb.

Acknowledgments

To the Rector of Universitas Muslim Indonesia (UMI) Makassar through the Institute for Research and Resource Development which has supported funds so that this research can be carried out.

Conflicts of interest

We declare that this research was conducted without any conflict of interest with any party.

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Reproductive biology of silver barb, *Barbonymus gonionotus* (Bleeker, 1850), in Tempe Lake, Indonesia

Andi Tamsil¹; Hasnidar Hasnidar^{1*}

Abstract

Information on the reproductive biology of silver barb is needed for conservation and domestication purposes. This study aims to analyze the reproductive biology of silver barb in Tempe Lake South Sulawesi, Indonesia. Aspects of reproductive biology analyzed were length-weight structure, sex ratio, length-weight relationship, condition factor, size at first gonad maturity (L_{50}), gonad of maturity, and fecundity. This study used primary data, silver barb were caught using gill nets every two weeks from January to July 2023. The total length of fish was measured using an ichthyometer with an accuracy of 0.1 cm, and weight using a digital scale with an accuracy of 0.01 g. The gonads are preserved in a 4% formalin solution, and fertility is measured using the gravimetric method. The size of the male gonads ranges from 8.9 to 22.9 cm in length, while the female gonads range from 8.9 to 28.5 cm. Males weigh between 21.2 and 183.2 g, and females weigh between 21.2 and 312.8 g. The overall sex ratio of males and females was 1:1, while the sex ratio during spawning was 1:3 (polygamous). Length-weight relationships between males and females were $W = 0.0234L^{2.7349}$ and $W = 0.0172L^{2.8766}$ respectively. The condition factor for males and females was the same at 1.02. The size of first maturing gonads for females was 18.3 cm and 19.9 cm for males. Partial spawning, with fertility ranging from 253 to 13,398 eggs.

Keywords: Reproductive biology, Silver barb, Tempe Lake, Length-weight relation

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Introduction

Silver barb, *Barbonymus gonionotus* (Bleeker, 1850) is an economically important freshwater fish in several countries such as Indonesia, Malaysia, Thailand, Myanmar, Bangladesh, India, and China. The taste is good and the price is relatively cheap so it becomes the main consumption of the community, especially some places in the territory of Indonesia. Silver barb production still mainly depends on fishing, so fishing pressure continues to increase.

Tempe Lake has a diversity of fish species consisting of native fish, introduced fish and migratory marine fish. According to Dina *et al.* (2019), the native fishes of Tempe Lake are *Monopterus albus*, *Anabas testudineus*, *Glossogobius aureus*, *Channa striata*. Introduced fish species are *Barbonymus gonionotus*, *Clarias batrachus*, *Trichopodus pectoralis*, *Pangasianodon hypophthalmus*, *Osteochilus vittatus*, *Oreochromis niloticus*, *Helostoma temminckii*, *Cyprinus carpio* (Yanuarita *et al.*, 2020). Migratory marine fish species are *Megalops cyprinoides*, *Stenogobius gymnopomus*, *Anguilla marmorata* and *Caranx sexfasciatus*. Introductions are carried out to increase the production of fishery products to meet increasing demand, optimize water productivity, increase production in a sustainable and increase biodiversity (Yanuarita *et al.*, 2020; FAO, 2022).

Tempe Lake is presently experiencing various environmental problems, including eutrophication (Aisyah and Nomosatryo, 2016). Eutrophication occurs allegedly due to the load of nutrients derived from the activities of humans, plantations and farms that are often found on the shores of the lake. Nitrate and phosphate nutrients are in the range of 0.1063-0.2620 mg/l and 0.0245-0.0655 mg/l respectively in the water (Samuel *et al.*, 2012). These conditions trigger the growth of aquatic weeds such as *Ipomoea aquatic* and *Eichhornia crassipes*. *E. crassipes* is the most dominant of these plants and its population is estimated to have covered the lake surface by about 30 - 40%. According to (Yani *et al.*, 2019), Lake Tempe has experienced moderate to severe pollution in several parameters including turbidity, total suspended solids, biological oxygen demand, nitrate, and phosphate.

Another problem is overfishing and the use of fishing gear that is not environmentally sustainable (Nasution, 2012), and a serious problem is the presence of invasive fish, i.e. *Pterygoplichthys* spp (Hasnidar *et al.*, 2021). The high population of *Pterygoplichthys* spp has caused fishermen's catches of target fish to decline (Hasrianti *et al.*, 2020). The presence of *Pterygoplichthys* spp impacts the lake ecosystem through competition for habitat, diet, and can even be a predator of native and endemic fish, as well as an agent of various diseases. It can change the species composition and structure of fish communities, dominating and excluding native and endemic fish (Syafei and Sudinno, 2018).

Silver barb or Java barb, *B. gonionotus* was introduced to Lake Tempe in 1937 (Dina *et al.*, 2019; Yanuarita *et al.*, 2020). Although an introduced fish, Tawes (Silver barb) successfully adapted well to the lake environment. The condition of Tempe Lake, which is rich with dominant aquatic plants, enables it to survive well. Silver barb are herbivorous, with phytoplankton (Chlorophyceae) as their main food (Ain *et al.*, 2021); aquatic plants (80%), detritus (12%), phytoplankton (8.5%) (Aida, 2018; Pratiwi *et al.*, 2021). Silver barb are considered useful in controlling excessive vegetation in lake waters. Although silver barb successfully lives in Tempe Lake, the declining environmental conditions of Tempe Lake certainly have an impact on the production of these fish.

Silver barb production has fluctuated in recent years, with capture mortality higher than natural mortality due to overfishing (Sukarman, 2022). This condition is thought to be due to the presence of *Pterygoplichthys* spp as an invasive fish (Hasnidar *et al.*, 2021). There are two species that are still caught in large numbers, i.e silver barb and bloso (*Glossogobius* sp), therefore both fish species are under very high fishing pressure. Conservation and domestication efforts will be carried out, but these efforts require the latest information including aspects of silver barb reproductive biology for the future management. The study aims to analyze the reproductive biology of silver barb including size distribution, sex ratio, length and weight relationship, condition factor, gonad maturity, size of first mature gonad, and fecundity.

Materials and methods

The study was conducted from January to July 2023 in Tempe Lake, Wajo Regency, South Sulawesi Province, Indonesia (Fig. 1). Fish sampling was collected every week for six months, using a gill net response tool. Fish samples caught were cleaned, put in a cooler box and given ice cubes. Sample observations were carried out at the Biota and Environmental Engineering Laboratory, Faculty of Fisheries and Marine Science, Universitas Muslim Indonesia (UMI) Makassar.

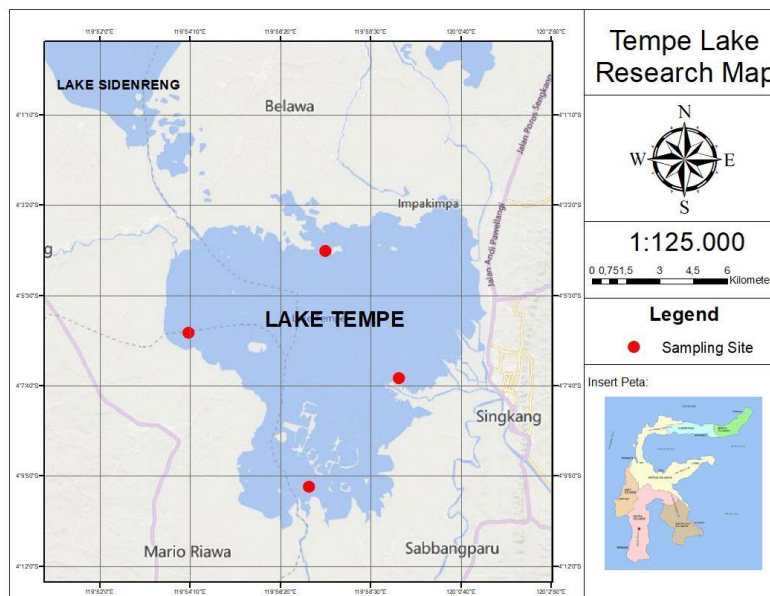


Fig 1. Silver barb fishing sampling points on the site in Tempe Lake, Wajo Regency, South Sulawesi, Indonesia.

The total length (Lt) of silver barb was measured using an ichthymeter (Vernier calipers, Mitutoyo) with an accuracy of 0.1 cm, body weight and gonads (g) were measured using digital scales (Digital elektrik scale, DIGI DS880) with an accuracy of 0.01g. The parameters analyzed were:

Length and weight structure

Length and weight size structures were determined as follows: determining the number of classes; determining the length class interval of 1 cm and weight of 1 g; inserting

Each fish sample in the predetermined class. The size structure was determined within the same class interval and then plotted on a graph.

Sex ratio

The sex of silver barb was determined morphologically and anatomically by dissecting the fish to see whether the gonads developed into testes or ovaries. Determination of male and female sex ratio is done by calculating the number of male fish and female fish caught using the formula (Oliveira *et al.*, 2012):

$$N = \frac{\text{number of male of female}}{\text{total number of fish observed}} \times 100$$

Next, sex ratio variability was tested using the Chi-square test (Oliveira *et al.*, 2012):

$$X^2 = \frac{\sum (oi - ei)^2}{ei}$$

Description: X^2 = Value for a random variable whose sampling distribution approximates the Chi-square distribution

oi = Observed frequencies of male and female fish

ei = Expected frequencies of male and female fish

Length-weight relationship

The relationship between length and weight was analyzed using the formula (Le Cren, 1951):

$$W = aL^b$$

Description W = Fish body weight (g), L = Total length of fish (cm), a = Coefficient of determination, b = exponent that indicates isometric or allometric.

To make the equation, the values of W and L were transformed into logarithms (base 10) as follows:

$$W = \log a + b \log L$$

The b values obtained were used to estimate the two parameters (length and weight) analyzed, with hypotheses: 1) $b = 3$ indicates an isometric growth pattern, 2) $b \neq 3$ indicates an allometric growth pattern, a) $b > 3$: faster weight gain (positive allometric), b) $b < 3$: faster length gain (negative allometric).

Condition factor

Because the growth pattern of silver barb in this study is negative allometric ($b \neq 3$),

the formulation (Le Cren, 1951) is:

$$Kn = \frac{W}{a L^b}$$

Description Kn = Condition factor, W = Fish body weight (g), L = Total length of fish (cm), a = a = Intercept, b = slope

Size at first gonadal maturity (L_{50})

The size of the first time the fish matures gonads is obtained by finding the value of L_{50} by plotting the cumulative percentage of gonadal mature fish with the size of the fish body length, this will yield a standard logistic curve, and the intersection point between the curve and the 50% cumulative frequency represents the length at which 50% of the fish first mature gonadally.

Gonad maturity

The stage of gonadal maturity was observed macroscopically, the observation procedure is when the silver barb was first dissected, and the visceral cavity was opened to observe the morphology of the gonads including: shape, color, size, gonad position in the abdominal cavity and egg diameter. Maturity stages were classified according to Brown-Peterson *et al.* (2011), and modified according to silver barb conditions, i.e. stage I (Immature); II (Developing); III (Maturing); IV (Mature) and V (Spent). Egg diameter was observed by taking samples of stage IV fish gonads then each fish gonad was taken in 3 parts, i.e. posterior, anterior, and middle gonads. Eggs were taken from each part of the gonad sample, with 30 eggs in each part. A total of 90 fish egg samples were measured in diameter using an ocular micrometer (0.01 mm) brand UYCP-12.

Fecundity

Fecundity can be known the procedure that the weight of the total gonads (WG), then take a subpart of the total gonad at each end of the bottom, middle and top then measure its weighed (Ws). The weight of the gonad subpart was then preserved in a 4% formalin solution to facilitate the calculation of the number of eggs (n). Fecundity was observed in maturity stage IV, calculated using the gravimetric method (Hasan *et al.*, 2020):

$$F = \frac{\text{Weight of the total gonad (WG)}}{\text{Weight subpart gonad (Ws)}} \times \text{number of eggs of the subpart gonad (n)}$$

The relationship between fecundity and total length and body weight using the formulation Hasan *et al.* (2020) is:

$$F = a L^b \quad \text{and} \quad F = a W + b$$

Description F = Fecundity (egg), L = Total length of fish (cm), W = Fish body weight (g), a = Intercept, b = slope

Results

Length and weight structure

The results of the length structure analysis of male Silver barb are 8.9 - 22.9 cm and females are 8.9 - 28.5 cm, the largest proportion caught at 14.5 cm both males and females. While the size structure of male weights is 21.2 - 183.2 g and female are 21.2 - 312.8 g; and the largest proportion of males and females caught is the same weight size of 21.2 g (Fig. 2 a and b).

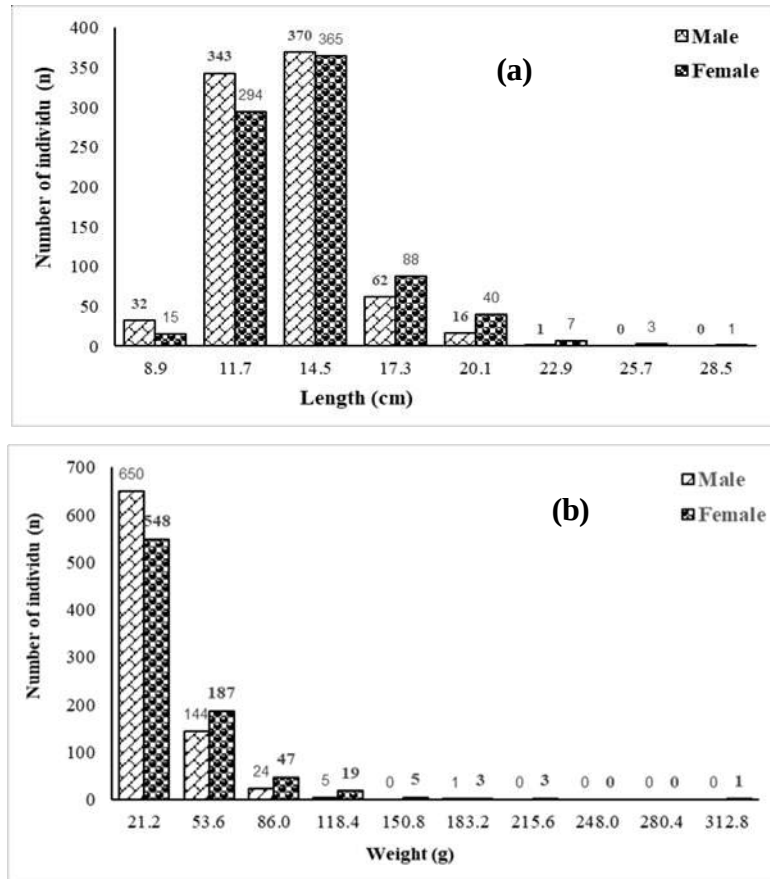


Fig 2. Length (a) and weight (b) structure of silver barb

Sex Ratio

The total sex ratio of males and females was 824 (50%) and 813 (50%), indicating a male-to-female sex ratio of 1:1 (Fig. 3a). The sex ratio of gonadally mature males and females was 27 (25%) and 83 (75%), indicating that 1 male was partnered with 3 females for spawning activities (Fig. 3b).

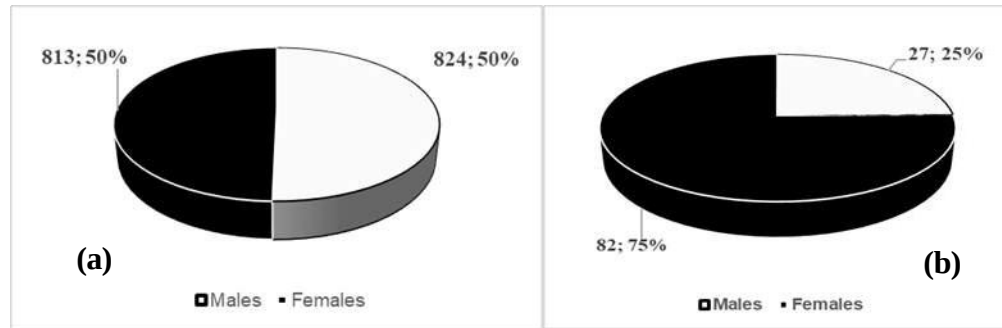


Fig 3. Male-to-female sex ratio of silver barb total fish (a), and gonad of maturity (b)

Length-weight relationship

The results of the analysis of the length-weight relationship of male was $W = 0.0234 L^{2.7349}$ and female $W = 0.0172 L^{2.8766}$ and combined (male and female) $W = 0.0183 L^{2.8415}$ (Fig. 4 a, b, c). The t-test results showed that the b value of male, female and combined (male and female) silver barb is different from 3 ($b \neq 3$) so it can be concluded that the growth pattern is allometric. Because the value of $b < 3$, it is negatively allometric.

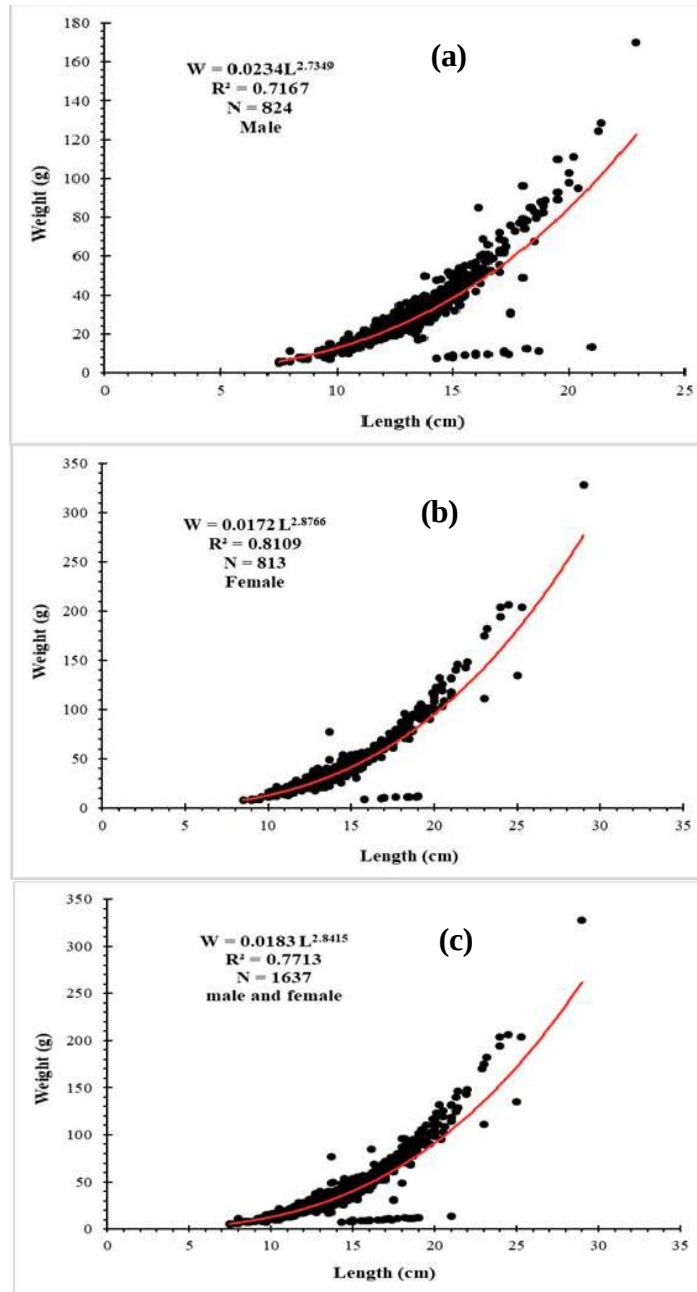


Fig 4. Length-weight relationship of male (a), female (b) and combined (male and female) (c)

Condition Factor

Condition factors for male and female silver barb were 1.0243 ± 0.0061 and 1.0181 ± 0.0054 , respectively.

Size at first gonad maturity (L_{50})

The results of the analysis of the size of the first mature gonads (L_{50}) of male fish are different from females. Female fish are faster to mature gonads, i.e. $L_{50} = 18.3$ cm than males $L_{50} = 19.9$ cm.

Gonad maturity

Determination of gonad maturity criteria is macroscopic by observing the morphological shape, size, color and position of the gonads in the abdominal cavity. The development of gonads (ovary and testes) of silver barb is classified into five levels according to the instructions Hasnidar *et al.* (2022) and the condition of silver barb gonads. The gonadal stages are stage I (Immature), II (Developing), III (Maturing), IV (Mature) and V (spent) (Table 1).

Table 1. Gonad maturity of female and male silver barb

Maturity stage	Note	Female	Male
I	Immature	Ovary is small, extending anteriorly to posteriorly in the dorsal abdominal cavity, filled with white and viscous fluid, eggs not yet visible, estimated to fill <15% of the abdominal cavity.	Testes are small and thin, extending from anterior to posterior of the abdominal cavity, filled with clear white fluid
II	Developing I	Ovary is larger than immature ovaries, white in color, egg grains are visible, estimated to fill 20-30% of the abdominal cavity. The average egg diameter is 0.20 – 0.425 mm	Testes are enlarged, larger than stage I (immature) testes; filled with white liquid
III	Maturing	Ovary is enlarged, filled with greenish-white soft granules, egg granules are still difficult to separate. Estimated to fill almost 30%-60% of the abdominal cavity. The average egg diameter is 0.450 - 0.750 mm	Testes are getting bigger and larger than stage II, the surface of the testes appears to be ridged. Contains thick white liquid
IV	Mature	Ovary is getting bigger, filling about 60-80% of the abdominal cavity. ovaries contain yellowish-green egg grains, the average egg diameter is 0.800 - 1.25 mm	Testes are getting bigger larger than stage III, the surface of the testes is grooved. Contains thick milky white liquid
V	Spent	Ovary reduced, creased, ovary wall thick and lobed, yellowish-green color containing	Testes reduced in size, wrinkled edges
		unspawned residual eggs	

Fecundity

There are 82 mature female fish (stage IV) with a length range of 7.5 to 17.5 cm and a weight range of 7 to 82 g, with gonad weights ranging from 1.25 to 10.11 g. The fecundity of silver barb obtained in this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The fecundity of silver barb obtained from the results of this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The relationship between fecundity and total length is $F = 4.6297 L^{2.958}$ ($R^2 = 0.3526$), fecundity with body weight is a linear relationship that is $F = 444.66W + 1489.3$ ($R^2 = 0.5145$) (Fig. 5 a, b).

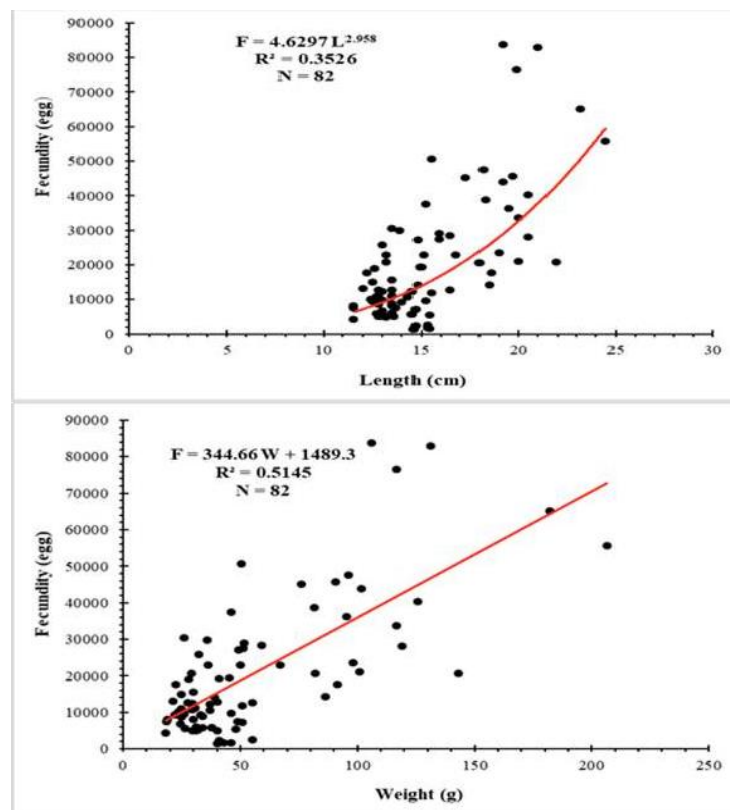


Fig 5. Fecundity-length (a), fecundity-weight (b) relationships of silver barb

Discussion

The length size structure of silver barb is 8.9 - 28.5 cm, with the highest caught size of 14.5 cm. Furthermore, the weight size structure is 21.2 - 312.8 g; and the largest proportion caught is 21.2 g in weight size. The data shows that the length and weight of silver barb captured are dominant in small size.

The length and weight structure of silver barb from several waters show low values compared to silver barb caught in Dan Tchang Reservoir, Thailand, which is 45 cm and 2,100 g (Chheng *et al.*, 2004). These data indicate that silver barb fishing, in Lake Tempe in particular, is very intensive and even overexploited (Sukarman, 2022). Silver barb do not have the opportunity to grow large due to intensive fishing. In addition, the less optimal environmental conditions of the lake, the presence of predators or competitors, and the limited ability of swimming larvae to escape from environmental factors are thought to affect the survival and growth. According to (Arevalo *et al.*, 2023), 99% mortality of a large number of fish species occurs in the early phase of fish life. Such high mortality is thought to have influenced variations in silver barb population size.

The total sex ratio of male and female is 1:1, indicating a balanced number of male and female fish. Silver barb with a male and female ratio of 1:1 (Maknuu, 2016), 1:1.27 (Jasmine and Begum, 2016), 1:2 (Ardelia *et al.*, 2023), 4:1 (Efizon *et al.*, 2021). Sex ratios can differ between the same fish species, because sex determination is not only determined by genetic factors but also by the environment (Capel, 2017), a sex ratio of 1:1 is an ideal description because both male and female fish have the same opportunity to maintain their species. Although silver barb experience high exploitation pressure, the sex ratio data shows that silver barb still have a high ability to maintain their population.

Furthermore, the sex ratio of gonads mature males and females is 27 fish (25%) and 83 fish (75%) or 1:3, meaning that 1 male is paired with 3 females for spawning activities (polygamy). The sex ratio in spawning is related to the interaction and synchronization between male and female fish (Mylonas *et al.*, 2010) as well as the

Efficient use of the number of male or female fish in spawning. Each fish species has an optimal sex ratio of males to females for spawning, for example climbing perch, *Anabas testudineus* is 1:2 (Hasnidar et al., 2022); Sailfin molly, *Poecilia latipinna* is 1:10 (Tamsil and Hasnidar, 2019); silver barb, *Barbonymus sp.* is 6:1 (Efizon *et al.*, 2021).

The results of the analysis of the length-weight relationship of male silver barb obtained relationship model $W = 0.0234 L^{2.7349}$, female $W = 0.0172 L^{2.8766}$, combined (male and female) $W = 0.0183 L^{2.8415}$. The t test results obtained the value of b silver barb male, female and combined different from 3 ($b \neq 3$) so it can be concluded that the growth pattern is allometric. Because the value of $b < 3$, it is called negative allometric. Some research results on the length-weight relationship of silver barb in several aquatic locations.

Differences in silver barb growth patterns are due to differences in aquatic conditions. An important factor affecting the growth of fish in the tropics is the availability of food (Froese, 2006). Therefore, the same fish species in different locations will have different growth patterns due to this factor. In addition to food, other factors are the stage of gonad development, water physico-chemistry, fish health conditions, season, time and sampling techniques (Sheridan, 2011; Mehanna and Farouk, 2021). The number of fish caught in this study was 1623 fish, of which only 109 fish or 6.7% were mature gonads (stage IV), which is thought to be the cause of the negative allometric growth pattern.

Condition Factor (CF) is a value that reflects the influence of environmental factors on the physiological condition (Faradonbeh *et al.*, 2015). Good environmental conditions including the availability of food will support good growth so that the weight of the fish is higher and the $CF \geq 1$, on the other hand, environmental conditions are not suitable and limited food availability causes small weight gain and $CF < 1$ (Dirican and Cilek, 2012). The CF value of the results of this study is 1.024 - 1.018; this value indicates the condition of the fish body is thin (compressed), the same as the growth pattern, which is negative allometric, that is length growth is faster than weight.

The condition factor of silver barb from several studies is 0.84 - 1.4 (Buwono *et al.*, 2019), 1.05 – 317 (Sidik *et al.*, 2020), 1.01 – 1.02 (Dwirastina and Marson, 2021), 0.82 – 1.10 (Syaiful *et al.*, 2019), 0.76 – 2.27 (Laila, 2018), 1.145-1.328 (Maknuu, 2016). The varying CF are due to differences in aquatic environment, density, food availability, and physiological conditions such as fish reproductive cycles. The higher the CF value indicates the compatibility of the fish with its environment.

The results of the analysis of the level of maturity of the gonads macroscopically show that in each level of maturity there are differences in size, color, and volume of gonads in the abdominal cavity of the ovary and testes. In the ovary, the higher the level of maturity, the diameter of oocytes tends to increase, but there are variations in the diameter of oocytes at the same maturity stage. Similarly, histological observations show that there are different sizes of oocyte diameter in the (Efizon *et al.*, 2021). These data indicate that silver barb are gradual spawners, that is, they do not release their eggs all at once during spawning. Gradual spawners have a long spawning season. The spawning season of silver barb in Tempe Lake is thought to be throughout the year, it can be seen in every fish sampling from January to June that mature (stage IV) is found every month of observation, with the highest mature in January. In contrast to silver barb in Padma River Bangladesh, the spawning season is April - July and the peak spawning is in June (Jasmine and Begum, 2016).

Length at first maturity (L_{50}) is the value at which 50% of individuals in a group have reproduced at least once (Barzotto and Mateus, 2017). The length at first maturity of male = 19.9 cm, and female = 18.3 cm. The L_{50} value of the results of this study is greater than the L_{50} of silver barb from Nagan river, Aceh Province, Indonesia, e.g. male = 7.3 cm and female = 8.5 cm (Efizon *et al.*, 2021). The length of the first maturing gonads of fish can differ due to competition and predation, fishing pressure and environmental conditions (de Souza *et al.*, 2019). Fish will perform the first maturation with a shorter length to reduce the risk of death before reproduction if environmental conditions are unfavorable (Barzotto and Mateus, 2017). Based on the

L_{50} value of male and female in relation to the length of the dominant silver barb caught in this study, $\pm 90\%$ of the fish caught have never reproduced.

Silver barb identified as maturity stage IV in this study were 82 fish, having a length range of 12.2 - 21.28 cm (average ± 15.0 cm) and body weight of 21.0 - 124.4 g (average ± 41 g), producing fecundity with a range of 1,443 - 83,822 eggs (average = 20,239 eggs). Fecundity data of silver barb in several aquatic are presented in Table 4.

The estimated coefficient of determination (R^2) of the relationship between fecundity-length (F-L) and fecundity-weight (F-W) showed that 35.3% of the variation in fecundity occurred due to variation in total fish length and 51.5% of the variation in fecundity due to the influence of variation in body weight. Similar observations on tawes from Nagan river, Aceh Province, Indonesia; the coefficient of determination (R^2) of the relationship between F-L and F-W was 51% and 24.2%, respectively (Efizon *et al.*, 2021). This means that tawes fecundity increases with increasing total length and body weight. Fish that have a larger size in addition to having a large visceral cavity to accommodate a larger number of oocytes also have sufficient energy for reproductive activities (Jonsson and Jonsson, 1999). Factors that affect fish fecundity are internal factors such as genetics, age, and size (Hunter *et al.*, 1992), while external factors are food availability and environmental conditions (Bryan *et al.*, 2007).

Conclusions

The length and weight structure of female fish were higher than male fish. The dominant lengths and weights caught were 14.5 cm and 21.2 g. Negative allometric growth pattern and condition factor 1.02; lean growth. The overall ratio of male and female was 1 : 1, while the spawning sex ratio was 1 : 3; that is, one male fish is paired with 3 females in spawning. The first size of gonad maturity of female fish was faster at 18.3 cm and 19.9 cm for males. Fecundity ranged from 253 to 13,398 eggs (mean

2,571 eggs). Variation in fecundity was more strongly influenced by variation in body weight than variation in total length of silver barb.

Acknowledgments

To the Rector of Universitas Muslim Indonesia (UMI) Makassar through the Institute for Research and Resource Development which has supported funds so that this research can be carried out.

Conflicts of interest

We declare that this research was conducted without any conflict of interest with any party.

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Reproductive biology of silver barb, *Barbonymus gonionotus* (Bleeker, 1850), in Lake Tempe, Indonesia

Andi Tamsil¹; Hasnidar Hasnidar^{1*}

Abstract

Information about the reproductive biology of the silver barb is essential for conservation and domestication purposes. This study aims to analyze the reproductive biology of the silver barb in Lake Tempe, South Sulawesi, Indonesia. The aspects of reproductive biology analyzed include length-weight structure, sex ratio, length-weight relationship, condition factor, first gonadal maturity size (L50), gonadal maturity, and fecundity. This study used primary data, with silver barb fish being caught using gill nets every weeks from January to July 2023. The total length of the fish was measured using an ichthyometer with an accuracy of 0.1 cm, and the weight was measured using a digital scale with an accuracy of 0.01 g. Gonads were preserved in a 4% formalin solution, and fecundity was measured using the gravimetric method. The length structure of male ranged from 8.9 to 22.9 cm, and females ranged from 8.9 to 28.5 cm. Males had weights between 21.2 and 183.2 g, and females 21.2 and 312.8 g. The overall sex ratio of males to females was 1:1, while the sex ratio during spawning was 1:3 (polygamy). The length-weight relationship for males and females was $W = 0.0234L^{2.7349}$ and $W = 0.0172L^{2.8766}$, respectively. The condition factor for both males and females was 1.02. The first gonadal maturity size for females was 18.3 cm, and 19.9 cm for males. Spawning was partial, with fecundity ranging from 253 to 13,398 eggs.

Keywords: Reproductive biology, Silver barb, Lake Tempe, Length-weight relationship

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Introduction

Silver barb, *Barbonymus gonionotus* (Bleeker, 1850), is an economically important freshwater fish in several countries such as Indonesia, Malaysia, Thailand, Myanmar, Bangladesh, India, and China. This fish has a delicious taste and is relatively inexpensive, making it a primary food source for communities, especially in certain regions of Indonesia. Its production largely relies on wild capture, leading to increasing fishing pressure.

Lake Tempe has a diverse range of fish species, consisting of native fish, introduced fish, and migratory marine fish. According to Dina et al. (2019), the native fish of Lake Tempe include *Monopterus albus*, *Anabas testudineus*, *Glossogobius aureus*, and *Channa striata*. The introduced fish species are *Barbonymus gonionotus*, *Clarias batrachus*, *Trichopodus pectoralis*, *Pangasianodon hypophthalmus*, *Osteochilus vittatus*, *Oreochromis niloticus*, *Helostoma temminckii*, and *Cyprinus carpio* (Yanuarita et al., 2020). The migratory marine fish species include *Megalops cyprinoides*, *Stenogobius gymnopomus*, *Anguilla marmorata*, and *Caranx sexfasciatus*. The introduction of these species was carried out to enhance fishery production to meet increasing demand, optimize water productivity, sustainably boost production, and increase biodiversity (Yanuarita et al., 2020; FAO, 2022).

Lake Tempe is currently facing environmental issues, including eutrophication (Aisyah and Nomosatryo, 2016). Eutrophication is suspected to be caused by nutrient loads originating from human activities, plantations, and livestock farming, which are prevalent around the lake's edge. Nitrate and phosphate nutrients in the water range from 0.1063-0.2620 mg/l and 0.0245-0.0655 mg/l, respectively (Samuel et al., 2012). This condition triggers the growth of aquatic weeds such as *Ipomoea aquatica* and *Eichhornia crassipes*. *E. crassipes* is the most dominant plant, with its population estimated to cover about 30-40% of the lake's surface. According to Yani et al. (2019), Lake Tempe has experienced moderate to severe pollution in several parameters, including turbidity, total suspended solids, biological oxygen demand, nitrate, and phosphate levels.

Another issue is overfishing and the use of non-environmentally friendly fishing gear (Nasution, 2012). A more serious problem is the presence of invasive fish species,

specifically *Pterygoplichthys* spp. (Hasnidar et al., 2021). The high population of *Pterygoplichthys* spp. has led to a decrease in the catch of target fish by fishermen (Hasrianti et al., 2020). The presence of *Pterygoplichthys* spp. impacts the lake ecosystem through habitat competition, feeding patterns, and even predation on native and endemic fish, as well as being vectors for various diseases. This can alter species composition and fish community structure, leading to the dominance and possible elimination of native and endemic fish (Syafei and Sudinno, 2018).

Silver barb, *B. gonionotus*, was introduced to Lake Tempe in 1937 (Dina et al., 2019; Yanuarita et al., 2020). Although an introduced species, silver barb have adapted well to the lake environment. The rich aquatic vegetation of Lake Tempe allows them to thrive. Silver barb are herbivores, with phytoplankton (Chlorophyceae) being their primary food source (Ain et al., 2021); their diet also includes aquatic plants (80%), detritus (12%), and phytoplankton (8.5%) (Aida, 2018; Pratiwi et al., 2021). Silver barb fish are considered beneficial in controlling excessive vegetation in lake waters. Despite their successful adaptation to Lake Tempe, the declining environmental conditions of the lake inevitably impact the production of this fish.

The production of silver barb has fluctuated in recent years, likely due to overfishing, environmental conditions, and high natural mortality (Sukarman, 2022). The high natural mortality is suspected to be caused by the presence of *Pterygoplichthys* spp. as an invasive species (Hasnidar et al., 2021). Two fish species that are still being caught in large numbers are the silver barb and bloso (*Glossogobius* sp.). As a result, these two species are under very high fishing pressure. Conservation and domestication efforts will continue, but these efforts require up-to-date information, including the reproductive biology of silver barb, for future management. The research aims to analyze the reproductive biology of silver barb, covering size distribution, sex ratio, length-weight relationship, condition factor, gonad maturity, first gonad maturity size, and fecundity.

Materials and methods

The study was conducted from January to July 2023 in Lake Tempe, Wajo Regency, South Sulawesi Province, Indonesia (Fig. 1). Fish sampling was collected every week for six months, using a gill net response tool. Fish samples caught were cleaned, put in a cooler box and given ice cubes. Sample observations were carried out at the Biota and Environmental Engineering Laboratory, Faculty of Fisheries and Marine Science, Universitas Muslim Indonesia (UMI) Makassar.

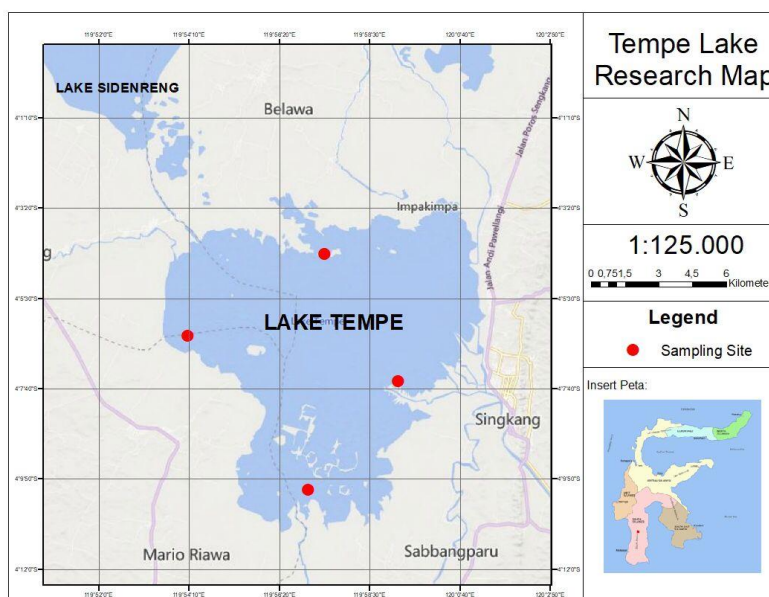


Fig 1. The sampling points for silver barb were located in Tempe Lake, Wajo Regency, South Sulawesi, Indonesia.

The total length (Lt) of the silver barb was measured using an ichthyometer (Vernier caliper, Mitutoyo) with an accuracy of 0.1 cm. Body and gonad weights (g) were measured using a digital scale (electric digital scale, DIGI DS880) with an accuracy of 0.01 g. The parameters analyzed were:

Length and Weight Structure

The length and weight size structure is determined as follows: determining the number of classes; setting the length class interval at 1 cm and the weight class interval at 1 g; placing each fish sample into the predetermined class. The size structure is determined within the same class intervals and then plotted on a graph.

Sex Ratio

The sex of silver barb is determined morphologically and anatomically by dissecting the fish to observe whether the gonads have developed into testes or ovaries. The determination of the male-to-female sex ratio is carried out by counting the number of male and female fish caught using the formula (Oliveira et al., 2012):

$$SR = \frac{\text{number of male of female}}{\text{total number of fish observed}} \times 100$$

Next, sex ratio variability was tested using the Chi-square test (Oliveira *et al.*, 2012):

$$X^2 = \frac{\sum(o_i - e_i)^2}{e_i}$$

Description: X^2 = Value for a random variable whose sampling distribution approximates the Chi-square distribution

o_i = Observed frequencies of male and female fish

e_i = Expected frequencies of male and female fish

Length-weight Relationship

The relationship between length and weight was analyzed using the formula (Le Cren, 1951):

$$W = aL^b$$

Description W = Body weight (g), L = Total length (cm), a = Coefficient of determination, b = exponent that indicates isometric or allometric.

To make the equation, the values of W and L were transformed into logarithms (base 10) as follows:

$$W = \log a + b \log L$$

The obtained b value is used to estimate the length-weight parameters, with the following hypotheses: 1) $b = 3$ indicates isometric growth, 2) $b \neq 3$ indicates allometric growth, a) $b > 3$: weight increases more rapidly (positive allometric), b) $b < 3$: length increases more rapidly (negative allometric).

Condition Factor (CF)

Because the growth pattern of silver barb in this study is negative allometric ($b \neq 3$), the formulation (Le Cren, 1951) is:

$$CF = \frac{W}{a L^b}$$

Description CF = Condition factor, W = Fish body weight (g), L = Total length of fish (cm), a = a = Intercept, b = slope

Size at first gonadal maturity (L_{50})

The size of the first time the fish matures gonads is obtained by finding the value of L_{50} by plotting the cumulative percentage of gonadal mature fish with the size of the fish body length, this will yield a standard logistic curve, and the intersection point between the curve and the 50% cumulative frequency represents the length at which 50% of the fish first mature gonadally.

Gonad Maturity Stage

The stages of gonad maturity are observed macroscopically. The observation procedure involves dissecting the fish sample to open the visceral cavity, then observing the morphology of the gonad, including its shape, color, size, and position within the visceral (abdominal) cavity. The stages of gonad maturity are classified according to Brown-Peterson et al. (2011) and modified according to the gonadal condition of tawes fish, as follows: Stage I (Immature); II (Developing); III (Maturing); IV (Mature); and V (Spent). For fish samples with gonads at maturity Stage IV, the egg diameter is measured. The gonad is taken from three parts: posterior, middle, and anterior. From each part of the gonad sample, 30 eggs are collected for egg diameter measurement. The egg diameter is measured using an ocular micrometer (0.01 mm) of the UYCP-12 brand.

Fecundity

Fecundity is determined by weighing the total gonad (WG), then taking a sub-part from the posterior, middle, and anterior parts of the gonad and weighing it (Ws). The weight of the sub-part gonad is then preserved in a 4% formalin solution to facilitate counting the number of eggs (n). Fecundity is observed at maturity stage IV and is calculated using the gravimetric method (Hasan et al., 2020):

$$F = \frac{\text{Weight of the total gonad (WG)}}{\text{Weight sub-part gonad (Ws)}} \times \text{number of eggs in sub-part gonad (n)}$$

The relationship between fecundity and total length and body weight using the formulation Hasan *et al.* (2020) is:

$$F = a L^b \quad \text{and} \quad F = a W + b$$

Description F = Fecundity (egg), L = Total length (cm), W = Body weight (g), a = Intercept, b = slope

Results

Length and weight structure

The results of the length structure analysis of the male silver barb ranged from 8.9 to 22.9 cm, and females ranged from 8.9 to 28.5 cm, with the largest proportion caught at 14.5 cm for both males and females. The weight structure for males ranged from 21.2 to 183.2 g, and for females, from 21.2 to 312.8 g, with the largest proportion caught at 21.2 g for both males and females (Figure 2 a and b).

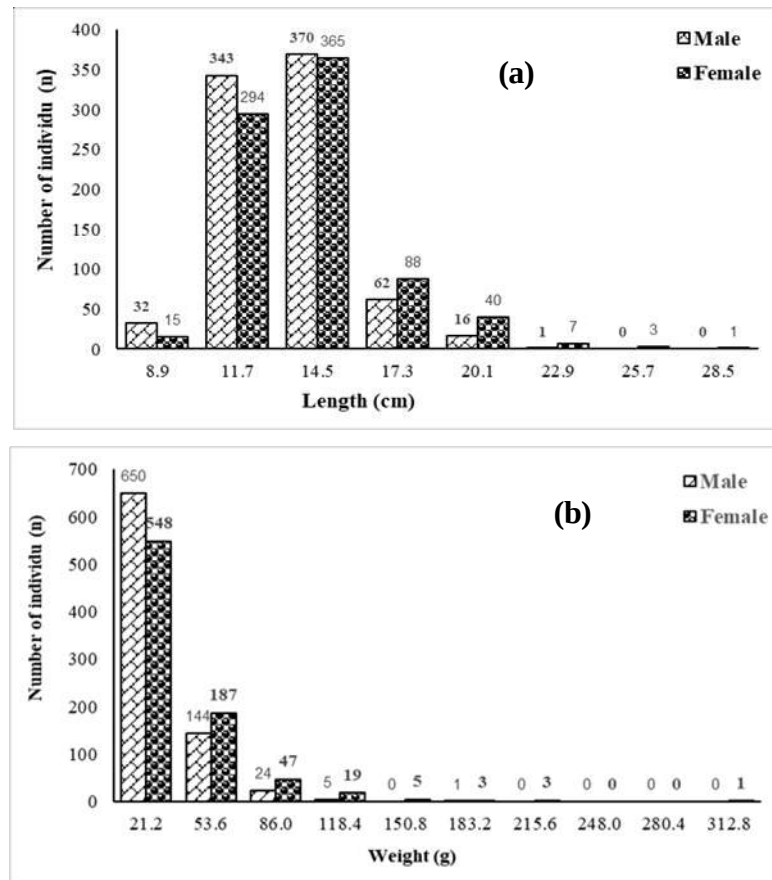


Fig 2. Length (a) and weight (b) structure of silver barb

Sex Ratio

The total number of Silver barb caught was 1,637, consisting of 824 males (50%) and 813 females (50%). Thus, the sex ratio of male to female fish is 1:1 (Figure 3a). Furthermore, the number of fish caught in a mature condition (stage IV) was 110, consisting of 27 males (25%) and 83 females (75%). Based on this data, the sex ratio of mature male to female fish is 1:3, indicating that 1 male pairs with 3 females for spawning activities (Figure 3b).

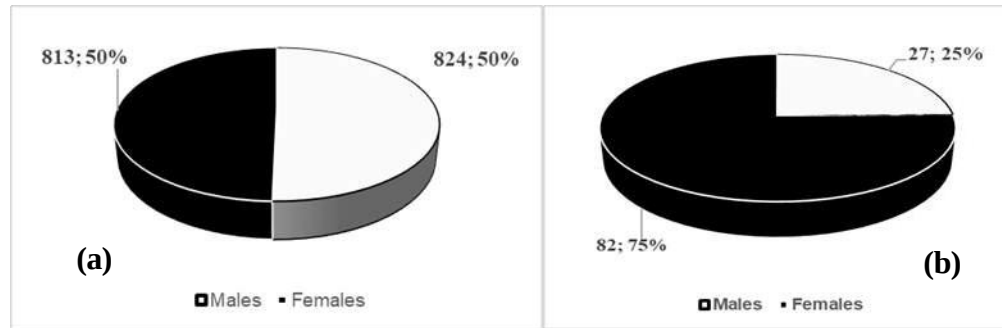


Fig 3. The sex ratio of male to female silver barb (a), and the sex ratio of male to female that have reached gonadal maturity (b)

Length-weight relationship

The results of the length-weight relationship analysis for male are $W = 0.0234 L^{2.7349}$, for female $W = 0.0172 L^{2.8766}$, and for the combined group (males and females) $W = 0.0183 L^{2.8415}$ (Figure 4 a, b, c). The t-test results show that the b values for male, female, and combined silver barb fish are different from 3 ($b \neq 3$), indicating that the growth pattern is allometric. Since the b value is less than 3 ($b < 3$), it indicates negative allometric growth, meaning that length increases faster than weight.

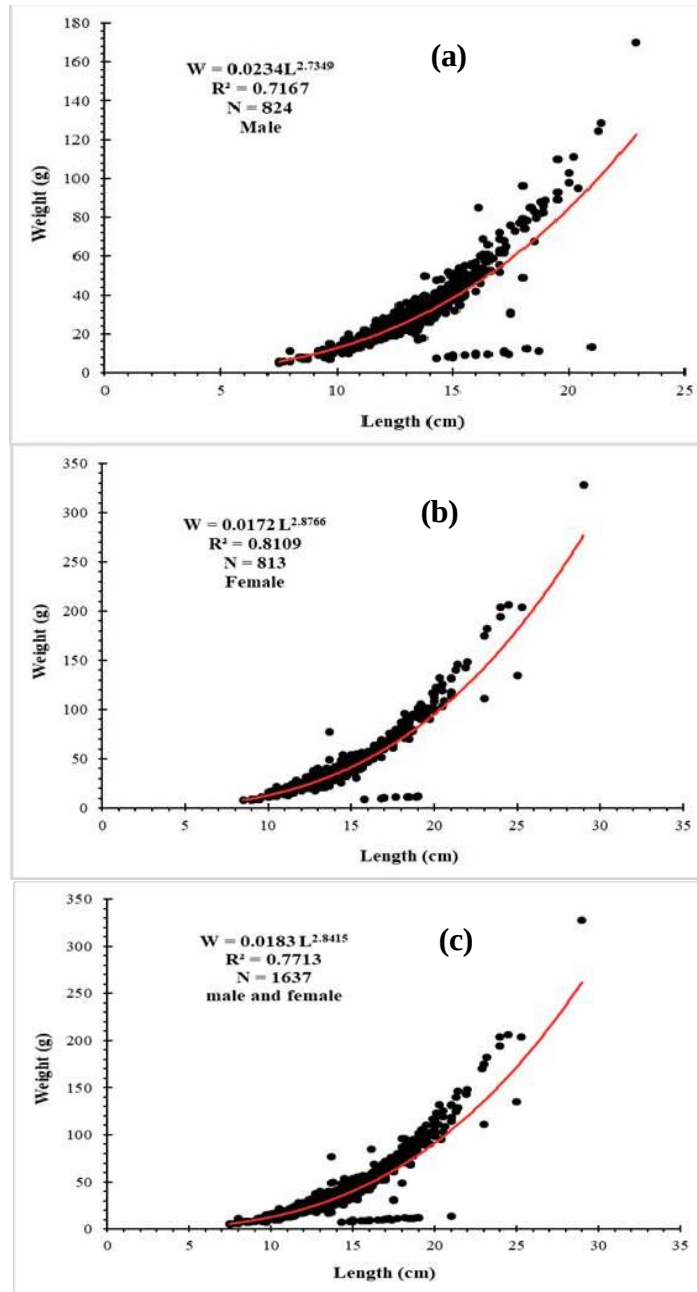


Fig 4. Length-weight relationship of male (a), female (b) and combined (male and female) (c)

Condition Factor (CV)

The condition factor for male and female silver barb is 1.0243 ± 0.0061 and 1.0181 ± 0.0054 , respectively.

Size at First Gonad Maturity (L_{50})

The analysis results for the size at first gonad maturity (L_{50}) show that male fish have an L_{50} of 19.9 cm, while female fish have an L_{50} of 18.3 cm. This data indicates that female mature faster than male fish.

Gonad Maturity Stage

The determination of gonad maturity level criteria was conducted macroscopically by observing the morphology, size, color, and position of the gonads within the abdominal cavity. The development stages of the gonads (ovaries and testes) of the silver barb were classified into five levels according to the guidelines of Hasnidar et al. (2022) and the condition of the silver barb gonads. The morphological characteristics of male and female gonads based on their maturity stages can be seen in Table 1.

Table 1. Gonad maturity stage of female and male silver barb

Maturity Stage	Note	Female	Male
I	immature	Ovary is very small, extending from the anterior to the posterior in the dorsal part of the abdominal cavity, filled with white fluid, eggs are not visible, estimated to occupy less than 15% of the abdominal cavity	Testis is very small and thin, extending from the anterior to the posterior of the abdominal cavity, containing clear white fluid
II	Developing	Ovary is larger than at maturity stage I, white in color, with visible egg grains, estimated to occupy 20-30% of the abdominal cavity. The average egg diameter is 0.20 – 0.425 mm	Testis enlarges, larger than at maturity stage I, containing white fluid
III	Maturing	Ovary enlarges, containing white egg grains, but the egg grains are still difficult to separate. It is estimated to occupy 30%-60% of the abdominal cavity. The average egg diameter is 0.450 - 0.750 mm	Testis further enlarges from maturity stage II, with grooves visible on the surface. Contains thick white fluid
IV	Mature	Ovary continues to enlarge, occupying about 60-80% of the abdominal cavity. The ovary contains yellowish-green eggs, with an average egg diameter of 0.800 - 1.25 mm	Testis enlarges further from maturity stage III, with grooves visible on the surface. Contains thick milky white fluid
V	Spent	Ovary shrinks, wrinkles, with thick and lobed walls, yellowish-green in color, containing residual eggs that were not spawned	Testis size decreases, edges become wrinkled

Fecundity

There are 82 mature female fish (stage IV) with a length range of 7.5 to 17.5 cm and a weight range of 7 to 82 g, with gonad weights ranging from 1.25 to 10.11 g. The fecundity of silver barb obtained in this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The fecundity of silver barb obtained from the results of this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The relationship between fecundity and total length is $F = 4.6297 L^{2.958}$ ($R^2 = 0.3526$), fecundity with body weight is a linear relationship that is $F = 344.66W + 1489.3$ ($R^2 = 0.5145$) (Fig. 5 a, b).

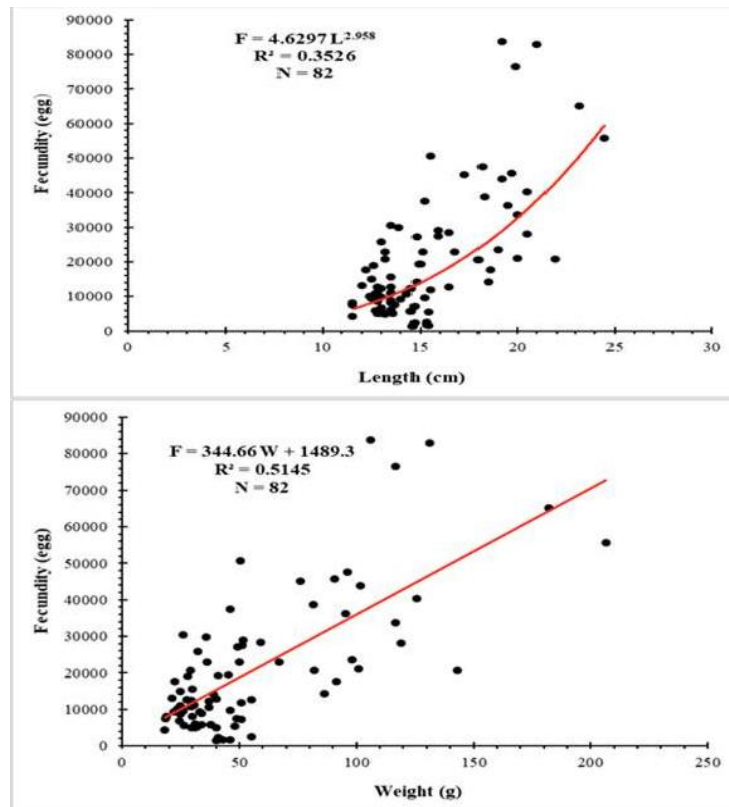


Fig 5. Fecundity-length (a), fecundity-weight (b) relationships of silver barb

Discussion

The length structure of male and female silver barb ranging from 8.9 to 28.5 cm, with the most frequently caught size being 14.5 cm. Similarly, the weight structure ranging from 21.2 to 312.8 g, with the largest proportion of catches at 21.2 g. This data

indicates that the length and weight structure of the silver barb caught is predominantly small in size.

The length and weight structure of the silver barb from these waters shows lower values compared to those caught in Tchang Reservoir, Thailand, which measure 45 cm in length and 2,100 g in weight (Chheng et al., 2004). This data suggests that fishing for silver barb, particularly in Lake Tempe, is very intensive, even excessively exploited (Sukarman, 2022). The silver barb does not have the opportunity to grow large due to intensive fishing. Additionally, suboptimal environmental conditions in the lake, the presence of predators or competitors, and the limited ability of swimming larvae to escape environmental factors are suspected to affect their survival and growth. According to Arevalo et al. (2023), 99% of the mortality in many fish species occurs during the early life stages. The high mortality rate is believed to influence the size variation of the silver barb population.

The overall sex ratio of male and female silver barb fish is 1:1, indicating a balanced number of male and female fish. This sex ratio is consistent with that reported by Maknuu (2016) for the silver barb from the Brantas River, Jombang Regency, West Java, Indonesia, which also has a ratio of 1:1. Similarly, silver barb from the Padma River in Bangladesh have a ratio of 1:1.27 (Jasmine and Begum, 2016); from the rivers in Ogan Komering Ilir Regency, South Sumatra, Indonesia, a ratio of 1:2 (Ardelia et al., 2023); and from the Nagan River, Aceh Province, Indonesia, a ratio of 4:1 (Efizon et al., 2021). The sex ratio can vary among the same species because sex determination is influenced not only by genetic factors but also by environmental factors (Capel, 2017). A 1:1 sex ratio is considered ideal because it ensures that both male and female fish have an equal opportunity to sustain their species. Although silver barb fish experience high exploitation pressure, the sex ratio data indicate that the species still has a strong ability to maintain its population.

Furthermore, the sex ratio of mature gonad males to females is 1:3, meaning that in spawning activities, 1 male and 3 females are needed (polygamy). The sex ratio in spawning is related to the interaction and synchronization between male and female fish (Mylonas et al., 2010), as well as the efficiency of using the number of males or females in spawning. Each fish species has an optimal sex ratio for spawning, for example,

climbing perch, *Anabas testudineus*, it is 1:2 (Hasnidar et al., 2022); sailfin molly, *Poecilia latipinna*, it is 1:10 (Tamsil and Hasnidar, 2019); and silver barb, *Barbonymus* sp., it is 6:1 (Efizon et al., 2021).

The length-weight relationship model for silver barb resulted in $W = 0.0234 L^{2.7349}$ for males, $W = 0.0172 L^{2.8766}$ for females, and $W = 0.0183 L^{2.8415}$ for the combined (males and females). The t-test results showed that the b values for male, female, and combined silver barb were different from 3 ($b \neq 3$), indicating that the growth pattern is allometric. Since the b value is less than 3 ($b < 3$), it is classified as negative allometric growth. Several studies on the length-weight relationship of silver barb fish in various water bodies have reported similar findings. For instance, in the Jatiluhur Reservoir, Indonesia, the relationship was $W = 0.0413 L^{2.231}$ for males and females (Chheng et al., 2004). Similarly, in the Brantas River, Kesamben Subdistrict, Jombang Regency, East Java, Indonesia, the relationship was $W = 0.024 L^{2.770}$ for males and $W = 0.021 L^{2.850}$ for females (Maknuu, 2016). In Gajah Mungkur Reservoir, Central Java Province, Indonesia, the relationship was $W = 0.020 L^{2.880}$ for males and $W = 0.001 L^{3.140}$ for females (Aida, 2018). In the Bengawan Solo River, Lamongan Regency, Indonesia, the relationship was $W = 0.037 L^{2.641}$ for males and $W = 0.029 L^{2.782}$ for females (Buwono et al., 2019). In Cipanas Reservoir, West Java Province, Indonesia, the relationship was $W = 0.006 L^{3.169}$ (Syaiful et al., 2019). The differences in the growth patterns of silver barb are caused by variations in water conditions. An important factor influencing fish growth in tropical regions is the availability of food (Froese, 2006). Therefore, the same species of fish in different locations will exhibit different growth patterns due to this factor. In addition to food, other factors include the stage of gonad development, the physicochemical properties of the water, fish health conditions, seasons, sampling time, and techniques (Sheridan, 2011; Mehanna and Farouk, 2021). In this study, 1,637 fish were caught, of which only 110 fish, or 6.7%, were in the mature gonad (stage IV), which is suspected to be the cause of the negative allometric growth pattern.

The condition factor is a value that reflects the influence of environmental factors on the physiological condition of fish (Faradonbeh et al., 2015). A favorable environment, including the availability of food, supports good growth, resulting in higher fish weight and a $CF \geq 1$. Conversely, an unsuitable environment and limited

food availability lead to smaller weight gain and a $CF < 1$ (Dirican and Cilek, 2012). The CF values in this study ranged from 1.024 to 1.018. These values indicate that the fish are in a lean condition, consistent with their negative allometric growth pattern, where length increases faster than weight. Condition factors for silver barb from several previous studies ranged from 0.84 to 1.4 (Buwono et al., 2019), 1.05 to 3.17 (Sidik et al., 2020), 1.01 to 1.02 (Dwirastina and Marson, 2021), 0.82 to 1.10 (Syaiful et al., 2019), 0.76 to 2.27 (Laila, 2018), and 1.145 to 1.328 (Maknuu, 2016). The variation in CF is caused by differences in the aquatic environment, density, food availability, and physiological conditions such as the fish's reproductive cycle. A higher CF value indicates a better adaptation of the fish to its environment.

The macroscopic analysis of gonad maturity stages showed that at each level of gonad maturity, there were differences in the size, color, and volume of the gonads in the abdominal cavity. In the ovaries, the higher the maturity stage, the larger the oocyte diameter tends to be; however, there is variation in oocyte diameter at the same maturity stage. Similarly, histological observations revealed differences in oocyte diameter (Efizon et al., 2021). This data indicates that silver barb exhibit batch spawning, meaning they do not release all their eggs at once during spawning. Batch spawning results in a prolonged spawning season. The spawning season of silver barb in Lake Tempe is estimated to last throughout the year, as adult fish (stage IV) were found during each monthly observation from January to June, with a peak in January. In contrast, the spawning season for silver barb in the Padma River, Bangladesh, occurs from April to July, with a peak in June (Jasmine and Begum, 2016).

The size at first gonad maturity (L50) is the size at which 50% of individuals in a group have reproduced at least once (Barzotto and Mateus, 2017). The L50 for males is 19.9 cm, and for females, it is 18.3 cm. The L50 values found in this study are larger than those of silver barb from the Nagan River, Aceh Province, Indonesia, where the L50 for males is 7.3 cm, and for females, it is 8.5 cm (Efizon et al., 2021). The size at first gonad maturity can vary due to competition and predation, fishing pressure, and environmental conditions (de Souza et al., 2019). Fish will undergo first maturity in a shorter time frame to reduce the risk of death before reproduction if environmental conditions are unfavorable (Barzotto and Mateus, 2017). Based on the L50 values for

males and females in relation to the dominant length of silver barb caught in this study, approximately 90% of the captured fish were not yet mature.

The silver barb identified at maturity stage IV in this study totaled 82 individuals, with a length range of 12.2 to 21.28 cm (average $\pm$ 15.0 cm) and a body weight range of 21.0 to 124.4 g (average $\pm$ 41 g), producing fecundity ranging from 1,443 to 83,822 eggs (average = 20,239 eggs). Fecundity data for silver barb in various water bodies are presented in Table 2.

Table 2. Fecundity of Silver Barb in Various Water Bodies

Water Body	Fecundity	Reference
Lake Tempe	1,443 – 83,822 eggs (average = 20,239 eggs)	This study
Nagan River, Aceh Province, Indonesia	656 – 5,725 eggs (average 2,663 eggs)	Efizon et al., 2021
Upper Serayu River, Central Java, Indonesia	2,760 - 50,085 eggs (average 17,347 eggs)	Haryono et al., 2015
Padma River, Bangladesh	13,192 – 98,325 eggs (average 58,660 eggs)	Jasmine & Begum, 2016
Bangladesh	18,001 – 42,034 eggs (average 24,959 eggs)	Bhuiyan et al., 2000

The coefficient of determination (R^2) for the relationship between fecundity and length (F-L) is $R^2 = 35.3\%$, and for fecundity and weight (F-W) it is $R^2 = 51.5\%$. This result indicates that 35.3% of the variation in fecundity is due to variation in the total length of the fish, and 51.5% of the variation in fecundity is due to variations in body weight. A similar observation was made for silver barb from the Nagan River, Aceh Province, Indonesia, where the coefficients of determination (R^2) for F-L and F-W were 51% and 24.2%, respectively (Efizon et al., 2021). This means that the fecundity of silver barb increases with the increase in total length and body weight. Larger fish not only have a bigger visceral cavity to hold a greater number of oocytes, but also have sufficient energy for reproductive activities (Jonsson and Jonsson, 1999). Factors influencing fish fecundity include internal factors such as genetics, age, and size (Hunter et al., 1992), while external factors include food availability and environmental conditions (Bryan et al., 2007).

Conclusions

The length and weight structure of female fish are higher than that of male fish. The dominant length and weight of the catch are 14.5 cm and 21.2 g. The growth pattern is negatively allometric, and the condition factor is 1.02. The overall male-to-female ratio is 1:1, while the sex ratio during spawning is 1:3; meaning one male fish pairs with three female fish during spawning. The size at first gonad maturity is faster for females, at 18.3 cm, compared to males at 19.9 cm. Fecundity ranges from 253 to 13,398 eggs (average 2,571 eggs). The variation in fecundity is more influenced by body weight variation than by the total length variation of the silver barb.

Acknowledgments

We would like to extend our gratitude to the Rector of Universitas Muslim Indonesia (UMI) Makassar and the Research and Development Agency for providing the financial support that made this research possible.

Conflicts of interest

We declare that this research was conducted without any conflict of interest with any party.

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Please find attached your paper. You are requested to check the paper and let us have all your corrections (for minor typographical or grammatical errors) within 48 hours.

Kind regards,

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Reproductive biology of silver barb, *Barbonymus gonionotus* (Bleeker, 1850), in Lake Tempe, Indonesia

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Abstract

Information about the reproductive biology of the silver barb is essential for conservation and domestication purposes. This study aims to analyze the reproductive biology of the silver barb in Lake Tempe, South Sulawesi, Indonesia. The aspects of reproductive biology analyzed include length-weight structure, sex ratio, length-weight relationship, condition factor, first gonadal maturity size (L50), gonadal maturity, and fecundity. This study used primary data, with silver barb fish being caught using gill nets every weeks from January to July 2023. The total length of the fish was measured using an ichthyometer with an accuracy of 0.1 cm, and the weight was measured using a digital scale with an accuracy of 0.01 g. The Ggonads were preserved in a 4% formalin solution, and fecundity was measured using the gravimetric method. The length structure of male ranged from 8.9 to 22.9 cm, and females ranged from 8.9 to 28.5 cm. Males had weights between 21.2 and 183.2 g, and females 21.2 and 312.8 g. The overall sex ratio of males to females was 1:1, while the sex ratio during spawning was 1:3 (polygamy). The length-weight relationship for males and females was $W = 0.0234L^{2.7349}$ and $W = 0.0172L^{2.8766}$, respectively. The condition factor for both males and females was 1.02. The first gonadal maturity size for females was 18.3 cm, and 19.9 cm for males. Spawning was partial, with fecundity ranging from 253 to 13,398 eggs.

Keywords: Reproductive biology, Silver barb, Lake Tempe, Length-weight relationship

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Introduction

Silver barb, *Barbonymus gonionotus* (Bleeker, 1850), is an economically important freshwater fish in several countries such as Indonesia, Malaysia, Thailand, Myanmar, Bangladesh, India, and China. This fish has a delicious taste and is relatively inexpensive, making it a primary food source for communities, especially in certain regions of Indonesia. Its production largely relies on wild capture, leading to increasing fishing pressure.

Lake Tempe has a diverse range of fish species, consisting of native fish, introduced fish, and migratory marine fish. According to Dina *et al.* (2019), the native fish of Lake Tempe include *Monopterus albus*, *Anabas testudineus*, *Glossogobius aureus*, and *Channa striata*. The introduced fish species are *Barbonymus gonionotus*, *Clarias batrachus*, *Trichopodus pectoralis*, *Pangasianodon hypophthalmus*, *Osteochilus vittatus*, *Oreochromis niloticus*, *Helostoma temminckii*, and *Cyprinus carpio* (Yanuarita *et al.*, 2020). The migratory marine fish species include *Megalops cyprinoides*, *Stenogobius gymnopomus*, *Anguilla marmorata*, and *Caranx sexfasciatus*. The introduction of these species was carried out to enhance fishery production to meet increasing demand, optimize water productivity, sustainably boost production, and increase biodiversity (Yanuarita *et al.*, 2020; FAO, 2022).

Lake Tempe is currently facing environmental issues, including eutrophication (Aisyah and Nomosatryo, 2016). Eutrophication is suspected to be caused by nutrient loads originating from human activities, plantations, and livestock farming, which are prevalent around the lake's edge. Nitrate and phosphate nutrients in the water range from 0.1063-0.2620 mg/l and 0.0245-0.0655 mg/l, respectively (Samuel *et al.*, 2012). This condition triggers the growth of aquatic weeds such as *Ipomoea aquatica* and *Eichhornia crassipes*. *E. crassipes* is the most dominant plant, with its population estimated to cover about 30-40% of the lake's surface. According to Yani *et al.* (2019), Lake Tempe has experienced moderate to severe pollution in several parameters, including turbidity, total suspended solids, biological oxygen demand, nitrate, and phosphate levels.

Another issue is overfishing and the use of non-environmentally friendly fishing gear (Nasution, 2012). A more serious problem is the presence of invasive fish species, specifically *Pterygoplichthys* spp. (Hasnidar *et al.*, 2021). The high population of *Pterygoplichthys* spp. has led to a decrease in the catch of target fish by fishermen (Hasrianti *et al.*, 2020). The presence of *Pterygoplichthys* spp. impacts the lake ecosystem through habitat competition, feeding patterns, and even predation on native and endemic fish, as well as being vectors for various diseases. This can alter species composition and fish community structure, leading to the dominance and possible elimination of native and endemic fish (Syafei and Sudinno, 2018).

Silver barb, *B. gonionotus*, was introduced to Lake Tempe in 1937 (Dina *et al.*, 2019; Yanuarita *et al.*, 2020). Although an introduced species, silver barb have adapted well to the lake environment. The rich aquatic vegetation of Lake Tempe allows them to thrive. Silver barb are herbivores, with phytoplankton (Chlorophyceae) being their primary food source (Ain *et al.*, 2021); their diet also includes aquatic plants (80%), detritus (12%), and phytoplankton (8.5%) (Aida, 2018; Pratiwi *et al.*, 2021). Silver barb fish are considered beneficial in controlling excessive vegetation in lake waters. Despite their successful adaptation to Lake Tempe, the declining environmental conditions of the lake inevitably impact the production of this fish.

The production of silver barb has fluctuated in recent years, likely due to overfishing, environmental conditions, and high natural mortality (Sukarman, 2022). The high natural mortality is suspected to be caused by the presence of *Pterygoplichthys* spp. as an invasive species (Hasnidar *et al.*, 2021). Two fish species that are still being caught in large numbers are the silver barb and bloso (*Glossogobius* sp.). As a result, these two species are under very high fishing pressure. Conservation and domestication efforts will continue, but these efforts require up-to-date information, including the reproductive biology of silver barb, for future management. The research aims to analyze the reproductive biology of silver barb, covering size distribution, sex ratio, length-weight relationship, condition factor, gonad maturity, first gonad maturity size, and fecundity.

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Materials and methods

The study was conducted from January to July 2023 in Lake Tempe, Wajo Regency, South Sulawesi Province, Indonesia (Fig. 1). Fish sampling was collected every week for six months, using a gill net response tool. Fish samples caught were cleaned, put in a cooler box and given ice cubes. Sample observations were carried out at the Biota and Environmental Engineering Laboratory, Faculty of Fisheries and Marine Science, Universitas Muslim Indonesia (UMI) Makassar.

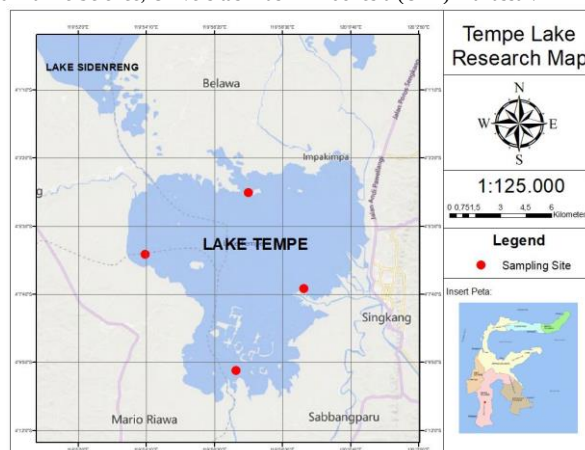


Fig. 1: The sampling points for silver barb were located in Tempe Lake, Wajo Regency, South Sulawesi, Indonesia.

The total length (Lt) of the silver barb was measured using an ichthyometer (Vernier caliper, Mitutoyo) with an accuracy of 0.1 cm. Body and gonad weights (g) were measured using a digital scale (electric digital scale, DIGI DS880) with an accuracy of 0.01 g. The parameters analyzed were:

Length and Weight Structure

The length and weight size structure is determined as follows: determining the number of classes; setting the length class interval at 1 cm and the weight class interval at 1 g; placing each fish sample into the predetermined class. The size structure is determined within the same class intervals and then plotted on a graph.

Sex Ratio

The sex of silver barb is determined morphologically and anatomically by dissecting the fish to observe whether the gonads have developed into testes or ovaries. The determination of the male-to-female sex ratio is carried out by counting the number of male and female fish caught using the formula (Oliveira *et al.*, 2012):

$$SR = \frac{\text{number of male of female}}{\text{total number of fish observed}} \times 100$$

Next, sex ratio variability was tested using the Chi-square test (Oliveira *et al.*, 2012):

$$\chi^2 = \frac{\sum (oi - ei)^2}{ei}$$

Description: χ^2 = Value for a random variable whose sampling distribution approximates the Chi-square distribution

oi = Observed frequencies of male and female fish
ei = Expected frequencies of male and female fish

Length-weight Relationship

The relationship between length and weight was analyzed using the formula (Le Cren, 1951):

$$W = aL^b$$

Description W = Body weight (g), L = Total length (cm), a = Coefficient of determination, b = exponent that indicates isometric or allometric.

To make the equation, the values of W and L were transformed into logarithms (base 10) as follows:

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$$W = \log a + b \log L$$

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The obtained *b* value is used to estimate the length-weight parameters, with the following hypotheses: 1) *b* = 3 indicates isometric growth, 2) *b* ≠ 3 indicates allometric growth, a) *b* > 3: weight increases more rapidly (positive allometric), b) *b* < 3: length increases more rapidly (negative allometric).

Condition Factor (*CF*)

Because the growth pattern of silver barb in this study is negative allometric (*b* ≠ 3), the formulation (Le Cren, 1951) is:

$$CF = \frac{W}{a L^b}$$

Description *CF* = Condition factor, *W* = Fish body weight (g), *L* = Total length of fish (cm), *a* = Intercept, *b* = slope

Size at first gonadal maturity (*L*₅₀)

The size of the first time the fish matures gonads is obtained by finding the value of *L*₅₀ by plotting the cumulative percentage of gonadal mature fish with the size of the fish body length, this will yield a standard logistic curve, and the intersection point between the curve and the 50% cumulative frequency represents the length at which 50% of the fish first mature gonadally.

Gonad Maturity Stage

The stages of gonad maturity are observed macroscopically. The observation procedure involves dissecting the fish sample to open the visceral cavity, then observing the morphology of the gonad, including its shape, color, size, and position within the visceral (abdominal) cavity. The stages of gonad maturity are classified according to Brown-Peterson *et al.* (2011) and modified according to the gonadal condition of tawes fish, as follows: Stage I (Immature); II (Developing); III (Maturing); IV (Mature); and V (Spent). For fish samples with gonads at maturity Stage IV, the egg diameter is measured. The gonad is taken from three parts: posterior, middle, and anterior. From each part of the gonad sample, 30 eggs are collected for egg diameter measurement. The egg diameter is measured using an ocular micrometer (0.01 mm) of the UYCP-12 brand.

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Fecundity

Fecundity is determined by weighing the total gonad (WG), then taking a sub-part from the posterior, middle, and anterior parts of the gonad and weighing it (Ws). The weight of the sub-part gonad is then preserved in a 4% formalin solution to facilitate counting the number of eggs (n). Fecundity is observed at maturity stage IV and is calculated using the gravimetric method (Hasan *et al.*, 2020):

$$F = \frac{\text{Weight of the total gonad (WG)}}{\text{Weight sub-part gonad (Ws)}} \times \text{number of eggs in sub-part gonad (n)}$$

The relationship between fecundity and total length and body weight using the formulation Hasan *et al.* (2020) is:

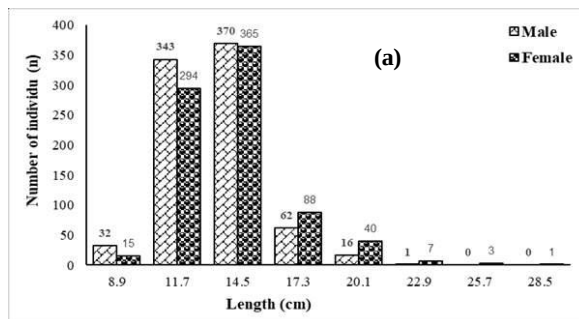
$$F = aL^b \quad \text{and} \quad F = aW + b$$

Description F = Fecundity (egg), L = Total length (cm), W = Body weight (g), a = Intercept, b = slope

Results

Length and weight structure

The results of the length structure analysis of the male silver barb ranged from 8.9 to 22.9 cm, and females ranged from 8.9 to 28.5 cm, with the largest proportion caught at 14.5 cm for both males and females. The weight structure for males ranged from 21.2 to 183.2 g, and for females, from 21.2 to 312.8 g, with the largest proportion caught at 21.2 g for both males and females (Figure 2 a and b).



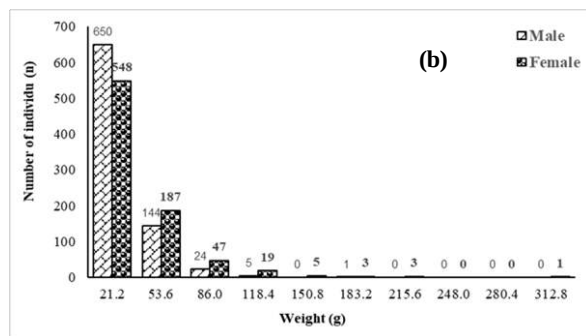


Fig. 2:- Length (a) and weight (b) structure of silver barb

Sex Ratio

The total number of Silver barb caught was 1,637, consisting of 824 males (50%) and 813 females (50%). Thus, the sex ratio of male to female fish is 1:1 (Figure 3a). Furthermore, the number of fish caught in a mature condition (stage IV) was 110, consisting of 27 males (25%) and 83 females (75%). Based on this data, the sex ratio of mature male to female fish is 1:3, indicating that 1 male pairs with 3 females for spawning activities (Figure 3b).

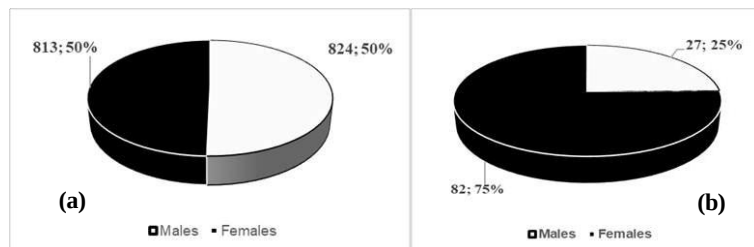


Fig. 3: The sex ratio of male to female silver barb (a); and the sex ratio of male to female that have reached gonadal maturity (b)

Length-weight relationship

The results of the length-weight relationship analysis for male are $W = 0.0234 L^{2.7349}$, for female $W = 0.0172 L^{2.8766}$, and for the combined group (males and females) $W = 0.0183 L^{2.8415}$ (Figure 4 a, b, c). The t-test results show that the b values for male, female, and combined silver barb fish are different from 3 ($b \neq 3$), indicating that the growth pattern is allometric. Since the b value is less than 3 ($b < 3$), it indicates negative allometric growth, meaning that length increases faster than weight.

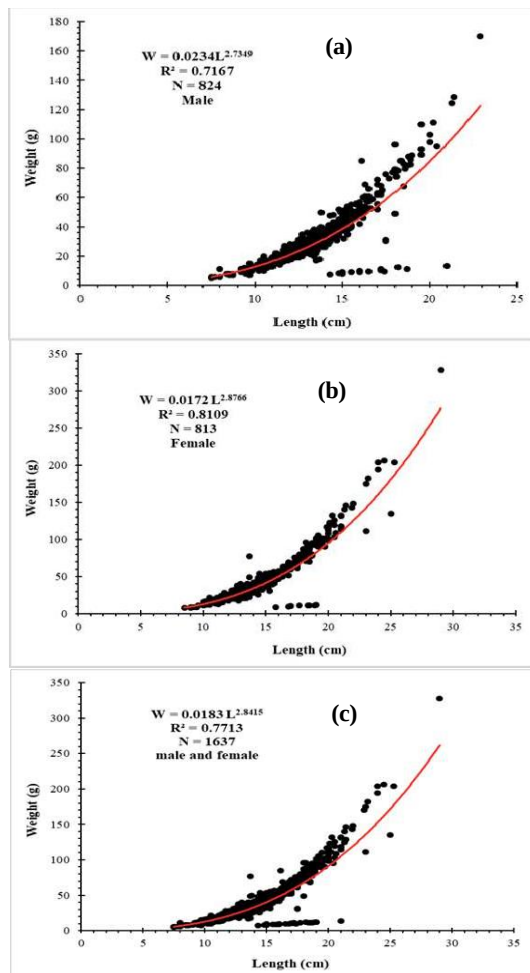


Fig. 4: Length-weight relationship of male (a), female (b) and combined (male and female) (c)

Condition Factor (CV)

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The condition factor for male and female silver barb is 1.0243 ± 0.0061 and 1.0181 ± 0.0054 , respectively.

Size at First Gonad Maturity (L_{50})

The analysis results for the size at first gonad maturity (L_{50}) show that male fish have an L_{50} of 19.9 cm, while female fish have an L_{50} of 18.3 cm. This data indicates that female mature faster than male fish.

Gonad Maturity Stage

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The determination of gonad maturity level criteria was conducted macroscopically by observing the morphology, size, color, and position of the gonads within the abdominal cavity. The development stages of the gonads (ovaries and testes) of the silver barb were classified into five levels according to the guidelines of Hasnidar *et al.* (2022) and the condition of the silver barb gonads. The morphological characteristics of male and female gonads based on their maturity stages can be seen in Table 1.

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Table 1:- Gonad maturity stage of female and male silver barb

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Maturity Stage	Note	Female	Male
I	immature	Ovary is very small, extending from the anterior to the posterior in the dorsal part of the abdominal cavity, filled with white fluid, eggs are not visible, estimated to occupy less than 15% of the abdominal cavity	Testis is very small and thin, extending from the anterior to the posterior of the abdominal cavity, containing clear white fluid
II	Developing	Ovary is larger than at maturity stage I, white in color, with visible egg grains, estimated to occupy 20-30% of the abdominal cavity. The average egg diameter is 0.20 – 0.425 mm	Testis enlarges, larger than at maturity stage I, containing white fluid
III	Maturing	Ovary enlarges, containing white egg grains, but the egg grains are still difficult to separate. It is estimated to occupy 30%-60% of the abdominal cavity. The average egg diameter is 0.450 - 0.750 mm	Testis further enlarges from maturity stage II, with grooves visible on the surface. Contains thick white fluid
IV	Mature	Ovary continues to enlarge, occupying about 60-80% of the abdominal cavity. The ovary contains yellowish-green eggs, with an average egg diameter of 0.800 - 1.25 mm	Testis enlarges further from maturity stage III, with grooves visible on the surface. Contains thick milky white fluid
V	Spent	Ovary shrinks, wrinkles, with thick and lobed walls, yellowish-green in color, containing residual eggs that were not spawned	Testis size decreases, edges become wrinkled

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Fecundity

There are 82 mature female fish (stage IV) with a length range of 7.5 to 17.5 cm and a weight range of 7 to 82 g, with gonad weights ranging from 1.25 to 10.11 g. The fecundity of silver barb obtained in this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The fecundity of silver barb obtained from the results of this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The relationship between fecundity and total length is $F = 4.6297 L^{2.958}$ ($R^2 = 0.3526$), fecundity with body weight is a linear relationship that is $F = 444.66W + 1489.3$ ($R^2 = 0.5145$) (Fig. 5 a, b).

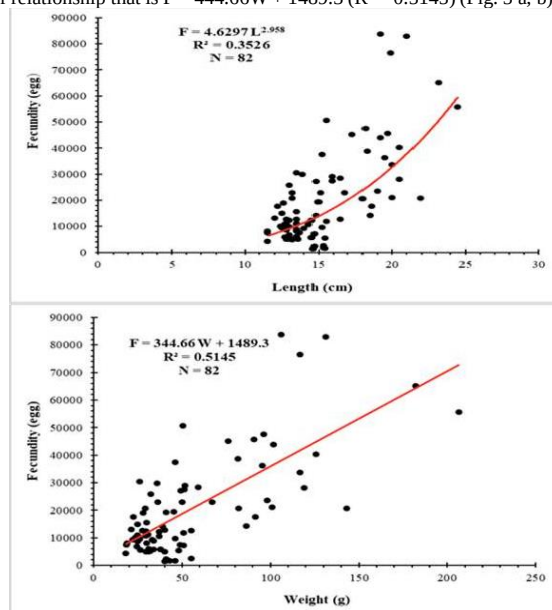


Fig. 5: Fecundity-length (a) and fecundity-weight (b) relationships of silver barb

Discussion

The length structure of male and female silver barb ranging from 8.9 to 28.5 cm, with the most frequently caught size being 14.5 cm. Similarly, the weight structure ranging from 21.2 to 312.8 g, with the largest proportion of catches at 21.2 g. This data indicates that the length and weight structure of the silver barb caught is predominantly small in size.

The length and weight structure of the silver barb from these waters shows lower values compared to those caught in Tchang Reservoir, Thailand, which measure 45 cm in length and 2,100 g in weight (Chheng *et al.*, 2004). This data suggests that fishing for silver barb, particularly in Lake Tempe, is very intensive, even excessively exploited (Sukarman, 2022). The silver barb does not have the opportunity to grow large due to intensive fishing. Additionally, suboptimal environmental conditions in the lake, the presence of predators or competitors, and the limited ability of swimming larvae to escape environmental factors are suspected to affect their survival and growth. According to Arevalo *et al.* (2023), 99% of the mortality in many fish species occurs during the early life stages. The high mortality rate is believed to influence the size variation of the silver barb population.

The overall sex ratio of male and female silver barb fish is 1:1, indicating a balanced number of male and female fish. This sex ratio is consistent with that reported by Maknuu (2016) for the silver barb from the Brantas River, Jombang Regency, West Java, Indonesia, which also has a ratio of 1:1. Similarly, silver barb from the Padma River in Bangladesh have a ratio of 1:1.27 (Jasmine and Begum, 2016); from the rivers in Ogan Komering Ilir Regency, South Sumatra, Indonesia, a ratio of 1:2 (Ardelia *et al.*, 2023); and from the Nagan River, Aceh Province, Indonesia, a ratio of 4:1 (Efizon *et al.*, 2021). The sex ratio can vary among the same species because sex determination is influenced not only by genetic factors but also by environmental factors (Capel, 2017). A 1:1 sex ratio is considered ideal because it

ensures that both male and female fish have an equal opportunity to sustain their species. Although silver barb fish experience high exploitation pressure, the sex ratio data indicate that the species still has a strong ability to maintain its population.

Furthermore, the sex ratio of mature gonad males to females is 1:3, meaning that in spawning activities, 1 male and 3 females are needed (polygamy). The sex ratio in spawning is related to the interaction and synchronization between male and female fish (Mylonas *et al.*, 2010), as well as the efficiency of using the number of males or females in spawning. Each fish species has an optimal sex ratio for spawning, for example, climbing perch, *Anabas testudineus*, it is 1:2 (Hasnidar *et al.*, 2022); sailfin molly, *Poecilia latipinna*, it is 1:10 (Tamsil and Hasnidar, 2019); and silver barb, *Barbonymus* sp., it is 6:1 (Efizon *et al.*, 2021).

The length-weight relationship model for silver barb resulted in $W = 0.0234 L^{2.7349}$ for males, $W = 0.0172 L^{2.8766}$ for females, and $W = 0.0183 L^{2.8415}$ for the combined (males and females). The t-test results showed that the b values for male, female, and combined silver barb were different from 3 ($b \neq 3$), indicating that the growth pattern is allometric. Since the b value is less than 3 ($b < 3$), it is classified as negative allometric growth. Several studies on the length-weight relationship of silver barb fish in various water bodies have reported similar findings. For instance, in the Jatiluhur Reservoir, Indonesia, the relationship was $W = 0.0413 L^{2.231}$ for males and females (Chheng *et al.*, 2004). Similarly, in the Brantas River, Kesamben Subdistrict, Jombang Regency, East Java, Indonesia, the relationship was $W = 0.024 L^{2.770}$ for males and $W = 0.021 L^{2.850}$ for females (Maknuu, 2016). In Gajah Mungkur Reservoir, Central Java Province, Indonesia, the relationship was $W = 0.020 L^{2.880}$ for males and $W = 0.001 L^{3.140}$ for females (Aida, 2018). In the Bengawan Solo River, Lamongan Regency, Indonesia, the relationship was $W = 0.037 L^{2.641}$ for males and $W = 0.029 L^{2.782}$ for females (Buwono *et al.*, 2019). In Cipanas Reservoir, West Java Province, Indonesia, the relationship was $W = 0.006 L^{3.169}$ (Syaiful *et al.*, 2019). The differences in the growth patterns of silver barb are caused by variations in water conditions. An important factor influencing fish growth in tropical regions is the availability of food (Froese, 2006). Therefore, the same species of fish in different locations will exhibit different growth patterns due to this factor. In addition to food, other factors include the stage of gonad development, the physicochemical properties of the water, fish health conditions, seasons, sampling time, and techniques (Sheridan, 2011; Mehanna and Farouk, 2021). In this study, 1,637 fish were caught, of which only 110 fish, or 6.7%, were in the mature gonad (stage IV), which is suspected to be the cause of the negative allometric growth pattern.

The condition factor is a value that reflects the influence of environmental factors on the physiological condition of fish (Faradonbeh *et al.*, 2015). A favorable environment, including the availability of food, supports good growth, resulting in higher fish weight and a $CF \geq 1$. Conversely, an unsuitable environment and limited food availability lead to smaller weight gain and a $CF < 1$ (Dirican and Cilek, 2012). The CF values in this study ranged from 1.024 to 1.018. These values indicate that the fish are in a lean condition, consistent with their negative allometric growth pattern, where length increases faster than weight. Condition factors for silver barb from several previous studies ranged from 0.84 to 1.4 (Buwono *et al.*, 2019), 1.05 to 3.17 (Sidik *et al.*, 2020), 1.01 to 1.02 (Dwirastina and Marson, 2021), 0.82 to 1.10 (Syaiful *et al.*, 2019), 0.76 to 2.27 (Laila, 2018), and 1.145 to 1.328 (Maknuu, 2016). The variation in CF is caused by differences in the aquatic environment, density, food availability, and physiological conditions such as the fish's reproductive cycle. A higher CF value indicates a better adaptation of the fish to its environment.

The macroscopic analysis of gonad maturity stages showed that at each level of gonad maturity, there were differences in the size, color, and volume of the gonads in the abdominal cavity. In the ovaries, the higher the maturity stage, the larger the oocyte diameter tends to be; however, there is variation in oocyte diameter at the same maturity stage. Similarly, histological observations revealed differences in oocyte diameter (Efizon *et al.*, 2021). This data indicates that silver barb exhibit batch spawning, meaning they do not release all their eggs at once during spawning. Batch spawning results in a prolonged spawning season. The spawning season of silver barb in Lake Tempe is estimated to last throughout the year, as adult fish (stage IV) were found during each monthly observation from January to June, with a peak in January. In contrast, the spawning season for silver barb in the Padma River, Bangladesh, occurs from April to July, with a peak in June (Jasmine and Begum, 2016).

The size at first gonad maturity (L50) is the size at which 50% of individuals in a group have reproduced at least once (Barzotto and Mateus, 2017). The L50 for males is 19.9 cm, and for females, it is 18.3 cm. The L50 values found in this study are larger than those of silver barb from the Nagan River, Aceh Province, Indonesia, where the L50 for males is 7.3 cm, and for females, it is 8.5 cm (Efizon *et al.*, 2021). The size at first gonad maturity can vary due to competition and predation, fishing pressure, and environmental conditions (de Souza *et al.*, 2019). Fish will undergo first maturity in a shorter time frame to reduce the risk of death before reproduction if environmental conditions are unfavorable (Barzotto and Mateus, 2017). Based on the L50 values for males and females in relation to the dominant

length of silver barb caught in this study, approximately 90% of the captured fish were not yet mature.

The silver barb identified at maturity stage IV in this study totaled 82 individuals, with a length range of 12.2 to 21.28 cm (average $\pm$ 15.0 cm) and a body weight range of 21.0 to 124.4 g (average $\pm$ 41 g), producing fecundity ranging from 1,443 to 83,822 eggs (average = 20,239 eggs). Fecundity data for silver barb in various water bodies are presented in Table 2.

Table 2. Fecundity of Silver Barb in Various Water Bodies

Water Body	Fecundity	Reference
Lake Tempe	1,443 – 83,822 eggs (average = 20,239 eggs)	This study
Nagan River, Aceh Province, Indonesia	656 – 5,725 eggs (average 2,663 eggs)	Efizon <i>et al.</i> , 2021
Upper Serayu River, Central Java, Indonesia	2,760 – 50,085 eggs (average 17,347 eggs)	Haryono <i>et al.</i> , 2015
Padma River, Bangladesh	13,192 – 98,325 eggs (average 58,660 eggs)	Jasmine & Begum, 2016
Bangladesh	18,001 – 42,034 eggs (average 24,959 eggs)	Bhuiyan <i>et al.</i> , 2000

The coefficient of determination (R^2) for the relationship between fecundity and length (F-L) is $R^2 = 35.3\%$, and for fecundity and weight (F-W) it is $R^2 = 51.5\%$. This result indicates that 35.3% of the variation in fecundity is due to variation in the total length of the fish, and 51.5% of the variation in fecundity is due to variations in body weight. A similar observation was made for silver barb from the Nagan River, Aceh Province, Indonesia, where the coefficients of determination (R^2) for F-L and F-W were 51% and 24.2%, respectively (Efizon *et al.*, 2021). This means that the fecundity of silver barb increases with the increase in total length and body weight. Larger fish not only have a bigger visceral cavity to hold a greater number of oocytes, but also have sufficient energy for reproductive activities (Jonsson and Jonsson, 1999). Factors influencing fish fecundity include internal factors such as genetics, age, and size (Hunter *et al.*, 1992), while external factors include food availability and environmental conditions (Bryan *et al.*, 2007).

Conclusions

The length and weight structure of female fish are higher than that of male fish. The dominant length and weight of the catch are 14.5 cm and 21.2 g. The growth pattern is negatively allometric, and the condition factor is 1.02. The overall male-to-female ratio is 1:1, while the sex ratio during spawning is 1:3; meaning one male fish pairs with three female fish during spawning. The size at first gonad maturity is faster for females, at 18.3 cm, compared to males at 19.9 cm. Fecundity ranges from 253 to 13,398 eggs (average 2,571 eggs). The variation in fecundity is more influenced by body weight variation than by the total length variation of the silver barb.

Acknowledgments

We would like to extend our gratitude to the Rector of Universitas Muslim Indonesia (UMI) Makassar and the Research and Development Agency for providing the financial support that made this research possible.

Conflicts of interest

We declare that this research was conducted without any conflict of interest with any party.

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Reproductive biology of silver barb, *Barbonymus gonionotus* (Bleeker, 1850), in Lake Tempe, Indonesia

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Abstract

Information about the reproductive biology of the silver barb is essential for conservation and domestication purposes. This study aims to analyze the reproductive biology of the silver barb in Lake Tempe, South Sulawesi, Indonesia. The aspects of reproductive biology analyzed include length-weight structure, sex ratio, length-weight relationship, condition factor, first gonadal maturity size (L50), gonadal maturity, and fecundity. This study used primary data, with silver barb fish being caught using gill nets every weeks from January to July 2023. The total length of the fish was measured using an ichthyometer with an accuracy of 0.1 cm, and the weight was measured using a digital scale with an accuracy of 0.01 g. The Ggonads were preserved in a 4% formalin solution, and fecundity was measured using the gravimetric method. The length structure of male ranged from 8.9 to 22.9 cm, and females ranged from 8.9 to 28.5 cm. Males had weights between 21.2 and 183.2 g, and females 21.2 and 312.8 g. The overall sex ratio of males to females was 1:1, while the sex ratio during spawning was 1:3 (polygamy). The length-weight relationship for males and females was $W = 0.0234L^{2.7349}$ and $W = 0.0172L^{2.8766}$, respectively. The condition factor for both males and females was 1.02. The first gonadal maturity size for females was 18.3 cm, and 19.9 cm for males. Spawning was partial, with fecundity ranging from 253 to 13,398 eggs.

Keywords: Reproductive biology, Silver barb, Lake Tempe, Length-weight relationship

Introduction

Silver barb, *Barbonymus gonionotus* (Bleeker, 1850), is an economically important freshwater fish in several countries such as Indonesia, Malaysia, Thailand, Myanmar, Bangladesh, India, and China. This fish has a delicious taste and is relatively inexpensive, making it a primary food source for communities, especially in certain regions of Indonesia. Its production largely relies on wild capture, leading to increasing fishing pressure.

Lake Tempe has a diverse range of fish species, consisting of native fish, introduced fish, and migratory marine fish. According to Dina *et al.* (2019), the native fish of Lake Tempe include *Monopterus albus*, *Anabas testudineus*, *Glossogobius aureus*, and *Channa striata*. The introduced fish species are *Barbonymus gonionotus*, *Clarias batrachus*, *Trichopodus pectoralis*, *Pangasianodon hypophthalmus*, *Osteochilus vittatus*, *Oreochromis niloticus*, *Helostoma temminckii*, and *Cyprinus carpio* (Yanuarita *et al.*, 2020). The migratory marine fish species include *Megalops cyprinoides*, *Stenogobius gymnopomus*, *Anguilla marmorata*, and *Caranx sexfasciatus*. The introduction of these species was carried out to enhance fishery production to meet increasing demand, optimize water productivity, sustainably boost production, and increase biodiversity (Yanuarita *et al.*, 2020; FAO, 2022).

Lake Tempe is currently facing environmental issues, including eutrophication (Aisyah and Nomosatryo, 2016). Eutrophication is suspected to be caused by nutrient loads originating from human activities, plantations, and livestock farming, which are prevalent around the lake's edge. Nitrate and phosphate nutrients in the water range from 0.1063-0.2620 mg/l and 0.0245-0.0655 mg/l, respectively (Samuel *et al.*, 2012). This condition triggers the growth of aquatic weeds such as *Ipomoea aquatica* and *Eichhornia crassipes*. *E. crassipes* is the most dominant plant, with its population estimated to cover about 30-40% of the lake's surface. According to Yani *et al.* (2019), Lake Tempe has experienced moderate to severe pollution in several parameters, including turbidity, total suspended solids, biological oxygen demand, nitrate, and phosphate levels.

Another issue is overfishing and the use of non-environmentally friendly fishing gear (Nasution, 2012). A more serious problem is the presence of invasive fish species, specifically *Pterygoplichthys* spp. (Hasnidar *et al.*, 2021). The high population of *Pterygoplichthys* spp. has led to a decrease in the catch of target fish by fishermen (Hasrianti *et al.*, 2020). The presence of *Pterygoplichthys* spp. impacts the lake ecosystem through habitat competition, feeding patterns, and even predation on native and endemic fish, as well as being vectors for various diseases. This can alter species composition and fish community structure, leading to the dominance and possible elimination of native and endemic fish (Syafei and Sudinno, 2018).

Silver barb, *B. gonionotus*, was introduced to Lake Tempe in 1937 (Dina *et al.*, 2019; Yanuarita *et al.*, 2020). Although an introduced species, silver barb have adapted well to the lake environment. The rich aquatic vegetation of Lake Tempe allows them to thrive. Silver barb are herbivores, with phytoplankton (Chlorophyceae) being their primary food source (Ain *et al.*, 2021); their diet also includes aquatic plants (80%), detritus (12%), and phytoplankton (8.5%) (Aida, 2018; Pratiwi *et al.*, 2021). Silver barb fish are considered beneficial in controlling excessive vegetation in lake waters. Despite their successful adaptation to Lake Tempe, the declining environmental conditions of the lake inevitably impact the production of this fish.

The production of silver barb has fluctuated in recent years, likely due to overfishing, environmental conditions, and high natural mortality (Sukarman, 2022). The high natural mortality is suspected to be caused by the presence of *Pterygoplichthys* spp. as an invasive species (Hasnidar *et al.*, 2021). Two fish species that are still being caught in large numbers are the silver barb and bloso (*Glossogobius* sp.). As a result, these two species are under very high fishing pressure. Conservation and domestication efforts will continue, but these efforts require up-to-date information, including the reproductive biology of silver barb, for future management. The research aims to analyze the reproductive biology of silver barb, covering size distribution, sex ratio, length-weight relationship, condition factor, gonad maturity, first gonad maturity size, and fecundity.

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Materials and methods

The study was conducted from January to July 2023 in Lake Tempe, Wajo Regency, South Sulawesi Province, Indonesia (Fig. 1). Fish sampling was collected every week for six months, using a gill net response tool. Fish samples caught were cleaned, put in a cooler box and given ice cubes. Sample observations were carried out at the Biota and Environmental Engineering Laboratory, Faculty of Fisheries and Marine Science, Universitas Muslim Indonesia (UMI) Makassar.

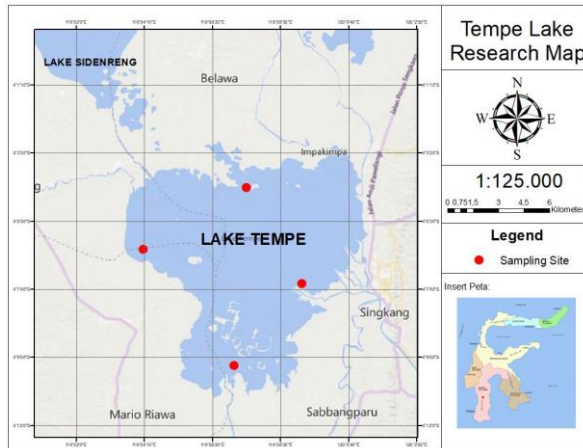


Fig. 1: The sampling points for silver barb were located in Tempe Lake, Wajo Regency, South Sulawesi, Indonesia.

The total length (Lt) of the silver barb was measured using an ichthyometer (Vernier caliper, Mitutoyo) with an accuracy of 0.1 cm. Body and gonad weights (g) were measured using a digital scale (electric digital scale, DIGI DS880) with an accuracy of 0.01 g. The parameters analyzed were:

Length and Weight Structure

The length and weight size structure is determined as follows: determining the number of classes; setting the length class interval at 1 cm and the weight class interval at 1 g; placing each fish sample into the predetermined class. The size structure is determined within the same class intervals and then plotted on a graph.

Sex Ratio

The sex of silver barb is determined morphologically and anatomically by dissecting the fish to observe whether the gonads have developed into testes or ovaries. The determination of the male-to-female sex ratio is carried out by counting the number of male and female fish caught using the formula (Oliveira *et al.*, 2012):

$$SR = \frac{\text{number of male of female}}{\text{total number of fish observed}} \times 100$$

Next, sex ratio variability was tested using the Chi-square test (Oliveira *et al.*, 2012):

$$\chi^2 = \frac{\sum (oi - ei)^2}{ei}$$

Description: χ^2 = Value for a random variable whose sampling distribution approximates the Chi-square distribution

oi = Observed frequencies of male and female fish
ei = Expected frequencies of male and female fish

Length-weight Relationship

The relationship between length and weight was analyzed using the formula (Le Cren, 1951):

$$W = aL^b$$

Description W = Body weight (g), L = Total length (cm), a = Coefficient of determination, b = exponent that indicates isometric or allometric.

To make the equation, the values of W and L were transformed into logarithms (base 10) as follows:

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$$W = \log a + b \log L$$

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The obtained b value is used to estimate the length-weight parameters, with the following hypotheses: 1) $b = 3$ indicates isometric growth, 2) $b \neq 3$ indicates allometric growth, a) $b > 3$: weight increases more rapidly (positive allometric), b) $b < 3$: length increases more rapidly (negative allometric).

Condition Factor (CF)

Because the growth pattern of silver barb in this study is negative allometric ($b \neq 3$), the formulation (Le Cren, 1951) is:

$$CF = \frac{W}{a L^b}$$

Description CF = Condition factor, W = Fish body weight (g), L = Total length of fish (cm), a = a = Intercept, b = slope

Size at first gonadal maturity (L50)

The size of the first time the fish matures gonads is obtained by finding the value of L50 by plotting the cumulative percentage of gonadal mature fish with the size of the fish body length, this will yield a standard logistic curve, and the intersection point between the curve and the 50% cumulative frequency represents the length at which 50% of the fish first mature gonadally.

Gonad Maturity Stage

The stages of gonad maturity are observed macroscopically. The observation procedure involves dissecting the fish sample to open the visceral cavity, then observing the morphology of the gonad, including its shape, color, size, and position within the visceral (abdominal) cavity. The stages of gonad maturity are classified according to Brown-Peterson *et al.* (2011) and modified according to the gonadal condition of [silver barb, tawes-fish](#), as follows: Stage I (Immature); II (Developing); III (Maturing); IV (Mature); and V (Spent). For fish samples with gonads at maturity Stage IV, the egg diameter is measured. The gonad is taken from three parts: posterior, middle, and anterior. From each part of the gonad sample, 30 eggs are collected for egg diameter measurement. The egg diameter is measured using an ocular micrometer (0.01 mm) of the UYCP-12 brand.

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Fecundity

Fecundity is determined by weighing the total gonad (WG), then taking a sub-part from the posterior, middle, and anterior parts of the gonad and weighing it (Ws). The weight of the sub-part gonad is then preserved in a 4% formalin solution to facilitate counting the number of eggs (n). Fecundity is observed at maturity stage IV and is calculated using the gravimetric method (Hasan *et al.*, 2020):

$$F = \frac{\text{Weight of the total gonad (WG)}}{\text{Weight sub-part gonad (Ws)}} \times \text{number of eggs in sub-part gonad (n)}$$

The relationship between fecundity and total length and body weight using the formulation Hasan *et al.* (2020) is:

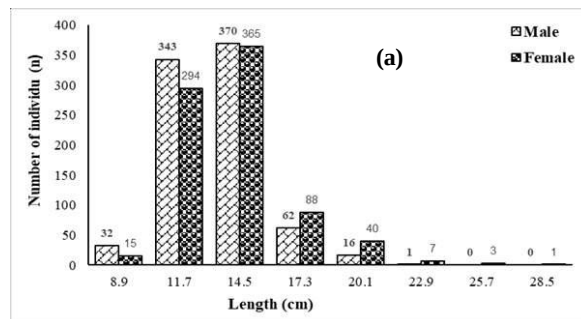
$$F = a L^b \quad \text{and} \quad F = a W + b$$

Description F = Fecundity (egg), L = Total length (cm), W = Body weight (g), a = Intercept, b = slope

Results

Length and weight structure

The results of the length structure analysis of the male silver barb ranged from 8.9 to 22.9 cm, and females ranged from 8.9 to 28.5 cm, with the largest proportion caught at 14.5 cm for both males and females. The weight structure for males ranged from 21.2 to 183.2 g, and for females, from 21.2 to 312.8 g, with the largest proportion caught at 21.2 g for both males and females (Figure 2 a and b).



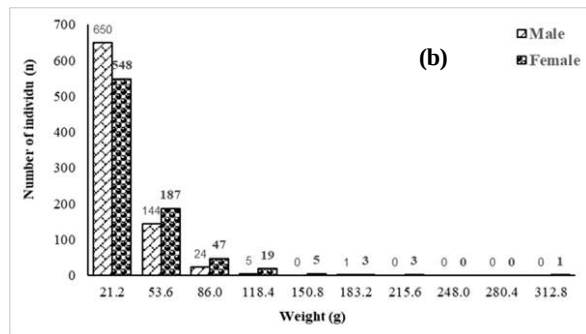


Fig. 2:- Length (a) and weight (b) structure of silver barb

Sex Ratio

The total number of Silver barb caught was 1,637, consisting of 824 males (50%) and 813 females (50%). Thus, the sex ratio of male to female fish is 1:1 (Figure 3a). Furthermore, the number of fish caught in a mature condition (stage IV) was 110, consisting of 27 males (25%) and 83 females (75%). Based on this data, the sex ratio of mature male to female fish is 1:3, indicating that 1 male pairs with 3 females for spawning activities (Figure 3b).

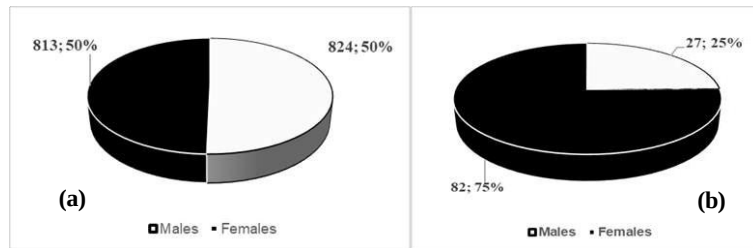


Fig. 3: The sex ratio of male to female silver barb (a); and the sex ratio of male to female that have reached gonadal maturity (b)

Length-weight relationship

The results of the length-weight relationship analysis for male are $W = 0.0234 L^{2.7349}$, for female $W = 0.0172 L^{2.8766}$, and for the combined group (males and females) $W = 0.0183 L^{2.8415}$ (Figure 4 a, b, c). The t-test results show that the b values for male, female, and combined silver barb fish are different from 3 ($b \neq 3$), indicating that the growth pattern is allometric. Since the b value is less than 3 ($b < 3$), it indicates negative allometric growth, meaning that length increases faster than weight.

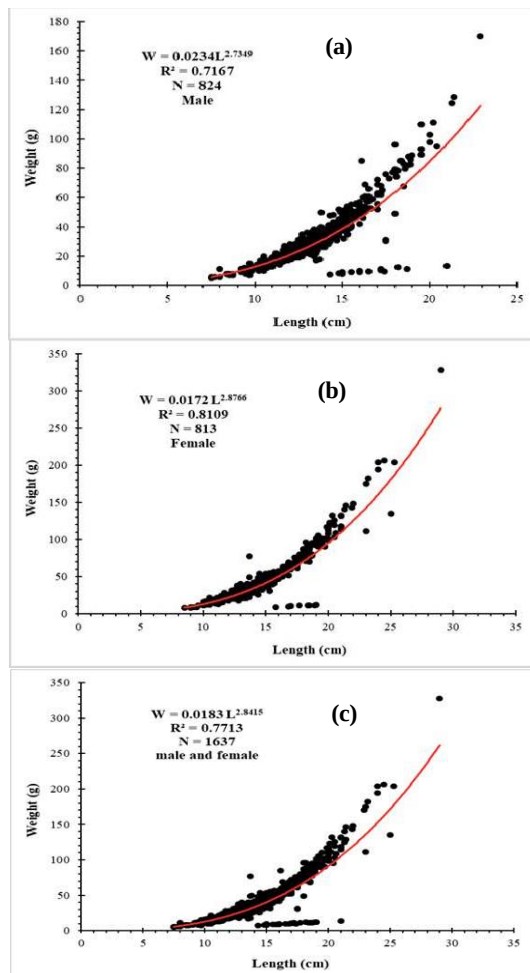


Fig. 4: Length-weight relationship of male (a), female (b) and combined (male and female) (c)

Condition Factor (CF)

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The condition factor for male and female silver barb is 1.0243 ± 0.0061 and 1.0181 ± 0.0054 , respectively.

Size at First Gonad Maturity (L_{50})

The analysis results for the size at first gonad maturity (L_{50}) show that male fish have an L_{50} of 19.9 cm, while female fish have an L_{50} of 18.3 cm. This data indicates that female mature faster than male fish.

Gonad Maturity Stage

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The determination of gonad maturity level criteria was conducted macroscopically by observing the morphology, size, color, and position of the gonads within the abdominal cavity. The development stages of the gonads (ovaries and testes) of the silver barb were classified into five levels according to the guidelines of Hasnidar *et al.* (2022) and the condition of the silver barb gonads. The morphological characteristics of male and female gonads based on their maturity stages can be seen in Table 1.

Table 1: Gonad maturity stage of female and male silver barb

Maturity Stage	Note	Female	Male
I	immature	Ovary is very small, extending from the anterior to the posterior in the dorsal part of the abdominal cavity, filled with white fluid, eggs are not visible, estimated to occupy less than 15% of the abdominal cavity	Testis is very small and thin, extending from the anterior to the posterior of the abdominal cavity, containing clear white fluid
II	Developing	Ovary is larger than at maturity stage I, white in color, with visible egg grains, estimated to occupy 20-30% of the abdominal cavity. The average egg diameter is 0.20 – 0.425 mm	Testis enlarges, larger than at maturity stage I, containing white fluid
III	Maturing	Ovary enlarges, containing white egg grains, but the egg grains are still difficult to separate. It is estimated to occupy 30%-60% of the abdominal cavity. The average egg diameter is 0.450 - 0.750 mm	Testis further enlarges from maturity stage II, with grooves visible on the surface. Contains thick white fluid
IV	Mature	Ovary continues to enlarge, occupying about 60-80% of the abdominal cavity. The ovary contains yellowish-green eggs, with an average egg diameter of 0.800 - 1.25 mm	Testis enlarges further from maturity stage III, with grooves visible on the surface. Contains thick milky white fluid
V	Spent	Ovary shrinks, wrinkles, with thick and lobed walls, yellowish-green in color, containing residual eggs that were not spawned	Testis size decreases, edges become wrinkled

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Fecundity

There are 82 mature female fish (stage IV) with a length range of 7.5 to 17.5 cm and a weight range of 7 to 82 g, with gonad weights ranging from 1.25 to 10.11 g. The fecundity of silver barb obtained in this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The fecundity of silver barb obtained from the results of this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The relationship between fecundity and total length is $F = 4.6297 L^{2.958}$ ($R^2 = 0.3526$), fecundity with body weight is a linear relationship that is $F = 444.66W + 1489.3$ ($R^2 = 0.5145$) (Fig. 5 a, b).

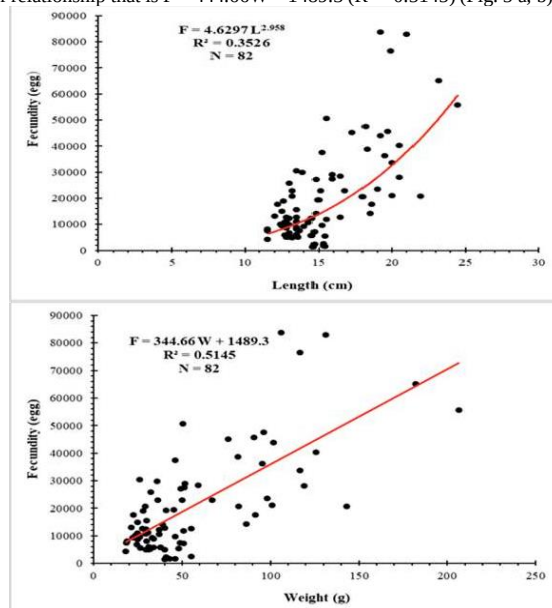


Fig. 5: Fecundity-length (a) and fecundity-weight (b) relationships of silver barb

Discussion

The length structure of male and female silver barb ranging from 8.9 to 28.5 cm, with the most frequently caught size being 14.5 cm. Similarly, the weight structure ranging from 21.2 to 312.8 g, with the largest proportion of catches at 21.2 g. This data indicates that the length and weight structure of the silver barb caught is predominantly small in size.

The length and weight structure of the silver barb from these waters shows lower values compared to those caught in Tchang Reservoir, Thailand, which measure 45 cm in length and 2,100 g in weight (Chheng *et al.*, 2004). This data suggests that fishing for silver barb, particularly in Lake Tempe, is very intensive, even excessively exploited (Sukarman, 2022). The silver barb does not have the opportunity to grow large due to intensive fishing. Additionally, suboptimal environmental conditions in the lake, the presence of predators or competitors, and the limited ability of swimming larvae to escape environmental factors are suspected to affect their survival and growth. According to Arevalo *et al.* (2023), 99% of the mortality in many fish species occurs during the early life stages. The high mortality rate is believed to influence the size variation of the silver barb population.

The overall sex ratio of male and female silver barb fish is 1:1, indicating a balanced number of male and female fish. This sex ratio is consistent with that reported by Maknuu (2016) for the silver barb from the Brantas River, Jombang Regency, West Java, Indonesia, which also has a ratio of 1:1. Similarly, silver barb from the Padma River in Bangladesh have a ratio of 1:1.27 (Jasmine and Begum, 2016); from the rivers in Ogan Komering Ilir Regency, South Sumatra, Indonesia, a ratio of 1:2 (Ardelia *et al.*, 2023); and from the Nagan River, Aceh Province, Indonesia, a ratio of 4:1 (Efizon *et al.*, 2021). The sex ratio can vary among the same species because sex determination is influenced not only by genetic factors but also by environmental factors (Capel, 2017). A 1:1 sex ratio is considered ideal because it

ensures that both male and female fish have an equal opportunity to sustain their species. Although silver barb fish experience high exploitation pressure, the sex ratio data indicate that the species still has a strong ability to maintain its population.

Furthermore, the sex ratio of mature gonad males to females is 1:3, meaning that in spawning activities, 1 male and 3 females are needed (polygamy). The sex ratio in spawning is related to the interaction and synchronization between male and female fish (Mylonas *et al.*, 2010), as well as the efficiency of using the number of males or females in spawning. Each fish species has an optimal sex ratio for spawning, for example, climbing perch, *Anabas testudineus*, it is 1:2 (Hasnidar *et al.*, 2022); sailfin molly, *Poecilia latipinna*, it is 1:10 (Tamsil and Hasnidar, 2019); and silver barb, *Barbonymus* sp., it is 6:1 (Efizon *et al.*, 2021).

The length-weight relationship model for silver barb resulted in $W = 0.0234 L^{2.7349}$ for males, $W = 0.0172 L^{2.8766}$ for females, and $W = 0.0183 L^{2.8415}$ for the combined (males and females). The t-test results showed that the b values for male, female, and combined silver barb were different from 3 ($b \neq 3$), indicating that the growth pattern is allometric. Since the b value is less than 3 ($b < 3$), it is classified as negative allometric growth. Several studies on the length-weight relationship of silver barb fish in various water bodies have reported similar findings. For instance, in the Jatiluhur Reservoir, Indonesia, the relationship was $W = 0.0413 L^{2.231}$ for males and females (Hardjamulia, *et al.*, 1988; Chheng *et al.*, 2004). Similarly, in the Brantas River, Kesamben Subdistrict, Jombang Regency, East Java, Indonesia, the relationship was $W = 0.024 L^{2.770}$ for males and $W = 0.021 L^{2.850}$ for females (Maknuu, 2016). In Gajah Mungkur Reservoir, Central Java Province, Indonesia, the relationship was $W = 0.020 L^{2.880}$ for males and $W = 0.001 L^{3.140}$ for females (Aida, 2018). In the Bengawan Solo River, Lamongan Regency, Indonesia, the relationship was $W = 0.037 L^{2.641}$ for males and $W = 0.029 L^{2.782}$ for females (Buwono *et al.*, 2019). In Cipanas Reservoir, West Java Province, Indonesia, the relationship was $W = 0.006 L^{3.169}$ (Syaiful *et al.*, 2019). The differences in the growth patterns of silver barb are caused by variations in water conditions. An important factor influencing fish growth in tropical regions is the availability of food (Froese, 2006). Therefore, the same species of fish in different locations will exhibit different growth patterns due to this factor. In addition to food, other factors include the stage of gonad development, the physicochemical properties of the water, fish health conditions, seasons, sampling time, and techniques (Sheridan, 2011; Mehanna and Farouk, 2021). In this study, 1,637 fish were caught, of which only 110 fish, or 6.7%, were in the mature gonad (stage IV), which is suspected to be the cause of the negative allometric growth pattern.

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The condition factor is a value that reflects the influence of environmental factors on the physiological condition of fish (Faradonbeh *et al.*, 2015). A favorable environment, including the availability of food, supports good growth, resulting in higher fish weight and a $CF \geq 1$. Conversely, an unsuitable environment and limited food availability lead to smaller weight gain and a $CF < 1$ (Dirican and Cilek, 2012). The CF values in this study ranged from 1.024 to 1.018. These values indicate that the fish are in a lean condition, consistent with their negative allometric growth pattern, where length increases faster than weight. Condition factors for silver barb from several previous studies ranged from 0.84 to 1.4 (Buwono *et al.*, 2019), 1.05 to 3.17 (Sidik *et al.*, 2020), 1.01 to 1.02 (Dwirastina and Marson, 2021), 0.82 to 1.10 (Syaiful *et al.*, 2019), 0.76 to 2.27 (Laila, 2018), and 1.145 to 1.328 (Maknuu, 2016). The variation in CF is caused by differences in the aquatic environment, density, food availability, and physiological conditions such as the fish's reproductive cycle. A higher CF value indicates a better adaptation of the fish to its environment.

The macroscopic analysis of gonad maturity stages showed that at each level of gonad maturity, there were differences in the size, color, and volume of the gonads in the abdominal cavity. In the ovaries, the higher the maturity stage, the larger the oocyte diameter tends to be; however, there is variation in oocyte diameter at the same maturity stage. Similarly, histological observations revealed differences in oocyte diameter (Efizon *et al.*, 2021). This data indicates that silver barb exhibit batch spawning, meaning they do not release all their eggs at once during spawning. Batch spawning results in a prolonged spawning season. The spawning season of silver barb in Lake Tempe is estimated to last throughout the year, as adult fish (stage IV) were found during each monthly observation from January to June, with a peak in January. In contrast, the spawning season for silver barb in the Padma River, Bangladesh, occurs from April to July, with a peak in June (Jasmine and Begum, 2016).

The size at first gonad maturity (L50) is the size at which 50% of individuals in a group have reproduced at least once (Barzotto and Mateus, 2017). The L50 for males is 19.9 cm, and for females, it is 18.3 cm. The L50 values found in this study are larger than those of silver barb from the Nagan River, Aceh Province, Indonesia, where the L50 for males is 7.3 cm, and for females, it is 8.5 cm (Efizon *et al.*, 2021). The size at first gonad maturity can vary due to competition and predation, fishing pressure, and environmental conditions (de Souza *et al.*, 2019). Fish will undergo first maturity in a shorter time frame to reduce the risk of death before reproduction if environmental conditions are unfavorable

(Barzotto and Mateus, 2017). Based on the L50 values for males and females in relation to the dominant length of silver barb caught in this study, approximately 90% of the captured fish were not yet mature.

The silver barb identified at maturity stage IV in this study totaled 82 individuals, with a length range of 12.2 to 21.28 cm (average $\pm$ 15.0 cm) and a body weight range of 21.0 to 124.4 g (average $\pm$ 41 g), producing fecundity ranging from 1,443 to 83,822 eggs (average = 20,239 eggs). Fecundity data for silver barb in various water bodies are presented in Table 2.

Table 2. Fecundity of Silver Barb in Various Water Bodies

Water Body	Fecundity	Reference
Lake Tempe	1,443 – 83,822 eggs (average = 20,239 eggs)	This study
Nagan River, Aceh Province, Indonesia	656 – 5,725 eggs (average 2,663 eggs)	Efizon <i>et al.</i> , 2021
Upper Serayu River, Central Java, Indonesia	2,760 – 50,085 eggs (average 17,347 eggs)	Haryono <i>et al.</i> , 2015
Padma River, Bangladesh	13,192 – 98,325 eggs (average 58,660 eggs)	Jasmine & Begum, 2016
Bangladesh	18,001 – 42,034 eggs (average 24,959 eggs)	Bhuiyan <i>et al.</i> , 2000

The coefficient of determination (R^2) for the relationship between fecundity and length (F-L) is $R^2 = 35.3\%$, and for fecundity and weight (F-W) it is $R^2 = 51.5\%$. This result indicates that 35.3% of the variation in fecundity is due to variation in the total length of the fish, and 51.5% of the variation in fecundity is due to variations in body weight. A similar observation was made for silver barb from the Nagan River, Aceh Province, Indonesia, where the coefficients of determination (R^2) for F-L and F-W were 51% and 24.2%, respectively (Efizon *et al.*, 2021). This means that the fecundity of silver barb increases with the increase in total length and body weight. Larger fish not only have a bigger visceral cavity to hold a greater number of oocytes, but also have sufficient energy for reproductive activities (Jonsson and Jonsson, 1999). Factors influencing fish fecundity include internal factors such as genetics, age, and size (Hunter *et al.*, 1992), while external factors include food availability and environmental conditions (Bryan *et al.*, 2007).

Conclusions

The length and weight structure of female fish are higher than that of male fish. The dominant length and weight of the catch are 14.5 cm and 21.2 g. The growth pattern is negatively allometric, and the condition factor is 1.02. The overall male-to-female ratio is 1:1, while the sex ratio during spawning is 1:3; meaning one male fish pairs with three female fish during spawning. The size at first gonad maturity is faster for females, at 18.3 cm, compared to males at 19.9 cm. Fecundity ranges from 253 to 13,398 eggs (average 2,571 eggs). The variation in fecundity is more influenced by body weight variation than by the total length variation of the silver barb.

Acknowledgments

We would like to extend our gratitude to the Rector of Universitas Muslim Indonesia (UMI) Makassar and the Research and Development Agency for providing the financial support that made this research possible.

Conflicts of interest

We declare that this research was conducted without any conflict of interest with any party.

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Hardy, R.W., 2002. Rainbow trout, *Oncorhynchus mykiss*. In: Webster, C.D. and Lim, C.E. (eds) Nutrient Requirements and Feeding of Finfish for Aquaculture. CABI, Wallingford, United Kingdom. pp 136–182.

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Research Article

Reproductive biology of silver barb, *Barbonymus gonionotus* (Bleeker, 1850), in Lake Tempe, Indonesia

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Keywords

Reproductive biology,
Silver barb,
Lake Tempe,
Length-weight relationship

Abstract

Information about the reproductive biology of the silver barb is essential for conservation and domestication purposes. This study aims to analyze the reproductive biology of the silver barb in Lake Tempe, South Sulawesi, Indonesia. The aspects of reproductive biology analyzed include length-weight structure, sex ratio, length-weight relationship, condition factor, first gonadal maturity size (L50), gonadal maturity, and fecundity. This study used primary data, with silver barb fish being caught using gill nets every week from January to July 2023. The total length of the fish was measured using an ichthyometer with an accuracy of 0.1 cm, and the weight was measured using a digital scale with an accuracy of 0.01 g. The gonads were preserved in a 4% formalin solution, and fecundity was calculated using the gravimetric method. The length structure of male ranged from 8.9 to 22.9 cm, and females ranged from 8.9 to 28.5 cm. Males had weights between 21.2 and 183.2 g, and females 21.2 and 312.8 g. The overall sex ratio of males to females was 1:1, while the sex ratio during spawning was 1:3 (polygamy). The length-weight relationship for males and females was $W = 0.0234L^{2.7349}$ and $W = 0.0172L^{2.8766}$, respectively. The condition factor for both males and females was 1.02. The first gonadal maturity size for females was 18.3 cm and 19.9 cm for males. Spawning was partial, with fecundity ranging from 253 to 13,398 eggs.

Article info

Received: November 2023
Accepted: July 2024
Published: November 2024



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Introduction

Silver barb, *Barbonymus gonionotus* (Bleeker, 1850), is an economically important freshwater fish in several countries such as Indonesia, Malaysia, Thailand, Myanmar, Bangladesh, India, and China. This fish has a delicious taste and is relatively inexpensive, making it a primary food source for communities, especially in certain regions of Indonesia. Its production largely relies on wild capture, leading to increasing fishing pressure.

Lake Tempe has a diverse range of fish species, consisting of native fish, introduced fish, and migratory marine fish. According to Dina *et al.* (2019), the native fish of Lake Tempe include *Monopterus albus*, *Anabas testudineus*, *Glossogobius aureus*, and *Channa striata*. The introduced fish species are *Barbonymus gonionotus*, *Clarias batrachus*, *Trichopodus pectoralis*, *Pangasianodon hypophthalmus*, *Osteochilus vittatus*, *Oreochromis niloticus*, *Helostoma temminckii*, and *Cyprinus carpio* (Yanuarita *et al.*, 2020). The migratory marine fish species include *Megalops cyprinoides*, *Stenogobius gymnopomus*, *Anguilla marmorata*, and *Caranx sexfasciatus*. The introduction of these species was carried out to enhance fishery production to meet increasing demand, optimize water productivity, sustainably boost production, and increase biodiversity (Yanuarita *et al.*, 2020; FAO, 2022).

Lake Tempe is currently facing environmental issues, including eutrophication (Aisyah and Nomosatryo, 2016). Eutrophication is suspected to be caused by nutrient loads originating from human activities, plantations, and livestock

farming, which are prevalent around the lake's edge. Nitrate and phosphate nutrients in the water range from 0.1063-0.2620 mg/L and 0.0245-0.0655 mg/L, respectively (Samuel *et al.*, 2012). This condition triggers the growth of aquatic weeds such as *Ipomoea aquatica* and *Eichhornia crassipes*. *E. crassipes* is the most dominant plant, with its population estimated to cover about 30-40% of the lake's surface. According to Yani *et al.* (2019), Lake Tempe has experienced moderate to severe pollution in several parameters, including turbidity, total suspended solids, biological oxygen demand, nitrate, and phosphate levels.

Another issue is overfishing and the use of non-environmentally friendly fishing gear (Nasution, 2012). A more serious problem is the presence of invasive fish species, specifically *Pterygoplichthys* spp. (Hasnidar *et al.*, 2021). The high population of *Pterygoplichthys* spp. has led to a decrease in the catch of target fish by fishermen (Hasrianti *et al.*, 2020). The presence of *Pterygoplichthys* spp. impacts the lake ecosystem through habitat competition, feeding patterns, and even predation on native and endemic fish, as well as being vectors for various diseases. This can alter species composition and fish community structure, leading to the dominance and possible elimination of native and endemic fish (Syafei and Sudinno, 2018).

Silver barb, *B. gonionotus*, was introduced to Lake Tempe in 1937 (Dina *et al.*, 2019; Yanuarita *et al.*, 2020). Although an introduced species, silver barb has adapted well to the lake environment. The rich aquatic vegetation of Lake Tempe

allows them to thrive. Silver barb are herbivores, with phytoplankton (Chlorophyceae) being their primary food source (Ain *et al.*, 2021); their diet also includes aquatic plants (80%), detritus (12%), and phytoplankton (8.5%) (Aida, 2018; Pratiwi *et al.*, 2021). Silver barb fish are considered beneficial in controlling excessive vegetation in lake waters. Despite their successful adaptation to Lake Tempe, the declining environmental conditions of the lake inevitably impact the production of this fish.

The production of silver barb has fluctuated in recent years, likely due to overfishing, environmental conditions, and high natural mortality (Sukarman, 2022). The high natural mortality is suspected to be caused by the presence of *Pterygoplichthys* spp. as an invasive species (Hasnidar *et al.*, 2021). Two fish species that are still being caught in large numbers are the silver barb and bloso (*Glossogobius* sp.). As a result, these two species are under very high fishing pressure. Conservation and domestication efforts will continue, but these efforts require up-to-date information, including the reproductive biology of silver barb, for future management. The research aims to analyze the reproductive biology of silver barb, covering size distribution, sex ratio, length-weight relationship, condition factor, gonad maturity, first gonad maturity size, and fecundity.

Materials and methods

The study was conducted from January to July 2023 in Lake Tempe, Wajo Regency, South Sulawesi Province, Indonesia (Fig. 1). Fish sampling was collected every week for six months, using a gill net response

tool. Fish samples caught were cleaned, put in a cooler box, and given ice cubes. Sample observations were carried out at the Biota and Environmental Engineering Laboratory, Faculty of Fisheries and Marine Science, Universitas Muslim Indonesia (UMI) Makassar.

The total length (Lt) of the silver barb was measured using an ichthyometer (Vernier caliper, Mitutoyo) with an accuracy of 0.1 cm. Body and gonad weights (g) were measured using a digital scale (electric digital scale, DIGI DS880) with an accuracy of 0.01 g. The parameters analyzed were:

Length and Weight Structure

The length and weight size structure is determined as follows: determining the number of classes; setting the length class interval at 1 cm and the weight class interval at 1 g. The fish sample was placed into the predetermined class. The size structure is determined within the same class intervals and then plotted on a graph.

Sex Ratio

The sex of silver barb is determined morphologically and anatomically by dissecting the fish to observe whether the gonads have developed into testes or ovaries. The determination of the male-to-female sex ratio is carried out by counting the number of male and female fish caught using the formula (Oliveira *et al.*, 2012):

$$SR = \frac{\text{number of male of female}}{\text{total number of fish observed}} \times 100$$

Next, sex ratio variability was tested using the Chi-square test (Oliveira *et al.*, 2012):

$$\chi^2 = \frac{\sum (oi - ei)^2}{ei}$$

Where, χ^2 = Value for a random

variable whose sampling distribution approximates the Chi-square distribution
 o_i =Observed frequencies of male and female fish
 e_i =Expected frequencies of

male and female fish.

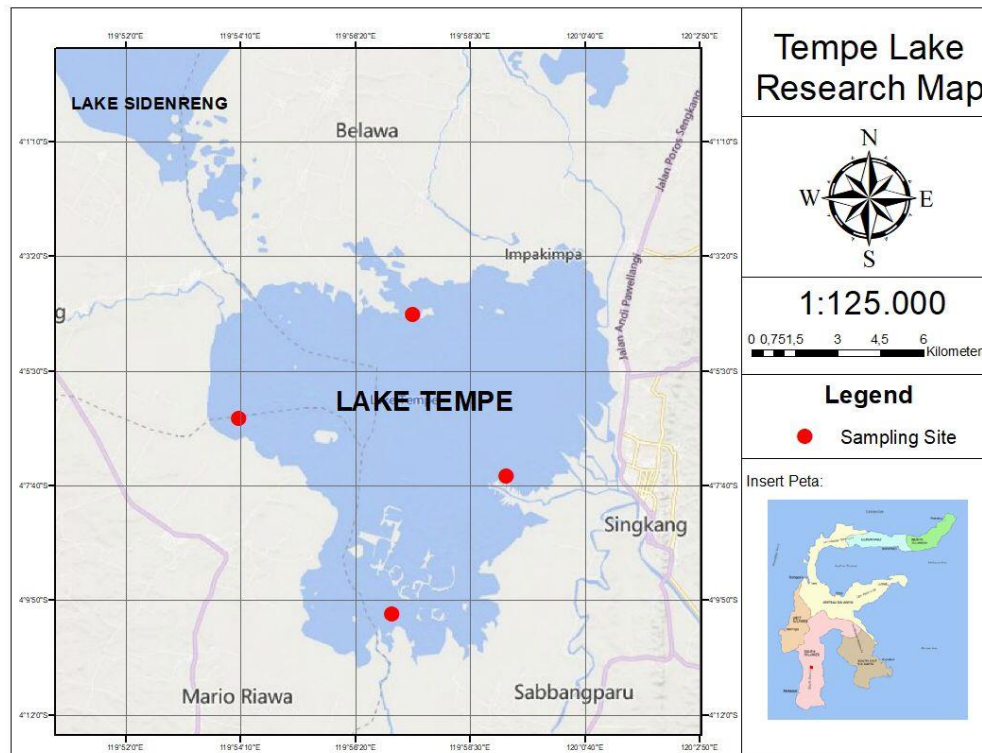


Figure 1: The sampling points for silver barb were located in Tempe Lake, Wajo Regency, South Sulawesi, Indonesia.

Length-weight Relationship

The relationship between length and weight was analyzed using the formula (Le Cren, 1951):

$$W = aL^b$$

Where, W: Body weight (g), L: Total length (cm), a: Coefficient of determination, b: Exponent that indicates isometric or allometric.

To make the equation, the values of W and L were transformed into logarithms (base 10) as follows:

$$W = \log a + b \log L$$

The obtained b value is used to estimate the length-weight parameters, with the following hypotheses: 1) $b = 3$ indicates

isometric growth, 2) $b \neq 3$ indicates allometric growth, a) $b > 3$: weight increases more rapidly (positive allometric), b) $b < 3$: length increases more rapidly (negative allometric).

Condition Factor (CF)

Because the growth pattern of silver barb in this study is negative allometric ($b \neq 3$), the formulation (Le Cren, 1951) is:

$$CF = \frac{W}{aL^b}$$

Where, CF: Condition factor, W: Fish body weight (g), L: Total length of fish (cm), a: Intercept, b: slope

Size at first gonadal maturity (L_{50})

The size of the first time the fish matures

gonads is obtained by finding the value of L50 by plotting the cumulative percentage of gonadal mature fish with the size of the fish body length, this will yield a standard logistic curve, and the intersection point between the curve and the 50% cumulative frequency represents the length at which 50% of the fish first mature gonadally.

Gonad Maturity Stage

The stages of gonad maturity are observed macroscopically. The observation procedure involves dissecting the fish sample to open the visceral cavity, and then observing the morphology of the gonad, including its shape, color, size, and position within the visceral (abdominal) cavity. The stages of gonad maturity are classified according to Brown-Peterson *et al.* (2011) and modified according to the gonadal condition of silver barb, as follows: Stage I (Immature); II (Developing); III

$$F = \frac{\text{Weight of the total gonad (WG)}}{\text{Weight sub-part gonad (Ws)}} \times \text{number of eggs in sub-part gonad (n)}$$

The relationship between fecundity and total length and body weight using the formulation Hasan *et al.* (2020) is:

$$F = a L^b \quad \text{and} \quad F = a W + b$$

Where, F: Fecundity (egg), L: Total length (cm), W: Body weight (g), a: Intercept, b: slope

Results

Length and weight structure

The results of the length structure analysis of the male silver barb ranged from 8.9 to 22.9 cm, and females ranged from 8.9 to 28.5 cm, with the largest proportion caught at 14.5 cm for both males and females. The weight structure for males ranged from 21.2

(Maturing); IV (Mature); and V (Spent). For fish samples with gonads at maturity Stage IV, the egg diameter is measured. The gonad is taken from three parts: posterior, middle, and anterior. From each part of the gonad sample, 30 eggs are collected for egg diameter measurement. The egg diameter is measured using an ocular micrometer (0.01 mm) of the UYCP-12 brand.

Fecundity

Fecundity is determined by weighing the total gonad (WG), then taking a sub-part from the posterior, middle, and anterior parts of the gonad and weighing it (Ws). The weight of the sub-part gonad is then preserved in a 4% formalin solution to facilitate counting the number of eggs (n). Fecundity is observed at maturity stage IV and is calculated using the gravimetric method (Hasan *et al.*, 2020):

to 183.2 g, and for females, from 21.2 to 312.8 g, with the largest proportion caught at 21.2 g for both males and females (Fig. 2a, b).

Sex Ratio

The total number of Silver barb caught was 1,637, consisting of 824 males (50%) and 813 females (50%). Thus, the sex ratio of male to female fish is 1:1 (Fig. 3a). Furthermore, the number of fish caught in a mature condition (stage IV) was 110, consisting of 27 males (25%) and 83 females (75%). Based on this data, the sex ratio of mature male to female fish is 1:3,

indicating that 1 male pairs with 3 females for spawning activities (Fig. 3b).

Length-weight relationship

The results of the length-weight relationship analysis for males are $W = 0.0234 L^{2.7349}$, for females $W = 0.0172 L^{2.8766}$, and for the combined group (males and females) $W = 0.0183 L^{2.8415}$ (Fig. 4 a,

b, c). The t-test results show that the b values for male, female, and combined silver barb fish are different from 3 ($b \neq 3$), indicating that the growth pattern is allometric. Since the b value is less than 3 ($b < 3$), it indicates negative allometric growth, meaning that length increases faster than weight.

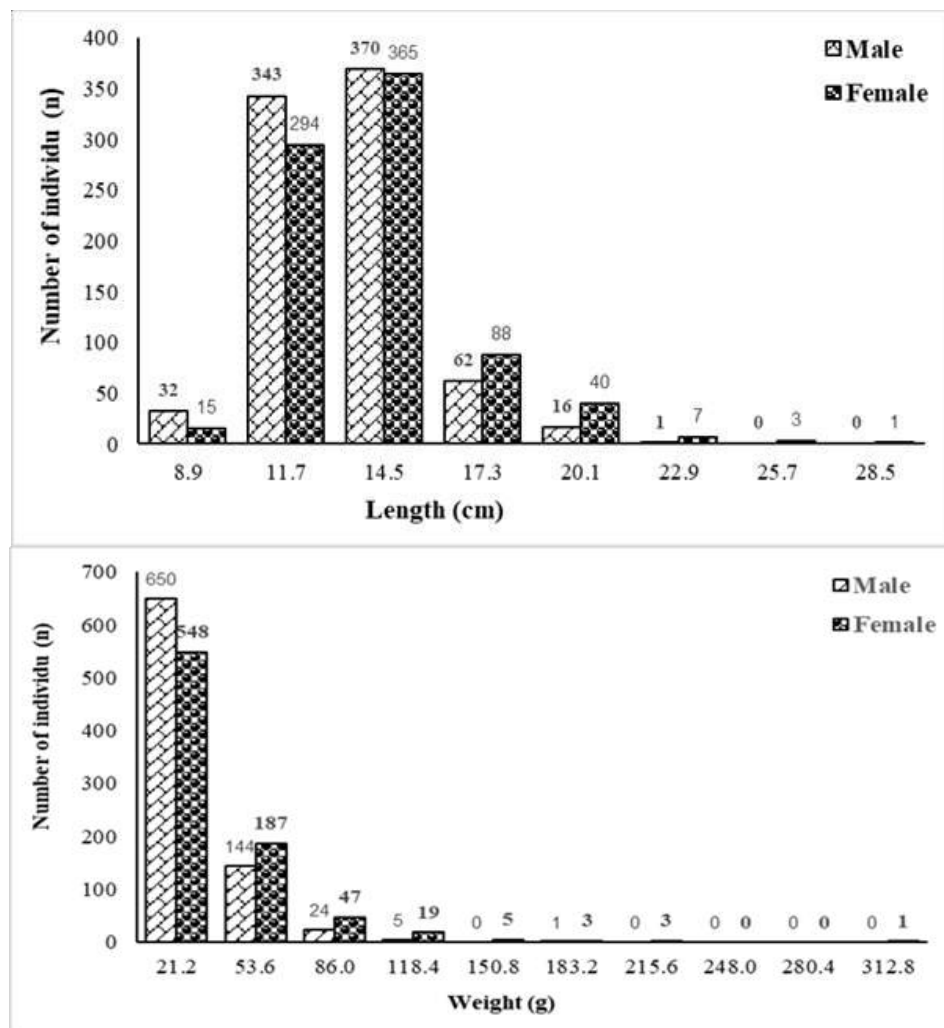


Figure 2: Length (a) and weight (b) structure of silver barb.

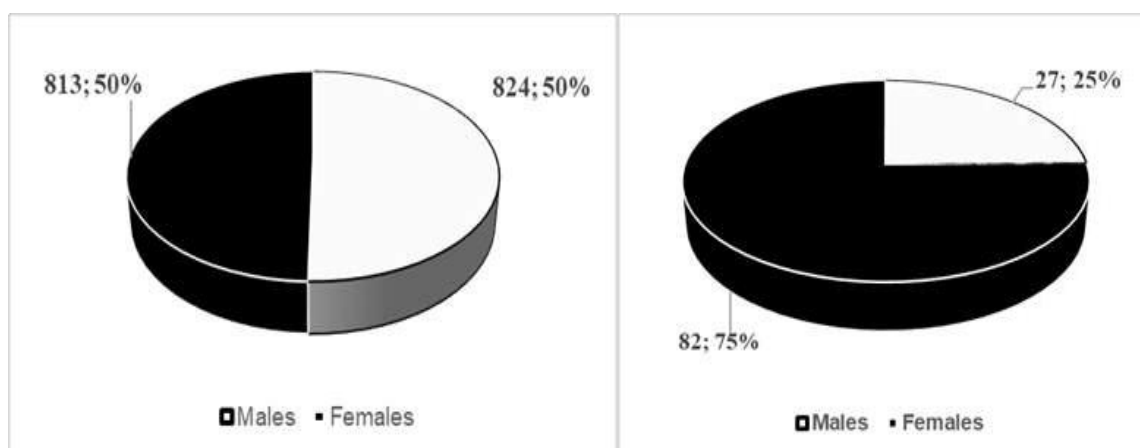
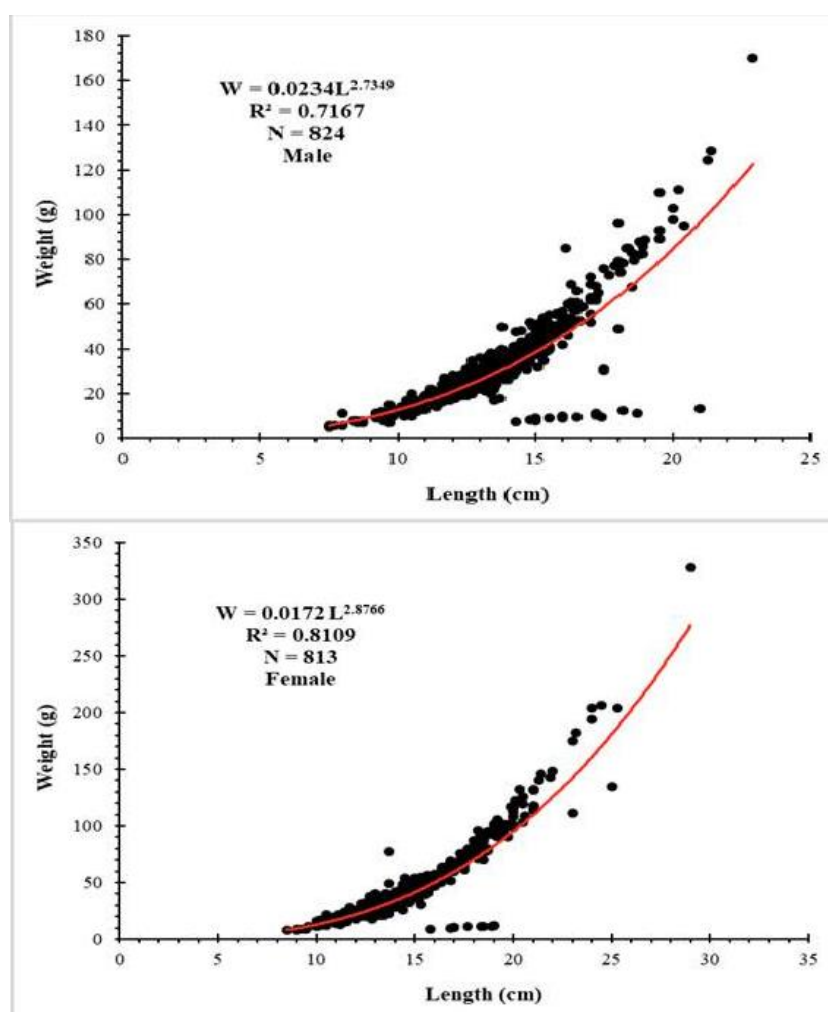


Figure 3: The sex ratio of male to female silver barb (a) and the sex ratio of male to female that have reached gonadal maturity (b).



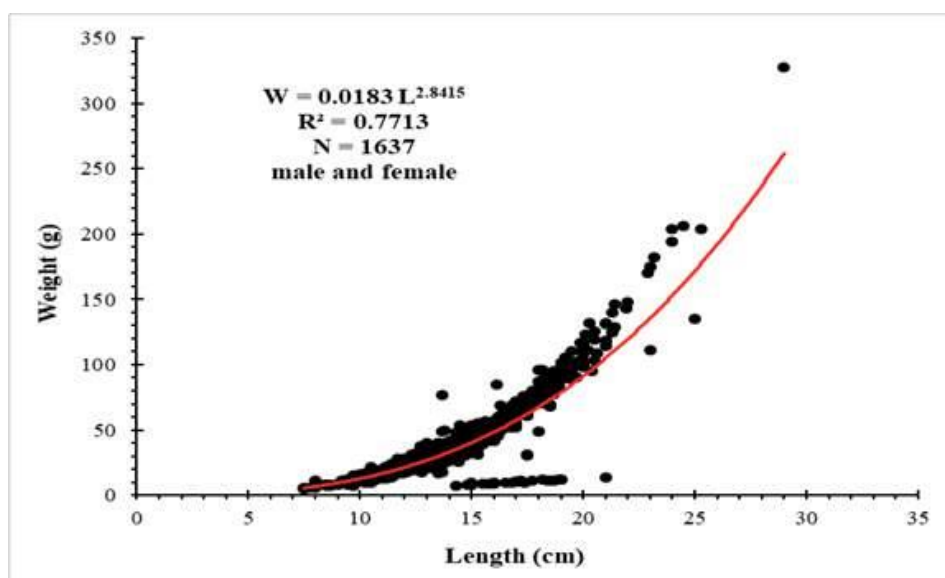


Figure 4: Length-weight relationship of male (a), female (b) and combined (male and female) (c).

Condition Factor (CF)

The condition factor for male and female silver barb is 1.0243 ± 0.0061 and 1.0181 ± 0.0054 , respectively.

Size at First Gonad Maturity (L_{50})

The analysis results for the size at first gonad maturity (L_{50}) show that male fish have an L_{50} of 19.9 cm, while female fish have an L_{50} of 18.3 cm. This data indicates that female mature faster than male fish.

Gonad Maturity Stage

The determination of gonad maturity level criteria was conducted macroscopically by observing the morphology, size, color, and position of the gonads within the abdominal cavity. The development stages of the gonads (ovaries and testes) of the silver barb were classified into five levels according to the guidelines of Hasnidar *et al.* (2022) and

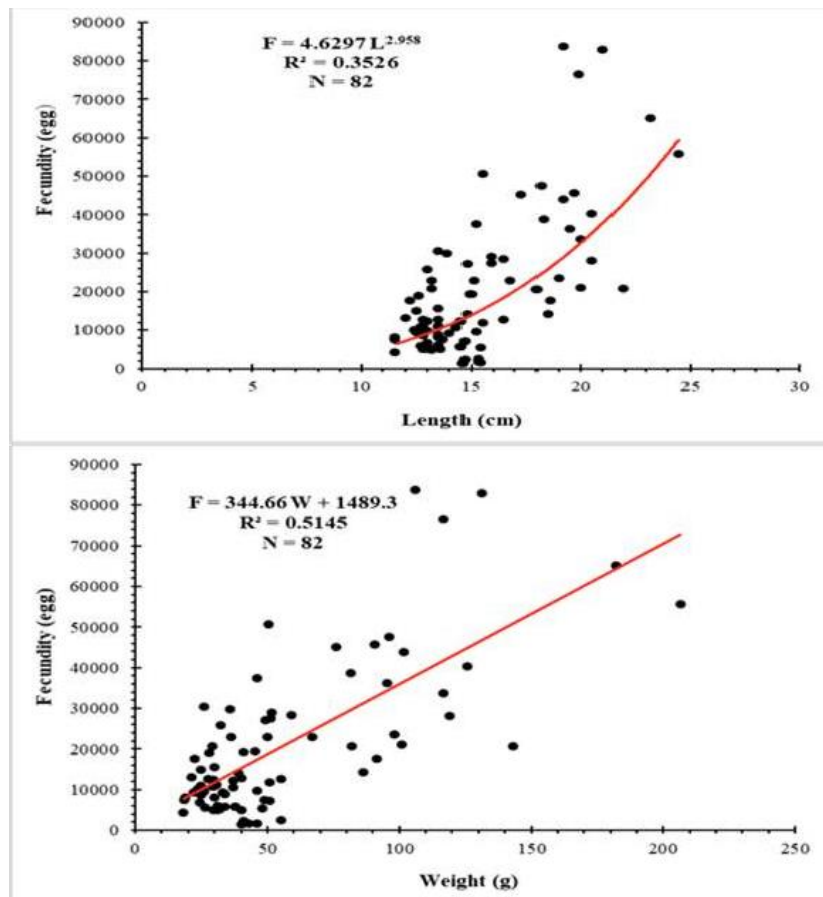
the condition of the silver barb gonads. The morphological characteristics of male and female gonads based on their maturity stages can be seen in Table 1.

Fecundity

There are 82 mature female fish (stage IV) with a length range of 7.5 to 17.5 cm and a weight range of 7 to 82 g, with gonad weights ranging from 1.25 to 10.11 g. The fecundity of silver barb obtained in this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The fecundity of silver barb obtained from the results of this study ranged from 253 to 13,398 eggs with an average value of 2,571 eggs. The relationship between fecundity and total length is $F = 4.6297 L^{2.958}$ ($R^2 = 0.3526$), fecundity with body weight is a linear relationship that is $F = 444.66W + 1489.3$ ($R^2 = 0.5145$) (Fig. 5a, b).

Table 1: Gonad maturity stage of female and male silver barb.

Maturity Stage	Note	Female	Male
I	immature	Ovary is very small, extending from the anterior to the posterior in the dorsal part of the abdominal cavity, filled with white fluid, eggs are not visible, estimated to occupy less than 15% of the abdominal cavity	Testis is very small and thin, extending from the anterior to the posterior of the abdominal cavity, containing clear white fluid
II	Developing	Ovary is larger than at maturity stage I, white in color, with visible egg grains, estimated to occupy 20-30% of the abdominal cavity. The average egg diameter is 0.20 – 0.425 mm	Testis enlarges, larger than at maturity stage I, containing white fluid
III	Maturing	Ovary enlarges, containing white egg grains, but the egg grains are still difficult to separate. It is estimated to occupy 30%-60% of the abdominal cavity. The average egg diameter is 0.450 - 0.750 mm	Testis further enlarges from maturity stage II, with grooves visible on the surface. Contains thick white fluid
IV	Mature	Ovary continues to enlarge, occupying about 60-80% of the abdominal cavity. The ovary contains yellowish-green eggs, with an average egg diameter of 0.800 - 1.25 mm	Testis enlarges further from maturity stage III, with grooves visible on the surface. Contains thick milky white fluid
V	Spent	Ovary shrinks, wrinkles, with thick and lobed walls, yellowish-green in color, containing residual eggs that were not spawned	Testis size decreases, edges become wrinkled

**Figure 5: Fecundity-length (a) and fecundity-weight (b) relationships of silver barb.**

Discussion

The length structure of male and female silver barb ranged from 8.9 to 28.5 cm, with the most frequently caught size being 14.5 cm. Similarly, the weight structure ranged from 21.2 to 312.8 g, with the largest proportion of catches at 21.2 g. This data indicates that the length and weight structure of the silver barb caught is predominantly small in size.

The length and weight structure of the silver barb from these waters shows lower values compared to those caught in Tchang Reservoir, Thailand, which measure 45 cm in length and 2,100 g in weight (Chheng *et al.*, 2005). This data suggests that fishing for silver barb, particularly in Lake Tempe, is very intensive, even excessively exploited (Sukarman, 2022). The silver barb does not have the opportunity to grow large due to intensive fishing. Additionally, suboptimal environmental conditions in the lake, the presence of predators or competitors, and the limited ability of swimming larvae to escape environmental factors are suspected to affect their survival and growth. According to Arevalo *et al.* (2023), 99% of the mortality in many fish species occurs during the early life stages. The high mortality rate is believed to influence the size variation of the silver barb population.

The overall sex ratio of male and female silver barb fish is 1:1, indicating a balanced number of male and female fish. This sex ratio is consistent with that reported by Maknuu (2016) for the silver barb from the Brantas River, Jombang Regency, West Java, Indonesia, which also has a ratio of 1:1. Similarly, silver barb from the Padma River in Bangladesh has a ratio of 1:1.27

(Jasmine and Begum, 2016); from the rivers in Ogan Komering Ilir Regency, South Sumatra, Indonesia, a ratio of 1:2 (Ardelia *et al.*, 2023); and from the Nagan River, Aceh Province, Indonesia, a ratio of 4:1 (Efizon *et al.*, 2021). The sex ratio can vary among the same species because sex determination is influenced not only by genetic factors but also by environmental factors (Capel, 2017). A 1:1 sex ratio is considered ideal because it ensures that both male and female fish have an equal opportunity to sustain their species. Although silver barb fish experience high exploitation pressure, the sex ratio data indicate that the species still has a strong ability to maintain its population.

Furthermore, the sex ratio of mature gonad males to females is 1:3, meaning that in spawning activities, 1 male and 3 females are needed (polygamy). The sex ratio in spawning is related to the interaction and synchronization between male and female fish (Mylonas *et al.*, 2010), as well as the efficiency of using the number of males or females in spawning. Each fish species has an optimal sex ratio for spawning, for example, climbing perch, *Anabas testudineus*, it is 1:2 (Hasnidar *et al.*, 2022); sailfin molly, *Poecilia latipinna*, it is 1:10 (Tamsil and Hasnidar, 2019); and silver barb, *Barbonymus* sp., it is 6:1 (Efizon *et al.*, 2021).

The length-weight relationship model for silver barb resulted in $W=0.0234 L^{2.7349}$ for males, $W=0.0172 L^{2.8766}$ for females, and $W=0.0183 L^{2.8415}$ for the combined (males and females). The t-test results showed that the b values for male, female, and combined silver barb were different from 3 ($b \neq 3$), indicating that the growth pattern is

allometric. Since the b value is less than 3 ($b < 3$), it is classified as negative allometric growth. Several studies on the length-weight relationship of silver barb fish in various water bodies have reported similar findings. For instance, in the Jatiluhur Reservoir, Indonesia, the relationship was $W = 0.0413 L^{2.231}$ for males and females (Hardjamulia, *et al.*, 1988; Chheng *et al.*, 2005). Similarly, in the Brantas River, Kesamben Subdistrict, Jombang Regency, East Java, Indonesia, the relationship was $W = 0.024 L^{2.770}$ for males and $W = 0.021 L^{2.850}$ for females (Maknuu, 2016). In Gajah Mungkur Reservoir, Central Java Province, Indonesia, the relationship was $W = 0.020 L^{2.880}$ for males and $W = 0.001 L^{3.140}$ for females (Aida, 2018). In the Bengawan Solo River, Lamongan Regency, Indonesia, the relationship was $W = 0.037 L^{2.641}$ for males and $W = 0.029 L^{2.782}$ for females (Buwono *et al.*, 2019). In Cipanas Reservoir, West Java Province, Indonesia, the relationship was $W = 0.006 L^{3.169}$ (Syaiful *et al.*, 2019). The differences in the growth patterns of silver barb are caused by variations in water conditions. An important factor influencing fish growth in tropical regions is the availability of food (Froese, 2006). Therefore, the same species of fish in different locations will exhibit different growth patterns due to this factor. In addition to food, other factors include the stage of gonad development, the physicochemical properties of the water, fish health conditions, seasons, sampling time, and techniques (Sheridan, 2011; Mehanna and Farouk, 2021). In this study, 1,637 fish were caught, of which only 110 fish, or 6.7%, were in the mature gonad (stage IV), which is suspected to be the cause of the negative allometric growth

pattern.

The condition factor is a value that reflects the influence of environmental factors on the physiological condition of fish (Faradonbeh *et al.*, 2015). A favorable environment, including the availability of food, supports good growth, resulting in higher fish weight and a $CF \geq 1$. Conversely, an unsuitable environment and limited food availability lead to smaller weight gain and a $CF < 1$ (Dirican and Cilek, 2012). The CF values in this study ranged from 1.024 to 1.018. These values indicate that the fish are in a lean condition, consistent with their negative allometric growth pattern, where length increases faster than weight. Condition factors for silver barb from several previous studies ranged from 0.84 to 1.4 (Buwono *et al.*, 2019), 1.05 to 3.17 (Sidik *et al.*, 2020), 1.01 to 1.02 (Dwirastina and Marson, 2021), 0.82 to 1.10 (Syaiful *et al.*, 2019), 0.76 to 2.27 (Laila, 2018), and 1.145 to 1.328 (Maknuu, 2016). The variation in CF is caused by differences in the aquatic environment, density, food availability, and physiological conditions such as the fish's reproductive cycle. A higher CF value indicates a better adaptation of the fish to its environment.

The macroscopic analysis of gonad maturity stages showed that at each level of gonad maturity, there were differences in the size, color, and volume of the gonads in the abdominal cavity. In the ovaries, the higher the maturity stage, the larger the oocyte diameter tends to be however, there is variation in oocyte diameter at the same maturity stage. Similarly, histological observations revealed differences in oocyte diameter (Efizon *et al.*, 2021). This data indicates that silver barb exhibit batch

spawning, meaning they do not release all their eggs at once during spawning. Batch spawning results in a prolonged spawning season. The spawning season of silver barb in Lake Tempe is estimated to last throughout the year, as adult fish (stage IV) were found during each monthly observation from January to June, with a peak in January. In contrast, the spawning season for silver barb in the Padma River, Bangladesh, occurs from April to July, with a peak in June (Jasmine and Begum, 2016).

The size at first gonad maturity (L50) is the size at which 50% of individuals in a group have reproduced at least once (Barzotto and Mateus, 2017). The L50 for males is 19.9 cm, and for females, it is 18.3 cm. The L50 values found in this study are larger than those of silver barb from the Nagan River, Aceh Province, Indonesia, where the L50 for males is 7.3 cm, and for females, it is 8.5 cm (Efizon *et al.*, 2021).

The size at first gonad maturity can vary due to competition and predation, fishing pressure, and environmental conditions (de Souza *et al.*, 2019). Fish will undergo first maturity in a shorter time frame to reduce the risk of death before reproduction if environmental conditions are unfavorable (Barzotto and Mateus, 2017). Based on the L50 values for males and females in relation to the dominant length of silver barb caught in this study, approximately 90% of the captured fish were not yet mature.

The silver barb identified at maturity stage IV in this study totaled 82 individuals, with a length range of 12.2 to 21.28 cm (average $\pm$ 15.0 cm) and a body weight range of 21.0 to 124.4 g (average $\pm$ 41 g), producing fecundity ranging from 1,443 to 83,822 eggs (average=20,239 eggs). Fecundity data for silver barb in various water bodies are presented in Table 2.

Table 2: Fecundity of Silver Barb in Various Water Bodies.

Water Body	Fecundity	Reference
Lake Tempe	1,443 – 83,822 eggs (average = 20,239 eggs)	This study
Nagan River, Aceh Province, Indonesia	656 – 5,725 eggs (average 2,663 eggs)	Efizon <i>et al.</i> , 2021
Upper Serayu River, Central Java, Indonesia	2,760 - 50,085 eggs (average 17,347 eggs)	Haryono <i>et al.</i> , 2015
Padma River, Bangladesh	13,192 – 98,325 eggs (average 58,660 eggs)	Jasmine and Begum, 2016
Bangladesh	18,001 – 42,034 eggs (average 24,959 eggs)	Bhuiyan <i>et al.</i> , 2000

The coefficient of determination (R^2) for the relationship between fecundity and length (F-L) is $R^2=35.3\%$, and for fecundity and weight (F-W) it is $R^2=51.5\%$. This result indicates that 35.3% of the variation in fecundity is due to variation in the total length of the fish, and 51.5% of the variation in fecundity is due to variations in body weight. A similar observation was

made for silver barb from the Nagan River, Aceh Province, Indonesia, where the coefficients of determination (R^2) for F-L and F-W were 51% and 24.2%, respectively (Efizon *et al.*, 2021). This means that the fecundity of silver barb increases with the increase in total length and body weight. Larger fish not only have a bigger visceral cavity to hold a greater number of oocytes,

but also have sufficient energy for reproductive activities (Jonsson and Jonsson, 1999). Factors influencing fish fecundity include internal factors such as genetics, age, and size (Hunter *et al.*, 1992), while external factors include food availability and environmental conditions (Bryan *et al.*, 2007).

Conclusions

The length and weight structure of female fish are higher than that of male fish. The dominant length and weight of the catch are 14.5 cm and 21.2 g. The growth pattern is negatively allometric, and the condition factor is 1.02. The overall male-to-female ratio is 1:1, while the sex ratio during spawning is 1:3; meaning one male fish pairs with three female fish during spawning. The size at first gonad maturity is faster for females, at 18.3 cm, compared to males at 19.9 cm. Fecundity ranges from 253 to 13,398 eggs (average 2,571 eggs). The variation in fecundity is more influenced by body weight variation than by the total length variation of the silver barb.

Acknowledgments

We would like to extend our gratitude to the Rector of Universitas Muslim Indonesia (UMI) Makassar and the Research and Development Agency for providing the financial support that made this research possible.

Conflicts of interest

We declare that this research was conducted without any conflict of interest with any party.

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