

Reproductive Biology and Population Dynamics of *Pethia conchonius* and *Crossocheilus diplochilus* in Dal Lake, Kashmir: Gonadosomatic Index, Fecundity, and Maturation Patterns

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Abstract

This paper discusses the reproduction and population dynamics of the *Pethia conchonius* and the *Crossocheilus diplochilus* in Dal Lake, Kashmir, including gonadosomatic index (GSI), reproductive fitness, sex ratio, maturity patterns as well as the effect of water quality. There were found to be seasonable changes in reproductive parameters and both species recorded a peak value of GSI in May, meaning reproductive seasons. *Pethia conchonius* had larger gonadosomatic index than *Crossocheilus diplochilus* indicating species-specific modes of reproduction. Sex ratios were found to vary between the expected 1:1 with *Pethia conchonius* having a female-biased ratio (1:1.22) and *Crossocheilus diplochilus* having a more extreme female-biased ratio (1:0.7). Seasonal peaks in fecundity were observed under both *Pethia conchonius* and *Crossocheilus diplochilus* with the highest fecundity occurring in May and March respectively. There were significant correlations between fecundity and body weight casting the importance of body condition on reproductive success. There was an increase in ova diameter between February and July in the two species, where *Pethia conchonius* peaked in July and *Crossocheilus diplochilus* peaked in June. *Pethia conchonius* was found to have length at first maturity smaller than *Crossocheilus diplochilus* (6.0 cm of males and 6.2 cm of females respectively). The results show that water quality, seasonal and environmental influences are also important issue in determining the reproductive success, and population structure of these species, hence invaluable data in conservation and management plans of Dal Lake.

Keywords: *Pethia conchonius*, *Crossocheilus diplochilus*, Dal Lake, gonadosomatic index, fecundity, sex ratio, maturation, water quality.

1. Introduction

Dal Lake located in the center of Srinagar, Kashmir is a freshwater lake that is highly biodiversified comprising of various aquatic life. These include *Pethia conchonius* and *Crossocheilus diplochilus* among others which are important species that create an ecological balance in the lake. Their reproduction as well as population dynamics are paramount factors that can be utilized to determine their sustainability and ecological relationships in such a distinct habitat (Ahmed et al., 2017; Bhat et al., 2022). The present research intends to determine the gonadosomatic index (GSI), fecundity, sex ratio, and maturation behaviors in the given fish species in Dal Lake, especially the seasonal changes and their association with the water quality.

Reproductive biology such as gonadosomatic index and fecundity is the determinant of insightful main reproductive techniques and health of fish population. These parameters are investigated in freshwater fish species in several studies and are mentioned to be the most important when it comes to clarifying the effects of environmental stressors (Kyritsi & Kokkinakis, 2020; Boucher, 2018). Also the sex ratio is an important measure of the population dynamics, where proportions other than the optimal figure of 1:1 are usually indicative of ecological or anthropogenic stress. We analyze the sex ratio of *Pethia conchonius* and *Crossocheilus diplochilus* and investigate possible reasons of a deviation observed citing expected values (Lateef et al., 2021).

The reproductive success and population well-being of the aquatic animals also largely depend on the environmental conditions including water quality. Such parameters as pH, temperature, and dissolved oxygen are also known to affect fish reproduction (Lopes et al., 2020; Rasool et al., 2022). The correlation between the abundance of such species and water quality is essential in the conservation of such species in Dal Lake, where the changes in water quality cause different degrees of anthropogenic stress to the species. The combination of the data regarding the water quality and reproductive and population indicators helps in defining the degree to which all these aspects are interconnected (Haque et al., 2023; Sudarshan et al., 2019).

This study will lead to the overall perception of the fish-population on which the parameters of the growth, the signs of the death and the maturation patterns will be examined. It is based on the previous research work on freshwater ichthyofauna, i.e., Yousuf et al. (2023) and Andrabi et al. (2022), which predetermines the importance of the given parameters in the context of freshwater life control and safety. It is in this regard that we hope to give a fine analysis of reproductive biology and population dynamics of *Pethia conchonius* and *Crossocheilus diplochilus* and provide the needed information about the effective conservation programs in the future.

2. Literature Review

2.1. Water Quality and Its Impact on Fish Population Dynamics

The quality of water is highly important in reproduction, survival and health of the aquatic organisms, which includes fish. Physicochemical conditions of water, such as pH, dissolved oxygen, temperature and nutrient availability is very important in the regulation of fishes. As an example, Al-Jasimee and Hussein (2023) conducted an assessment of the water quality at Dalmaj Marsh, Iraq, in terms of the key water quality parameters, and the effects on the local biota in general. Coming to the same point, Sudarshan et al. (2019) showed the seasonal water quality influence on fish species in Hebbal Lake in India with a specific reference to such indicators as the biochemical oxygen demand (BOD) and total dissolved solids (TDS). The water of the Dal Lake is impacted by the natural as well as man-made pressure of the domestic and industrial wastes. They are likely to be reflected in the difference between contaminations of the lake basins and seasonal differences in fish population and biological characteristics of various fish species such as the *Pethia conchonius* and the *Crossocheilus diplochilus* (Eneogwe et al., 2021). The interactions play a significant role in conservation and fishery management since the quality of water can be so low that it leads to the decline in fish abundance, reproductive success and even a decline in population.

2.2. Interference in Freshwater reproductive biology and fecundity.

Fecundity as the reproductive production of fish is another significant point that one should not ignore during the process of knowing the growth of population and sustainability of species. It was already demonstrated that environmental factors, including temperature, quality of water, and availability of food, could be of a critical importance in the fecundity (Kyritsi and Kokkinakis, 2020). In the study of the *Dissostichus eleginoides*, Boucher (2018) established the possible effect of reproductive methods including missed spawning and seasonal migration on the fecundity of the species and the reproductive success of the fish, in general. Likewise, research on other aquatic organisms such as the *Schizothorax labiatus* (Arafat & Bakhtiyar, 2018) are to determine the significance of learning the effects of the environment on the fecundity of aquatic environments. These abiotic and biotic conditions that affect the fecundity of *Pethia conchonius* and *Crossocheilus diplochilus* are - water temperature and levels of nutritional levels fluctuate with seasons in Dal Lake. This paper is intended to compare the reproductive success where *Pethia conchonius* reaches its highest fecundity in the month of May and *crossocheilus diplochilus* reaches its greatest fecundity in the month of March. These types of copulation are some of the major clues on how these species shall respond to the changes in the environmental situation at Dal Lake.

2.3. Sex Ratio and Population Structure.

Another important element in fish population dynamics is the sex ratio which has a direct influence on reproductive success. The sex ratio of a healthy population is usually expected to be 1:1, though it can be expected to deviate, a process of sex ratio also may suggest the existence of ecological imbalances such as the impacts of pollution, overfishing or habitat destruction. Lateef et al. (2021) found that the anthropogenic pressure which may pressure skewness sex ratios in freshwater fish populations may indeed be true and the same is reported by Yousuf et al. (2023) in their research on Kashmir Valley fish populations. The article by Andrabi et al. (2022) about the diversity and relative abundance of ichthyofauna in Manasbal Lake, Kashmir, also emphasized the possible impact of many environmental and ecological factors on the sex ratio of freshwater fish populations. The *Pethia conchonius* Ratio of males to female was 1:1.22 in this study and the ratio in the *Crossocheilus diplochilus* was found to be highly skewed at 1:0.7. The statistical tests indicated that the sex ratio of the *Crossocheilus diplochilus* was basically varied at 1:1 ratio which suggests that there might be a stressful environmental or ecological factor in Dal Lake. Environmental changes also demand a better examination of sex ratios to properly explain management and conservation of fish populations.

2.4. Ecology of Growth and Maturation in Fish Species.

The growth and maturation process of the fish species is influenced by different factors including the environmental conditions, and the resources available including the genetic factors. Complete of particular interest regarding the analysis of reproductive timing and success are the length at first maturity (Lm). It was found out that fish reach sexual maturity at different sizes depending on the environmental factors. When Kyritsi and Kokkinakis (2020) undertook a study regarding the age, development, and fecundity of the roach (*Rutilus rutilus*) in the Volvi Lake, Greece the age and the size of the organism at the initial maturity was found to be dependent on the environmental factors as well. Similarly, the correlation between reproductive success and growth patterns of freshwater fish species inhabiting Kashmir have also been examined by Arafat and Bakhtiyar (2018) as a consequence of the studies regarding *Schizothorax labiatus*. At first maturity, the intersectional length of *Pethia conchonius* in a male and female was 6.0 cm and 6.2 cm respectively in a Dal Lake, but the intersectional length of *Crossocheilus diplochilus* was 8.8 cm and 9.2 cm respectively in a male and a female. The research paper contributes to what is currently known in maturation among fish and provides an information on the usefulness of maturation in *Pethia conchonius* and *Crossocheilus diplochilus* under the special environmental conditions of Dal Lake. Reproduction is a critical research since it establishes the reproductive health of these species, thereby their population can be managed by unraveling the growth and maturation cycle of these species.

The research articles discussed in this paper highlight the intricacy of reproductive biology, populations and environmental factors on freshwater fish species. Water quality, the level of fecundity, sex ratio, and the mode of maturation are all intertwined factors that promote the future health and sustainability of fish population. The results of this study along with the results of earlier studies can provide valuable knowledge about the ecological state of Dal lake and the issues that affect the reproductive success and/or population of *Pethia conchonius* and *Crossocheilus diplochilus*. These lessons will be important in informed conservation policies and sustainable management in the region.

3. Methods and Materials

3.1 Study Area

The study was carried out at Dal Lake near the northeast of the city of Srinagar, Kashmir Valley, with a latitude of 34° 5' N, a longitude of 74° 48' E. Its catchment area is about 337 sq. km and a surface area is 24 sq. km and a water open area is 10.5 sq. km (Rashid et al., 2017). Dal Lake is an open drainage system that accepts run-off of various streams, particularly, Telbal Nallah and Botkol, minor streams such as Meerakshah Nallah and springs that spots on the lake bed and the neighbouring mountains (Qadri and Yousuf, 1980). The lake boasts of two major exits: Nallah Amir Khan

and Dalgate. The faunal composition of the lake is very rich particularly fish species of *Cyprinus carpio*, *Crossocheilus diplochilus*, *Schizothorax niger*, *S. curvifrons*, *Botia birdi*, *Pethia conchonius*, *Carassius carassius* and *Gambusia holbrooki* (Ahmed et al., 2017; Bhat et al., 2022).

3.2 Design of Sampling

Five distinct sampling sites (S1 to S5) were selected to capture spatial variation in anthropogenic pressures:

- **S1 (Hazratbal):** A heavily polluted area adjacent to Hazratbal Shrine, impacted by domestic waste.
- **S2 (Dalgate):** Located near houseboats, this site receives waste generated from the houseboats.
- **S3 (Nishat):** A tourism-heavy area of Dal Lake.
- **S4 (Telbal):** Adjacent to the primary inflow channel (Telbal Nallah), this site experiences direct inflow from the stream.
- **S5 (Centre):** The least polluted site located at the center of the lake.

The water and fish samples were transported to the Fish Biology and Limnology Laboratory for further analysis.

3.3 Abundance of *Pethia conchonius* and *Crossocheilus diplochilus*

The abundance of these fish species was determined using various diversity indices:

- **Simpson's Index (Dominance):** Calculated to determine species dominance.
- **Shannon-Weiner Index (Richness):** Used to estimate species diversity.
- **Pielou's Evenness Index:** Assessed the distribution of individuals across species.
- **Catch per Unit Effort (CPUE):** Estimated the relative abundance of fish using the formula $CPUE = \frac{C}{F}$, where C represents catch and F represents fishing effort.

3.4 Population Dynamics and Population Structure

Several metrics were used to understand the population structure of *Pethia conchonius* and *Crossocheilus diplochilus*:

- **Length-Weight Relationship (LWR):** Determined using the equation $W = aL^b$, where W is weight, L is length, a is the intercept, and b is the slope.
- **Relative Condition Factor (Krel):** Calculated to evaluate the health condition of the fish.
- **Growth Parameters:** Asymptotic length (L_∞) and growth constant (K) were computed using FiSAT II software, based on the equation $L_t = L_\infty(1 - e^{-K(t-t_0)})$.
- **Mortality:** Natural mortality (M) was calculated using Pauly's equation. The fishing mortality (F) and total mortality (Z) were derived using the length-converted catch curve method. The exploitation ratio (E) was computed as $E = F/Z$.

3.5 Reproductive Biology

Reproductive parameters were assessed for both fish species:

- **Fecundity:** Estimated by counting the eggs in a subsample of gonads after extraction and fixation in formalin.
- **Gonado-Somatic Index (GSI):** Determined using the formula $GSI = \frac{\text{Gonad weight}}{\text{Body weight}} \times 100$ (Zin et al., 2011).
- **Sex Ratio:** Determined through gonadal examination and analyzed using chi-squared tests to compare observed and expected ratios.
- **Ova Diameter:** Measured under a microscope fitted with a camera (Magcam DC 10) to examine the maturity stages of ovaries.
- **Length at First Maturity (Lm):** Estimated by plotting the frequency of adult mature individuals against length class and fitting the data to a logistic function.

3.6 Impact of Water Quality on Fish Abundance

Water quality was monitored using various physicochemical parameters, as follows:

- **pH:** Measured using a Hanna HI98129 meter.
- **Dissolved Oxygen:** Measured using the Winkler's Iodometric method.
- **Temperature, TDS, EC, Alkalinity, Nitrate, Phosphorus:** Measured using Hanna HI98129 and other standard methods.
- **Biochemical Oxygen Demand (BOD):** Measured using the Winkler's Iodometric method (APHA, 2017).
- **Free Carbon Dioxide:** Titrimetric method.

The water quality data was analyzed using multiple statistical tests, including ANOVA, box plot analysis, principal component analysis (PCA), and cluster analysis to examine spatial and seasonal variations. The relationship between water quality and fish abundance was explored using Pearson correlation and Canonical Correspondence Analysis (CCA).

3.7 Statistical Analysis

Data were subjected to statistical analysis using:

- **MS-Excel 2019** for length-weight relationship and data presentation.
- **PAST 4.17** for diversity analysis.
- **SPSS Ver. 26** for water quality data analysis.
- **FiSAT II** for population dynamics and growth parameters.

- **Principal Component Analysis (PCA) and Cluster Analysis** for water quality data interpretation.

The results of statistical tests such as ANOVA and correlation were used to draw conclusions about the influence of water quality on the abundance and reproductive parameters of *Pethia conchonius* and *Crossocheilus diplochilus* in Dal Lake.

4. Data Analysis and Results

4.1 Gonadosomatic index

The gonadosomatic index of both the fishes was calculated separately for males and females. In both fishes, the gonads were visible during all the months, though variation in size was pronounced. GSI was calculated only for the months of January to September because the sex in case of immature gonads could not be deciphered due very small size and similar consistency. The variation in GSI of *Pethia conchonius* and *Crossocheilus diplochilus* is depicted in Table 4.1 and graphically presented in Figure 4.1 and 4.2 respectively. In case of *Pethia conchonius* the maximum GSI was reported during the month of May with a value of 11.57 ± 3.02 for females and 5.34 ± 0.72 for males whereas in case of *Crossocheilus diplochilus* the maximum GSI was recorded during the month of May with a value of 11.36 ± 4.31 for females and 5.22 ± 3.41 for males.

Table 4.1: Monthly GSI values (Mean $\pm$ SD) for *Pethia conchonius* and *Crossocheilus diplochilus* from Dal Lake

Fish		GSI (Mean $\pm$ SD)								
		January	February	March	April	May	June	July	August	September
P. conchonius	F	4.55 $\pm$ 1.44	5.55 $\pm$ 1.02	6.32 $\pm$ 1.07	7.05 $\pm$ 2.27	11.57 $\pm$ 3.02	7.17 $\pm$ 1.89	6.26 $\pm$ 1.72	5.74 $\pm$ 2.15	4.76 $\pm$ 2.07
	M	3.04 $\pm$ 0.7	3.57 $\pm$ 0.74	4.43 $\pm$ 0.64	4.6 $\pm$ 0.89	5.34 $\pm$ 0.72	4.17 $\pm$ 0.24	3.35 $\pm$ 0.35	3.48 $\pm$ 0.88	2.86 $\pm$ 1.08
C. diplochilus	F	2.76 $\pm$ 1.06	3.24 $\pm$ 1.03	4.65 $\pm$ 1.87	4.7 $\pm$ 0.32	11.36 $\pm$ 4.31	10.67 $\pm$ 4.41	6.3 $\pm$ 0.88	3.79 $\pm$ 1.45	2.05 $\pm$ 1.08
	M	1.74 $\pm$ 0.78	2.13 $\pm$ 0.81	2.21 $\pm$ 0.75	3.21 $\pm$ 0.71	5.22 $\pm$ 3.41	4.95 $\pm$ 3.75	4.32 $\pm$ 0.55	1.49 $\pm$ 0.61	1.26 $\pm$ 0.62

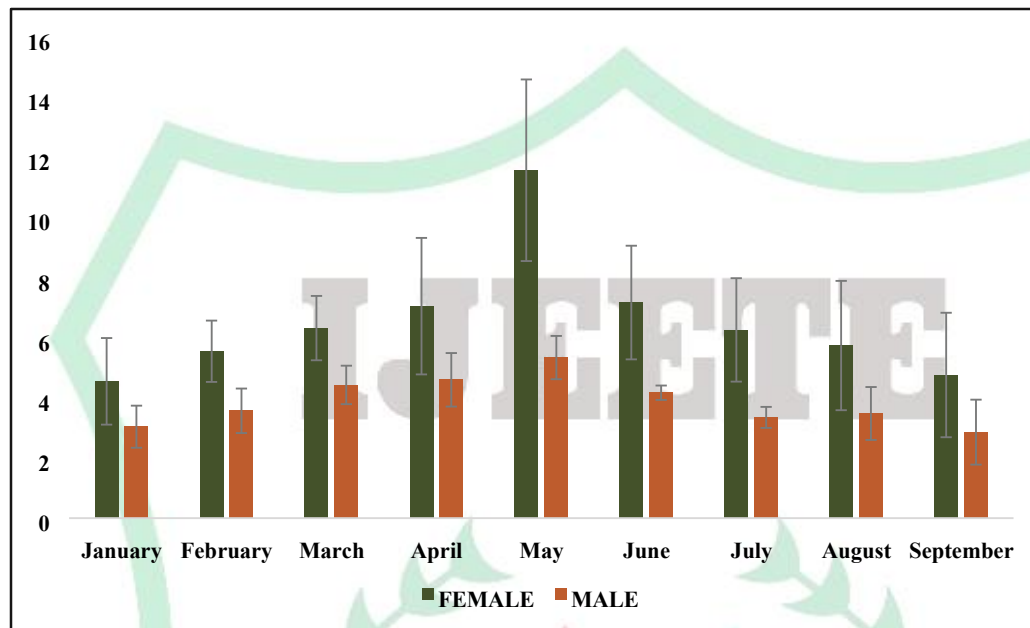


Figure 4.1: Graphical representation of GSI value (Mean±SD) for *Pethia conchonius* from Dal Lake

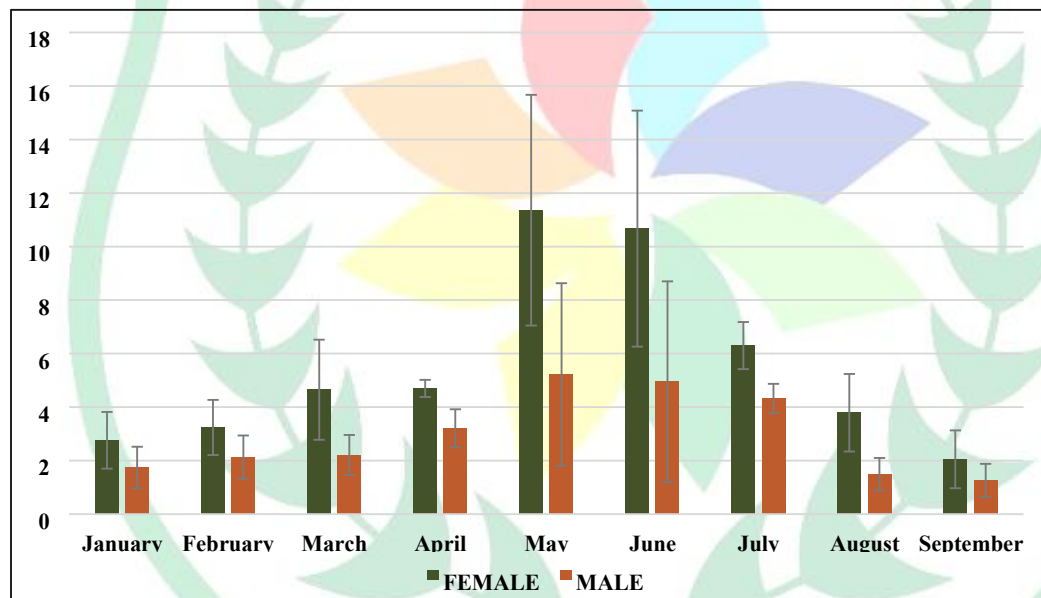


Figure 4.2: Graphical representation of GSI value (Mean±SD) for *Crossocheilus diplochilus* from Dal Lake

4.2 Sex ratio

The sex determination was done after analyzing the gonads as no marked morphological difference, except during the breeding season was witnessed in both the fishes. The overall male to female sex ratio in case of *Pethia conchonius* was reported to be 1:1.22 and for *Crossocheilus diplochilus* it was reported to be 1:0.7, both showing a marked deviation from the ideal 1:1 ratio. The data was subjected to Chi-square (χ^2) test to find any significant difference between the calculated and the ideal sex ratio as depicted in Table 4.2. The Chi square test revealed that the difference was found to be statistically non-significant for *Pethia conchonius* ($p > 0.05$) whereas it was found to be statistically

significant for *Crossocheilus diplocheilus* ($p < 0.05$).

Table 4.2: Sex ratio of *Pethia conchonius* and *Crossocheilus diplocheilus* from Dal Lake

Fish	Males	Females	Sex ratio (M:F)	Z2	p value
<i>Pethia conchonius</i>	93	75	1:1.22	1.93	0.16
<i>Crossocheilus diplocheilus</i>	129	183	1:0.7	9.35	0.002

4.3 Fecundity (Absolute and relative)

In case of fishes, fecundity is either measured as absolute (that accounts for the total number of ripe eggs in a female ovary) or relative (which is the ratio of fecundity and total weight of the fish). The absolute fecundity for *Pethia conchonius* was reported to be 1085.97 ± 351.50 eggs whereas the average relative fecundity was reported to be 226.09 ± 63.24 eggs/g. The absolute and relative fecundity was reported to be highest in the month of May i.e., 1291.46 ± 308.57 eggs and 275.40 ± 39.09 eggs/g respectively. In case of *Crossocheilus diplocheilus* the absolute fecundity was reported to be 2340.18 ± 1148.92 eggs, whereas the relative fecundity was reported to be 274.42 ± 108.19 eggs/g. The absolute and relative fecundity was reported to be highest in the month of March i.e., 3251.21 ± 902.21 eggs and 377.50 ± 102.94 eggs/g respectively. The absolute and relative fecundity of *Pethia conchonius* and *Crossocheilus diplocheilus* is depicted in Table 4.3 and 4.4 respectively.

Table 4.3: Absolute and relative fecundity of *Pethia conchonius*

Parameter	<i>Pethia conchonius</i>						
	February	March	April	May	June	July	Overall
Absolute Fecundity (eggs)	820 ± 267.06	1150 ± 197.79	1113.08 ± 255.81	1291.46 ± 308.57	1051.26 ± 426.59	890 ± 240.19	1085.97 ± 351.50
Relative Fecundity (eggs/g)	149.80 ± 34.99	209.89 ± 28.99	224.74 ± 38.74	275.40 ± 39.09	222.22 ± 73.68	194.42 ± 56.56	226.09 ± 63.24
Total length (cm)	7.02 ± 0.42	7.07 ± 0.40	6.67 ± 0.48	6.58 ± 0.55	6.47 ± 0.36	6.52 ± 0.20	6.62 ± 0.45
Total weight (g)	5.4 ± 0.72	5.48 ± 0.70	4.98 ± 0.88	4.73 ± 1.07	4.71 ± 0.91	4.65 ± 0.59	4.84 ± 0.90

Ovary weight (g)	0.31±0.10	0.37±0.10	0.35±0.07	0.35±0.07	0.29±0.08	0.28±0.06	0.32±0.08
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Table 4.4: Absolute and relative fecundity of *Crossocheilus diplochilus*

Parameter	<i>Crossocheilus diplochilus</i>						
	February	March	April	May	June	July	Overall
Absolute Fecundity (eggs)	1551.76±348.41	3251.21±902.21	2875.89±659.65	2667.37±1507.99	1925.79±1126.89	1425.38±389.67	2340.18±1148.92
Relative Fecundity (eggs/g)	179.86±21.79	377.50±102.94	301.94±89.30	312.35±112.14	261.82±80.44	172.29±24.27	274.42±108.19
Total length (cm)	10.16±0.76	10.14±0.64	10.51±0.66	9.58±1.43	9.04±1.48	9.79±1.03	9.86±1.15
Total weight (g)	8.69±1.93	8.72±1.48	10.00±2.71	8.45±4.02	7.42±4.0	8.44±2.73	8.62±3.03
Ovary weight (g)	0.30±0.10	0.44±0.18	0.33±0.14	1.01±0.62	0.81±0.50	0.51±0.11	0.58±0.44

4.4 Correlation between fecundity (absolute) and various body parameters

The absolute fecundity and various body parameters (total length, total weight and ovary weight) of the fish were log transformed and subjected to regression analysis. It was reported that ovary weight showed strong correlation with the fecundity with “r” value ranging from 0.72 to 0.98. The “r” value ranged from 0.11 to 0.91, when total length and fecundity were correlated and it ranged from 0.017 to 0.91, when total weight and fecundity were correlated. The correlation between fecundity and various body parameters of *Pethia conchonius* and *Crossocheilus diplochilus* is depicted in Table 4.5 (Figure 4.3) and Table 4.6 (Figure 4.4) respectively.

Table 4.5: Regression and correlation analysis of fecundity (absolute) with different body parameters of *Pethia conchonius*

Correlation	<i>Pethia conchonius</i>					
	February	March	April	May	June	July
log TW vs log F equation (r)	$y = 2.0465x - 4.737$ (0.80)	$y = 1.0936x - 1.0241$ (0.72)	$y = 0.8151x + 0.0278$ (0.71)	$y = 0.8229x + 0.084$ (0.83)	$y = 1.0057x - 0.7129$ (0.38)	$y = 0.0491x + 2.747$ (0.017)
log TL vs log F equation (r)	$y = 4.7438x - 5.8593$ (0.87)	$y = 2.5727x - 1.6933$ (0.79)	$y = 2.2779x - 1.131$ (0.71)	$y = 2.437x - 1.3291$ (0.82)	$y = 2.0892x - 0.8092$ (0.22)	$y = -2.3642x + 7.2155$ (0.20)
log OW vs log F equation (r)	$y = 1.0317x + 0.349$ (0.94)	$y = 0.6028x + 1.5165$ (0.83)	$y = 1.0335x + 0.4152$ (0.86)	$y = 1.0565x + 0.4202$ (0.87)	$y = 1.5849x - 0.9002$ (0.88)	$y = 1.3873x - 0.4565$ (0.91)

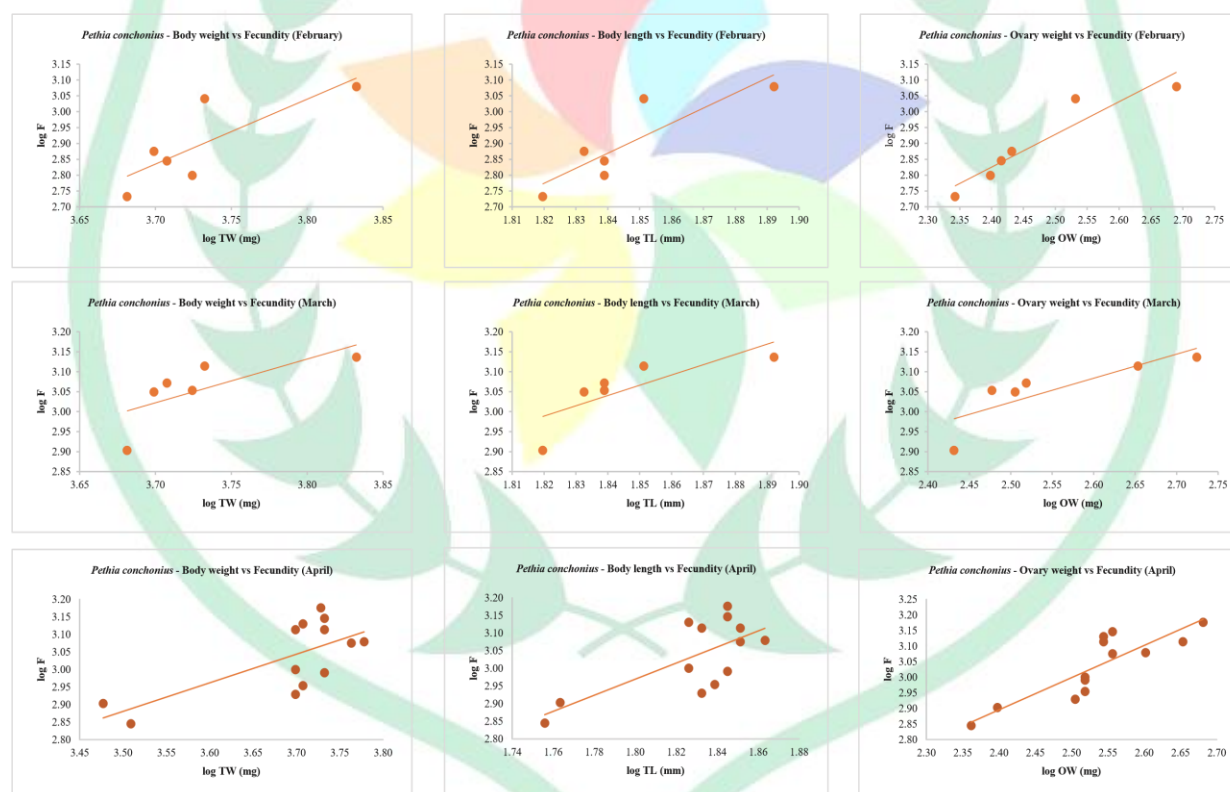


Figure 4.3: Correlation between fecundity (absolute) and various body parameters (*Pethia conchonius*) contd.

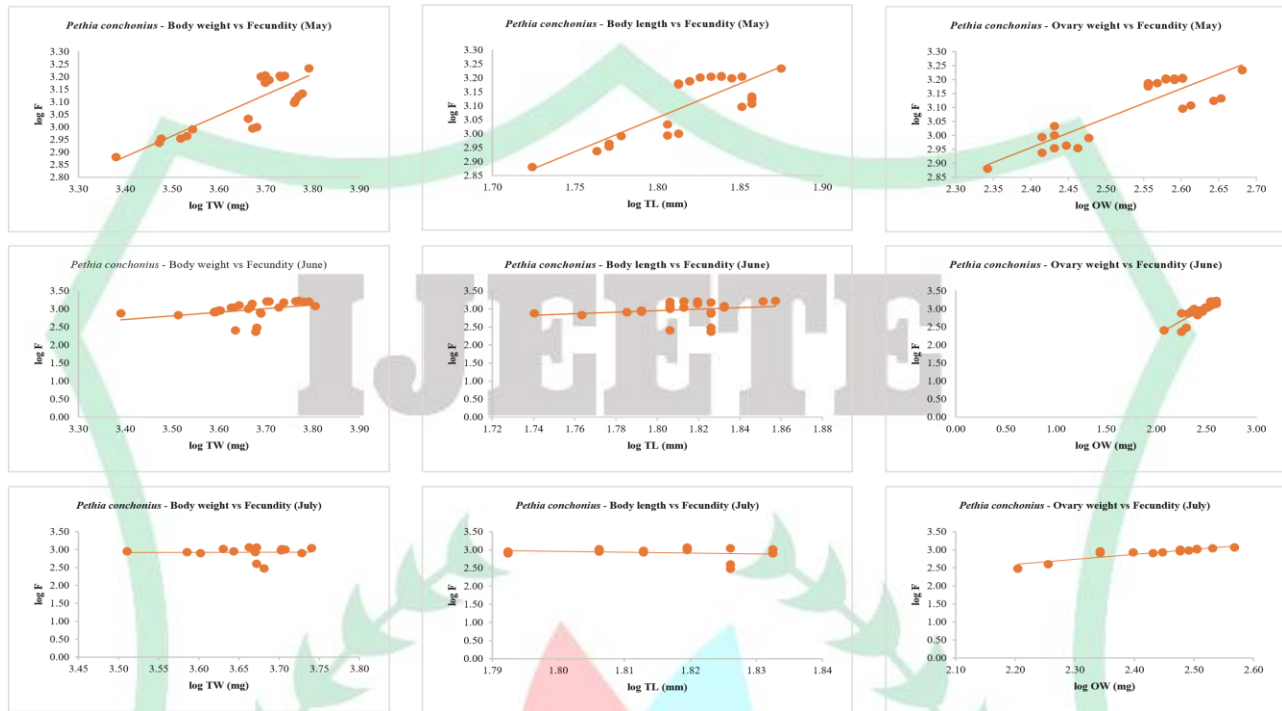


Figure 4.3.A: Correlation between fecundity (absolute) and various body parameters (*Pethia conchonius*)

Table 4.6: Regression and correlation analysis of fecundity (absolute) with different body parameters of *Crossocheilus diplochilus*

Correlation	<i>Crossocheilus diplochilus</i>					
	February	March	April	May	June	July
log TW vs log F equation (r)	$y = 0.8918x - 0.3212$ (0.86)	$y = 0.0203x + 3.4173$ (0.39)	$y = 0.0188x + 3.3725$ (0.06)	$y = 1.1104x - 0.9564$ (0.86)	$y = 0.9973x - 0.5906$ (0.85)	$y = 0.8027x + 0.0029$ (0.91)
log TL vs log F equation (r)	$y = 2.2483x - 1.3276$ (0.71)	$y = 0.6843x + 2.123$ (0.15)	$y = 0.3998x + 2.6406$ (0.11)	$y = 3.5152x - 0.0824$ (0.85)	$y = 2.7954x - 2.2356$ (0.82)	$y = 2.409x - 1.6526$ (0.91)
log OW vs log F equation (r)	$y = 0.568x + 1.7917$ (0.98)	$y = 0.6171x + 1.8868$ (0.94)	$y = 0.3596x + 2.5552$ (0.72)	$y = 0.9282x + 0.6357$ (0.94)	$y = 0.8708x + 0.7558$ (0.97)	$y = 1.2982x - 0.3681$ (0.94)

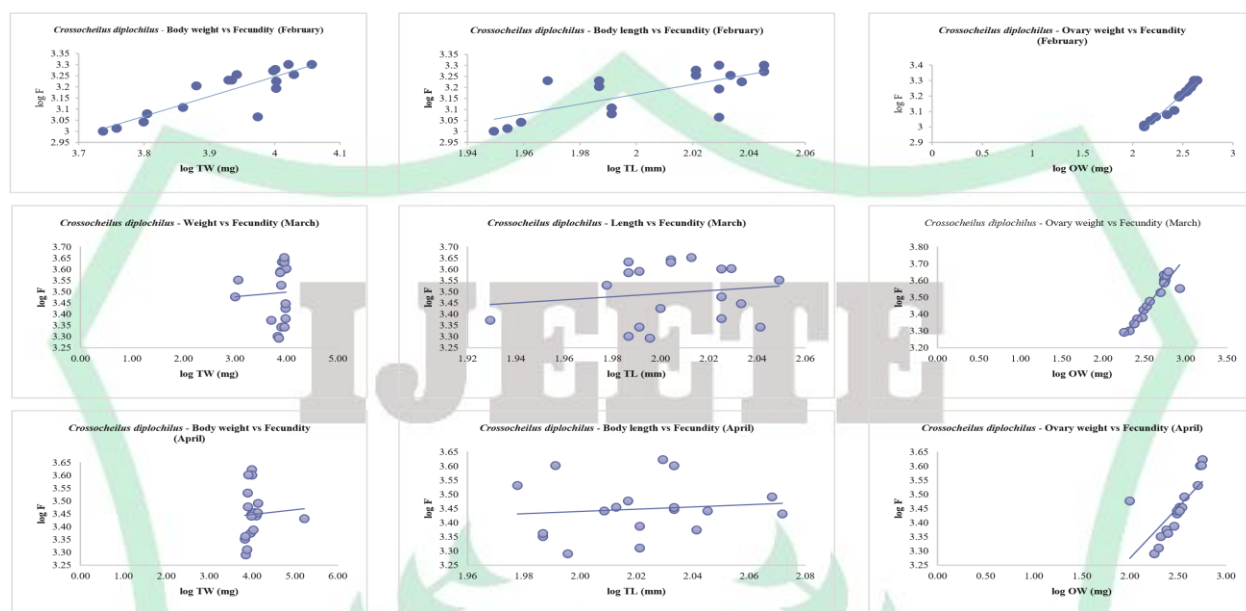


Figure 4.4: Correlation between fecundity (absolute) and various body parameters (*Crossocheilus diplocheilus*) contd.

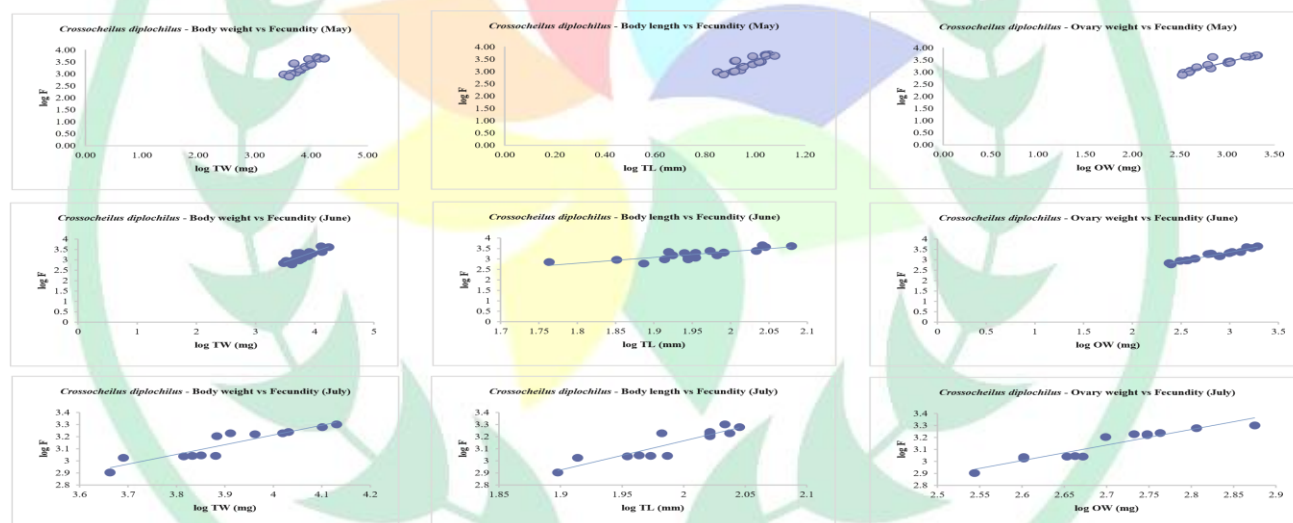


Figure 4.4.A: Correlation between fecundity (absolute) and various body parameters (*Crossocheilus diplocheilus*)

4.5 Ova diameter

The eggs were visible and conspicuous only from February to July in both the fishes, constituting the developing and the spawning capable phase of these fishes, as such the ova diameter was recorded for these months only. In case of *Pethia conchoni* the smallest and the largest ova diameter were reported to be 210.05 μm (May) and 830.14 μm (July) respectively. In case of *Crossocheilus diplocheilus* the smallest and the largest ova diameter were reported to be 200.12 μm (February) and 1025.5 μm (May) respectively. In case of *Pethia conchoni*, the ova diameter increased

from February ($368.10 \pm 151.32 \mu\text{m}$) and attained a peak in July ($614.28 \pm 137.77 \mu\text{m}$) whereas in case of *Crossocheilus diplochilus* the ova diameter increased from February ($320.11 \pm 163.68 \mu\text{m}$) and attained a peak in June ($724.70 \pm 198.51 \mu\text{m}$) and showed a decline towards July ($551.35 \pm 216.27 \mu\text{m}$). The variation in ova diameter for *Pethia conchonius* and *Crossocheilus diplochilus* is depicted in Table 4.7 and graphically presented in Figure 4.5 and 4.6 respectively.

Table 4.7: Monthly variation in the ova diameter of *Pethia conchonius* and *Crossocheilus diplochilus* from Dal Lake

Fish	Ova diameter (Average $\pm$ SD) μm						Minimum	Maximum
	February	March	April	May	June	July	ova diameter (μm)	ova diameter (μm)
P. conchonius	368.10 ± 151.32	527.13 ± 208.30	531.02 ± 198.42	543.73 ± 177.92	488.81 ± 158.58	614.28 ± 137.77	210.05	830.14
C. diplochilus	320.11 ± 163.68	524.69 ± 167.29	556.66 ± 159.89	706.04 ± 255.76	724.70 ± 198.51	551.35 ± 216.27	200.12	1025.5

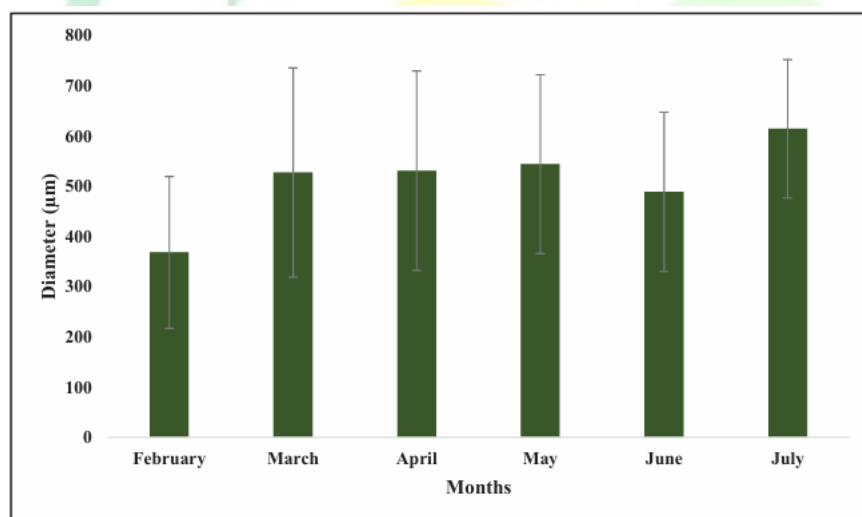


Figure 4.5: Monthly variation (average $\pm$ SD) in ova diameter of *Pethia conchonius*

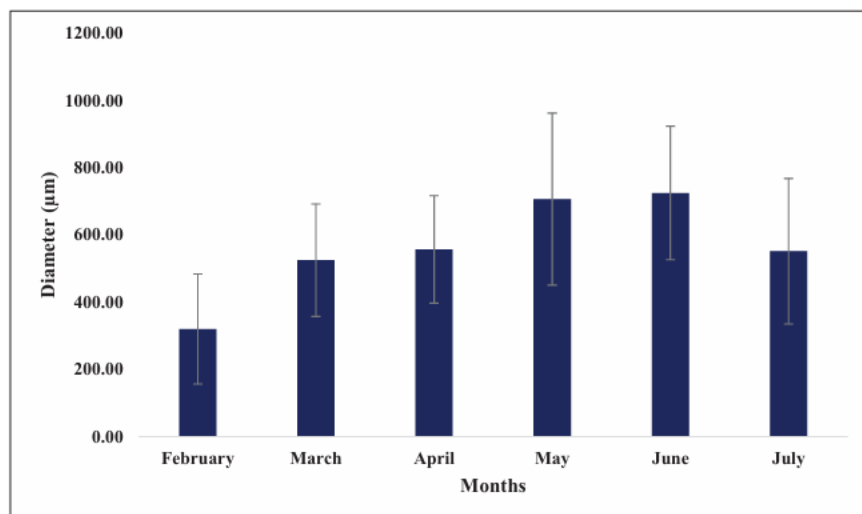


Figure 4.6: Monthly variation (average±SD) in ova diameter of *Crossocheilus diplocheilus*

The ovaries of the developing and spawning capable phase were assessed for the ova diameter frequency, wherein it was observed that in developing phase the small sized eggs (200 – 399 μm) were most abundant in the ovaries of both fishes. During the spawning capable phase, the medium (400 – 599 μm) and large sized (600 μm and above) were found to be most abundant. The frequency distribution of ova diameter during developing and spawning capable phase in *Pethia conchonius* and *Crossocheilus diplocheilus* is depicted in Figure 4.7. The pictorial representation of different types of ova of *Pethia conchonius* and *Crossocheilus diplocheilus* are presented in Figure 4.8 and 4.9 respectively.

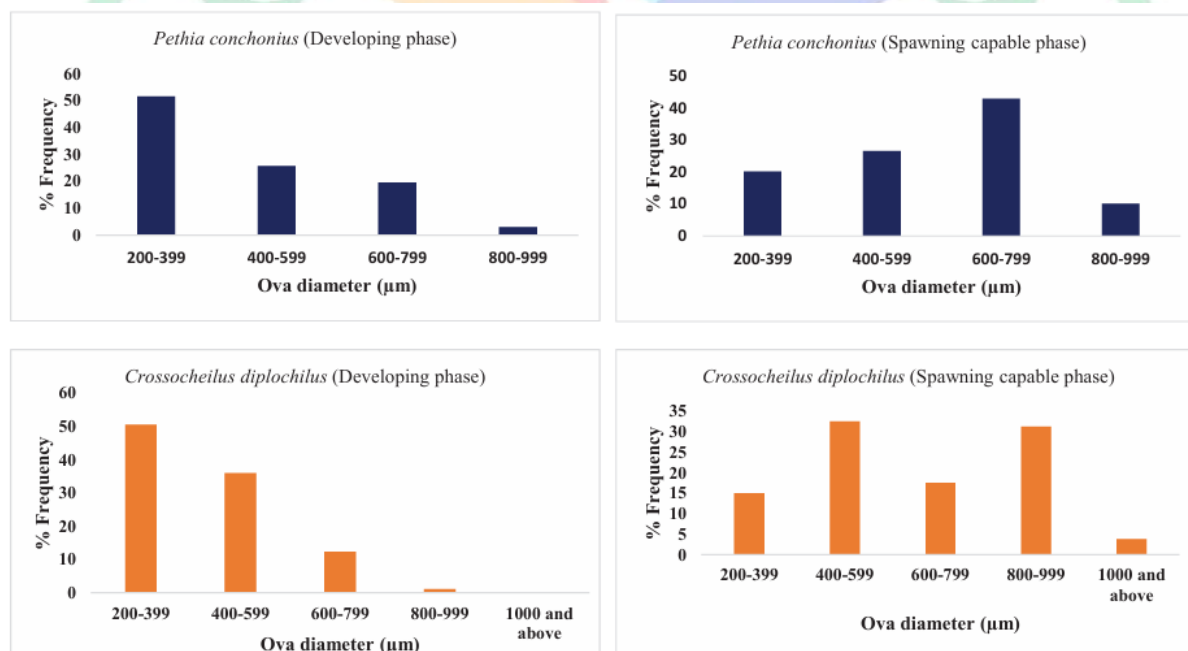


Figure 4.7: Frequency distribution of ova diameter during developing and spawning capable phase in *Pethia conchonius* and *Crossocheilus diplocheilus*

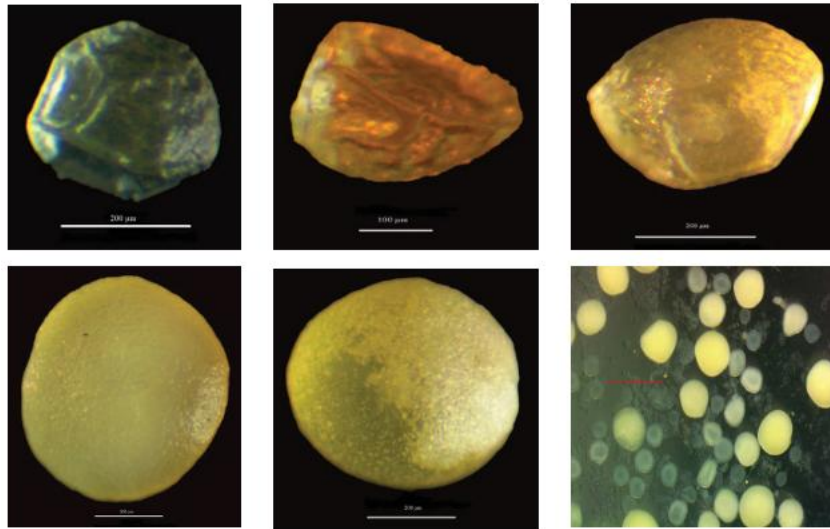


Figure 4.8: Pictorial representation of different types of ova in *Pethia conchoni*

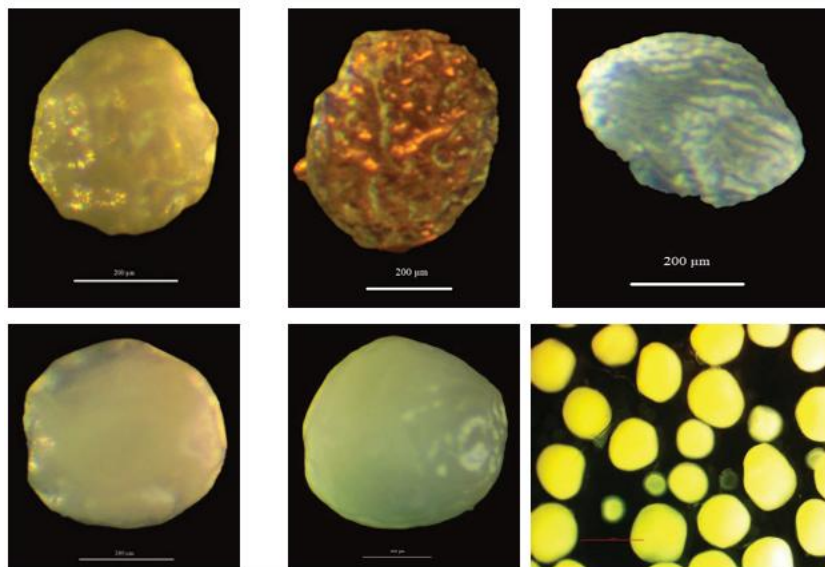


Figure 4.9: Pictorial representation of different types of ova in *Crossocheilus diplochilus*

4.6 Length at first maturity

The frequency of occurrence of adult specimens was plotted against length class and fitted to a logistic function to determine the mean fish length at first sexual maturity (Lm). In case of *Pethia conchoni* the length at first sexual maturity was reported to be 6.0 cm for males and 6.2 cm for females whereas it was reported to be 8.8 cm for males and 9.2 cm for females in *Crossocheilus diplochilus*. The graphs depicting the length at first sexual maturity in *Pethia conchoni* and *Crossocheilus diplochilus* are presented in Figure 4.10.

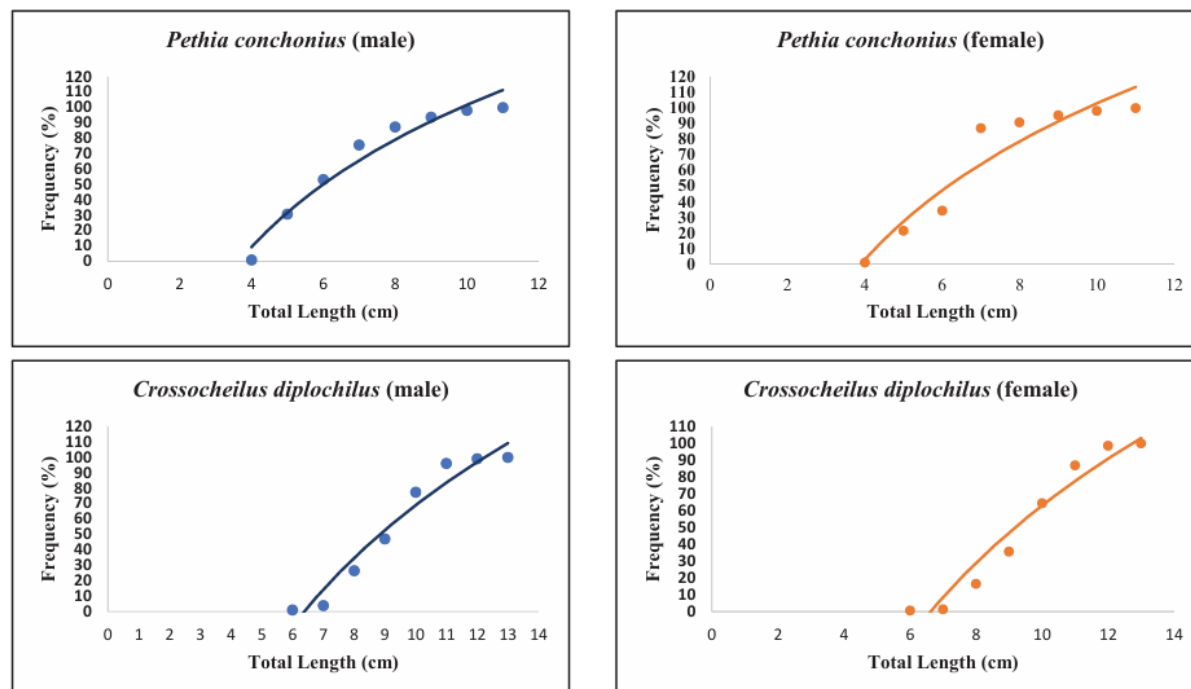


Figure 4.10: Graphs showing length at first maturity in males and females of *Pethia conchonius* and *Crossocheilus diplochilus*

5. Discussion

The reproductive biology as well as population of *Pethia conchonius* and *Crossocheilus diplochilus* in the Dal Lake have been a relief of providing the ecological status of the species in response to both the environmental and the anthropogenic pressure. This paper is consistent with the research by other scholars, which identify high value of water quality, reproductive variables, and population measures in health and sustainability of freshwater fish populations.

The gonadosomatic index (GSI) data were indicative of different seasonal trends in the reproductive activity of both the *Pethia conchonius* and *Crossocheilus diplochilus*. The maximum GSI was found in both species in the month of May when the reproductive period was at the peak. The given observation agrees with other related studies on freshwater, including Kyritsi and Kokkinakis (2020) who similarly reported a significant rise in the GSI during the breeding season in the roach (*Rutilus rutilus*) in Volvi Lake, Greece. The values of GSI, of *Pethia conchonius* were greater than *Crossocheilus diplochilus*, and they could be connected with the reproductive opportunities and environmental adoptions of organisms. Such differences indicate that species require species-specific management techniques especially species such as *Pethia conchonius* which might have a higher reproductive activity than *Crossocheilus diplochilus*. The large peaks recorded in May of both species in keeping with that of Boucher (2018) of *Dissostichus eleginoides*, indicates that environmental conditions, i.e. temperature and nutrient supply, are important in the initiation of reproductive cycles. Sex ratio analysis demonstrated that there were some deviations in the one to one sex ratio, with *Pethia conchonius* had a slight but female bias sex ratio (1:1.22) and *Crossocheilus diplochilus* having a stronger female bias sex ratio (1: 0.7). These are also in line with the study conducted by Lateef et al. (2021) who also reported on such skewed sex ratios of freshwater species in the Kashmir region. In the case of *Crossocheilus diplochilus*, the deviation was statistically significant ($p < 0.05$), indicating that there is a possibility of a pinching on one of the sexes, e.g. due to selective fishing or environmental pressures. Conversely, the non significant deviation of *Pethia conchonius* ($p > 0.05$) is evidence that the sex ratio is more balanced which can be explained by

the adaptability of the species or a less disturbed habitat in Dal Lake. The results are obtained in line with the study by Andrabi et al. (2022), who emphasized the potential of the environmental stressors, including pollution and habitat destruction, that predisposes the skewed sex ratios among freshwater fish populations, influences the stability of the entire population.

The fecundity data of the two species point to seasonal variations with the highest absolute and relative fecundity of *Pethia conchonius* in May and *Crossocheilus diplochilus* in March. Such seasonal changes agree with the report by Arafat and Bakhtiyar (2018) who reported the same pattern of *Schizothorax labiatus* in the Vishav Stream in South Kashmir. It is possible that the greater fecundity of *Crossocheilus diplochilus* than that of *Pethia conchonius* be a consequence of the larger size, since the correlation between body weight and fecundity represents it (Kyritsi & Kokkinakis, 2020). The fecundity of *Crossocheilus diplochilus* was found absolute, and therefore high in comparison with *Pethia conchonius*, and this result is similar to what Raymond et al. (2019) proposed in their prey-predator interaction model as a larger fish turned out to be relatively more fruitful. Moreover, the close relationship between the ovary weight and fecundity in both of the species proves the assumption according to which the development of reproductive success is directly related to the general health and size of fish, a conclusion confirmed by Boucher (2018) in his research on fish reproduction. Ovarian difference of diameter each month further gave information about the reproductive cycle of *Pethia conchonius* and *Crossocheilus diplochilus*. The two species also exhibited an evident growth in the ova diameter between February and July, which associated with the findings by Souza et al. (2019) comparing the Brazilian river basin reservoirs, where the egg maturation was correlated with the seasonal environmental factors. The ovarian diameter of *Pethia conchonius* and *Crossocheilus diplochilus* were highest in July and June respectively. The shift in the reproductive cycle could also be the cause of the identified ovarian diameter reduction of *Crossocheilus diplochilus* by July, and it may be linked to the environmental parameters, including the temperatures or bylideness of water, which may influence the development of the spawning (Lopes et al., 2020). The dispersion rate of the ovarian diameter was also found to utilise small ova (200-399 μ) during the developing stage and the big ova (600 μ and above) during the spawning-capability stage had the final frequency. This would be a similar tendency that was represented by the Fedor and Zvarikova (2019) who have identified the same trends of the species that inhabit the fresh water, and this is an indicator that the size of eggs could potentially be a very good indicator of reproduction and maturity.

The length at first sexual maturity (Lm) was established in the two species; *Pethia conchonius* (6.0 cm in males and 6.2 cm in females) and *Crossocheilus diplochilus* (8.8 cm in males, and 9.2 cm in females). Its results are consistent with the results of Yousuf et al. (2023) and Kyritsi and Kokkinakis (2020) and other authors that smaller fish species were more prone to grow to smaller sizes. The ecological adaptation of the two species in the Dal Lake could have been the reason behind the difference in Lm of the two species. The maturation history (maturing earlier) in the *Pethia conchonius* might be an evolutionary adaptive behaviour of achieving the greatest reproductive success in a habitat that might be changing and the greater size of the *Pethia conchonius* at maturity might be a product of the greater size, which also takes a long time to become mature.

6. Conclusion

Pethia conchonius and *Crossocheilus diplochilus* reproductive and population dynamics depends on the intricate interaction between environmental aspects such as water quality, habitat conditions as well as seasonal factors in Dal Lake. The results of this study backed up by literature in the past tend to support the significance of the surveillance of important reproductive parameters, which include GSI, fecundity, sex ratio, and the ova diameter, to determine the health and sustainability of fish stocks. The seasonal changes and trends in the reproductive patterns observed give very crucial information, which can then be used to develop conservation strategies that would conserve the biodiversity of Dal Lake. The paper also emphasizes the necessity of further investigation into the consequences of environmental stressors on freshwater environments, including pollution and climate change, and fish species living in those ecosystems.

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