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Original Article

Stock assessment of *Crossocheilus diplochilus* (Heckel, 1838) in Dal Lake of Kashmir Himalayas

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Abstract
The intricate dynamics governing population parameters stand as pivotal pillars in the realm of fish management and conservation. Accordingly, the various parameters of population dynamics of *Crossocheilus diplochilus* (Heckel, 1838) from the Dal Lake of Kashmir valley were investigated. The study reported that the fish exhibits a length range of 5.4 to 14.8 cm and a weight range of 1.24 to 17.19 g. The *b* value was reported to be 2.9 depicting negative allometric growth. The Fulton and relative condition factors were reported to be 0.86 and 0.99 respectively. The growth constant, asymptotic length, age at zero length and growth performance index were reported to be 0.33 year^{-1}, 17.40 cm, –0.62 years and 2.0 respectively. Fishing mortality was found to be higher than the natural mortality. The exploitation ratio was reported to be 0.52 which was found to be lower than the exploitation rate producing maximum yield (0.81). This is suggestive of an underexploited state of fishery of *C. diplochilus* from this lake.

Keywords: condition factor; FiSAT-II; forage fish; length-weight relationship

1 | INTRODUCTION

The studies on population dynamics (growth, recruitment and mortality) and population demographics (age structure) are quite imperative from a management point of view, indicating the exploitation intensity of various stocks and enabling decision-makers to sustainably manage fish stocks (Allen and Hightower 2010; Kumari *et al.* 2018). The management of stocks depends particularly on the assessment of the dynamics of a fish stock, growth, recruitment and mortality (Sissenwine *et al.* 1979; Vivekanandan 2005). The growth of fish plays a key role in shaping population dynamics, and understanding these growth patterns is essential for analyzing changes in fish populations over time. Accurately determining the growth of fish populations is vital for effective fisheries management and evaluation (Zhan 2005; Yousuf *et al.* 2025). Length-weight relationships are crucial tools for fisheries biologists to assess the health and reproductive potential of fish populations (Le Cren 1951; Bhakta *et al.* 2023). Moreover, estimating growth parameters like the growth coefficient (*K*) and asymptotic size (L_∞) allows for comparisons of growth rates between species in various environments, helping to evaluate recruitment and exploitation rates of fish stocks (Isaac 1990). Fish stocks decline when the gains from spawning, individual growth and recruitment outweigh the losses from natural and fishing mortality (Tesfaye and Wolff 2015; Hixon *et al.* 2016).

Crossocheilus diplochilus is a freshwater benthopelagic fish belonging to the order Cypriniformes, commonly known as Kashmir latia and locally known as tethur in Kashmir, India. Although primarily a lotic species, the fish prefers river banks and lakes and rarely moves to cold-water tributaries (Froese and Pauly 2024). The fish has a colour gradient along its body with dark olive colouration on the upper side and creamy white colouration towards the ventral side separated by a prominent lateral line, with the entire body possessing a golden sheen. The fish is native to the Kashmir valley and is deemed as a vital bait fish. Moreover, owing to its colour gradient and golden sheen, the fish has a potential for the ornamental industry too. Biometric studies on *C. diplochilus* are quite paltry and mainly pertain to the analysis of LWRs and condition factor (e.g. Sharma *et al.* 2014; Mushtaq *et al.* 2016; Sidiq *et al.* 2021; Bhat *et al.* 2022; Yousuf *et al.* 2023). Under this backdrop, the current study made use of length frequency data to determine the various population parameters of *C. diplochilus*.

2 | METHODOLOGY

2.1 Study area

Dal Lake (34°04′ – 34°11′N, 74°48′ – 74°53′E), situated in the Kashmir Valley of the Northwestern Himalayas is the second largest lake in the Kashmir valley, known for its ecological diversity and socio-economic importance. Spanning an area of about 25 square km, with a water surface area of roughly 10.5 square km and a storage capacity of 15.45×10^6 cubic meters, the lake is an integral feature of the region's landscape (Solim and Wanganeo 2007). The lake harbours many fish species, particularly *Cyprinus carpio communis*, *C. carpio specularis*, *Schizothorax* spp., *Carassius carassius*, *Crossocheilus diplochilus*, *Pethia conchonius* and *Gambusia holbrooki* (Bhat *et al.* 2022). Unfortunately, the lake has been a prey of human stoicism, as evident from its ecology and hydrology (Ganaie and Hashia 2020), shrinking in the area from a hideous 75 square km (in 1200 AD) to a mere 10.5 square km (Rashid *et al.* 2017). The ecological changes taking place in Dal Lake as a result of various anthropogenic interferences (Trisal 1987; Khan *et al.* 2012) coupled with the intensive extraction of fish have impacted the population dynamics of various fish species. This mandates the monitoring of the population of these fish species to ascertain the factors influencing their population and prevent their overexploitation.

2.2 Sampling design

During the present study, a total of 956 fish specimens were collected using local fishermen. A monthly sampling routine was followed wherein fish samples were collected from five distinct locations within the lake (Figure 1) from October 2021 to September 2023, using cast nets (locally, Guran Zaal; mesh size: 10 mm). The specimens were sorted following the keys of Kullander *et al.* (1999) and bought to the laboratory for biometric analysis. The total weight of the fish was measured with a 0.01 g accuracy (using Sartorius GM 312) and the total length was measured to the nearest 0.1 cm (using Vernier caliper, Aero Space, China).

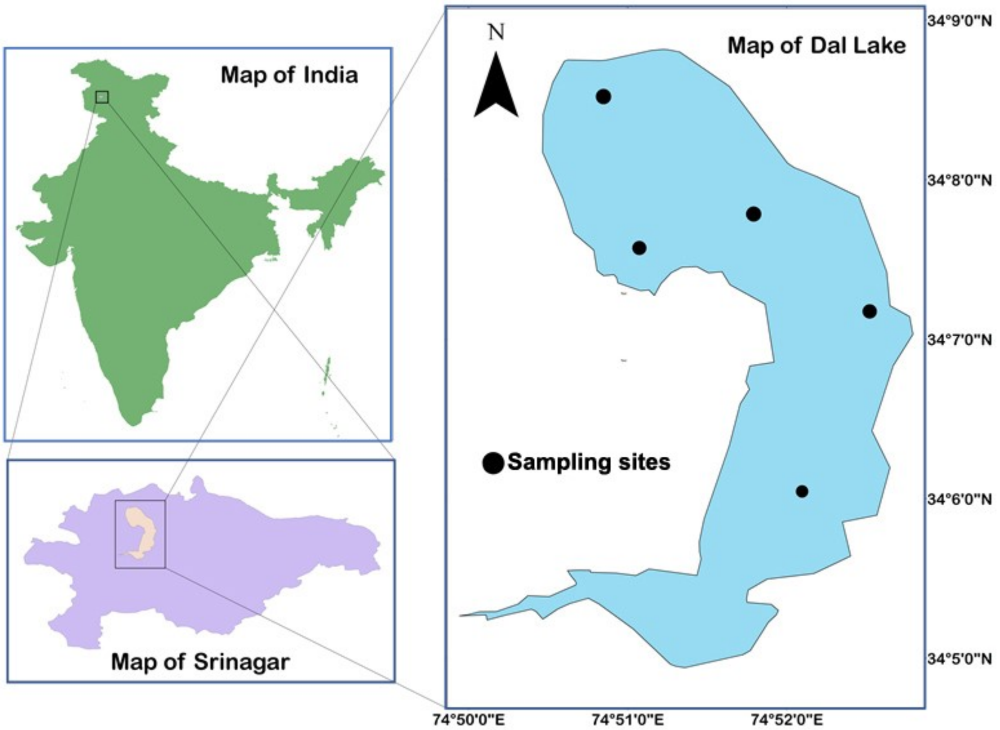

FIGURE 1 Sampling sites in Dal Lake, Kashmir, India.

2.3 Length-weight relationship (LWR)

The length-weight relationship of *C. diplochilus* was calculated using the equation given below (Le Cren 1951).

$W = aL^b$

where, fish weight (g) is represented by W, total length (cm) is represented by L, *a* and *b* represent the intercept and slope respectively.

2.4 Condition factor

The Fulton condition factor (K_f) was estimated to evaluate the health of the fish within the lake, with the difference in the condition factor being indicative of histological events like gonadal development, fat reservation and environmental adaptation (Le Cren 1951). According to Fulton (1904) the condition factor was calculated using the equation given below:

$K_f = (W \times 100) / L^3$

where, fish weight (g) is represented by W, total length (cm) is represented by L.

The relative condition factor (K_n) is the ratio of observed weight to that of calculated weight ($W_c = aL^b$) and is provided below (Le Cren 1951):

$K_n = W / aL^b$

2.5 Growth parameters

The various growth parameters like asymptotic length (L_∞), age at zero length (t_0) and growth coefficient (K) of von Bertalanffy growth function (VBGF) (von Bertalanffy 1960) were determined using the equation given below (ELEFAN-I module of FiSAT-II) (Gayanilo *et al.* 2005):

$L_t = L_\infty [1 - e^{-K(t-to)}]$

The asymptotic length represents the maximum theoretical length that an individual within a fish population can attain. The growth coefficient indicates the rate at which a fish reaches its maximal length. Age at zero length (t_0) is the age (theoretical) at which the fish length is assumed to be zero, if the growth pattern confirms to the VBGF, was calculated using equation given below (Pauly 1979):

$\log(-t_0) = -0.392 - 0.275 \log L_\infty - 1.038 \log K$

The growth performance index (Ø) has been reported to be remarkably constant between various populations of a species and is calculated using the equation developed by Pauly and Munro (1984), given below:

$Ø = \log K + 2 \log L_\infty$

2.6 Mortality and exploitation

The formula given below (Pauly 1980) was used to determine the natural (M) mortality:

$\log M = -0.0152 - 0.279 \log L_\infty + 0.6543 \log K + 0.463 \log T$

where K is expressed in per year, T indicates the mean annual ambient temperature (°C) and L_∞ is expressed in cm.

The length-converted catch curve was utilized to determine the total mortality coefficient (Z) (Pauly 1983). The difference between total and natural mortality gives us fishing mortality (F). The exploitation ratio was determined using the equation given below:

$E = F / Z$ (Beverton and Holt 1993)

2.7 Recruitment, virtual population and Beverton and Holt analysis

Using L_∞, t_0 and K as inputs, the plot showing the monthly recruitment pattern was also constructed (Dadzie *et al.* 2007). Length-structured virtual population analysis, using the input of natural mortality, fishing mortality, L_∞, K and growth coefficients (*a* and *b*) of the LWR equation was also carried out (Gayanilo *et al.* 2005). Besides the Beverton and Holt analysis module was also utilized to plot yield and biomass per recruit (Y/R and B/R) against the exploitation rate, using FiSAT II (knife edge function) (Beverton and Holt 1966; Pauly and Soriano 1986).

3 | RESULTS

3.1 Length-weight relationship and condition factor

The fish length ranged from 5.4 cm to 14.8 cm, and the total weight ranged from 1.24 g to 17.19 g. The overall mean total length and total weight were reported to be 9.15 cm and 7.04 g, respectively. The majority of the fish specimens belonged to the length range of 7.2 to 11.6 cm. The LWR equation revealed the value of *a* and *b* to be 0.0108 and 2.9 respectively (Figure 2). The average value of the Fulton condition factor and relative condition factor was reported to be 0.86 and 0.99 respectively.

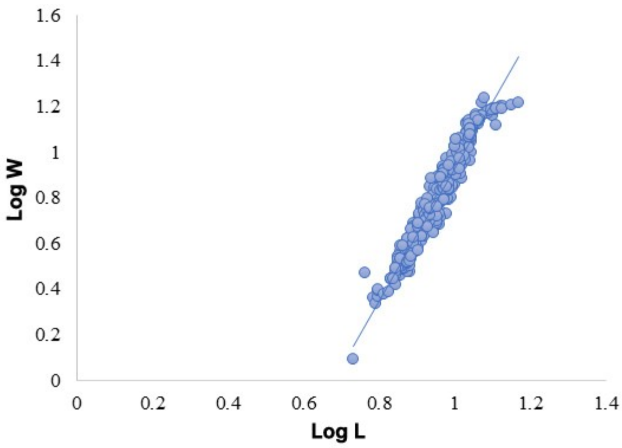

FIGURE 2 Scatter diagram depicting length-weight relationship of *Crossocheilus diplochilus*.

3.2 Growth parameters

The growth coefficient (K) was found to be 0.33 year^{-1} and the asymptotic length (L_∞) was found to be 17.40 cm. The length–frequency histograms are presented in Figure 3. The index of growth performance of the fish was reported to be 2.0 and the age at zero length (t_0) was found to be –0.62 years.

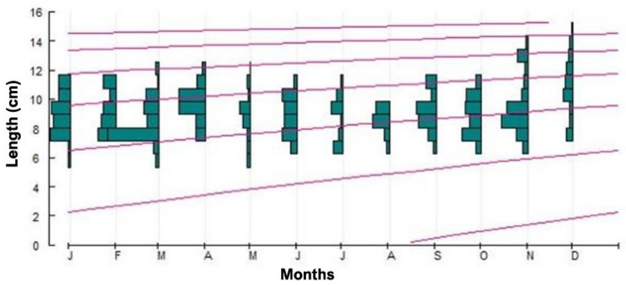

FIGURE 3 VBGF plot of *Crossocheilus diplochilus* from Dal Lake.

3.3 Mortality and rate of exploitation

The total mortality of the fish was found to be 1.66 year^{-1}, with the natural mortality being 0.80 year^{-1} and the fishing mortality being 0.86 year^{-1}. The exploitation ratio was found to be 0.52. The length-converted catch curve of *C. diplochilus* is presented in Figure 4.

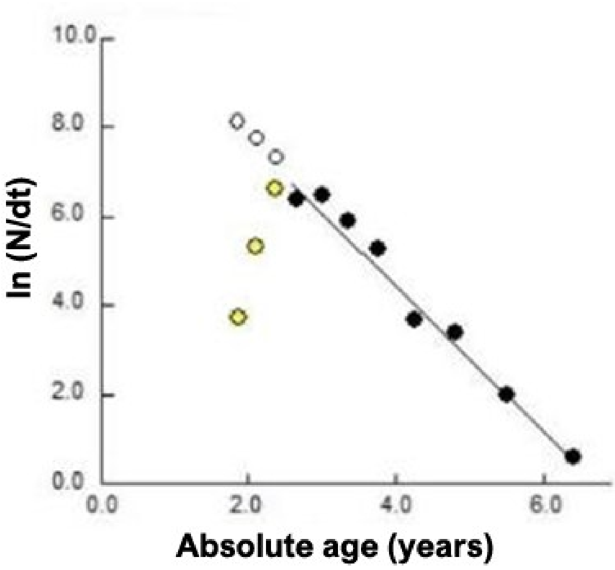

FIGURE 4 Length-converted catch curve of *Crossocheilus diplochilus* from Dal Lake.

3.4 Recruitment, virtual population and Beverton and Holt analysis

Crossocheilus diplochilus has a continuous recruitment pattern with peaks obtained in January, June and July, contributing 54.37% to the total recruitment (Figure 5). The fishing mortality escalated beyond the length of 8 cm as revealed by virtual population analysis (VPA) (Figure 6). The Beverton and Holt (yield per recruit) plot estimated the economic yield (exploitation rate at which the marginal increase in relative yield per recruit is 10%) ($E_{0.1}$) to be 0.66, the optimum sustainable yield (the exploitation rate corresponding to 50% of the unexploited relative biomass per recruit) ($E_{0.5}$) to be 0.36 and the exploitation rate producing maximum yield (E_{max}) of 0.81 (Figure 7). The (L_c) length at first capture was reported to be 8.23 cm. The population parameters of *C. diplochilus* are depicted in Figure 8.

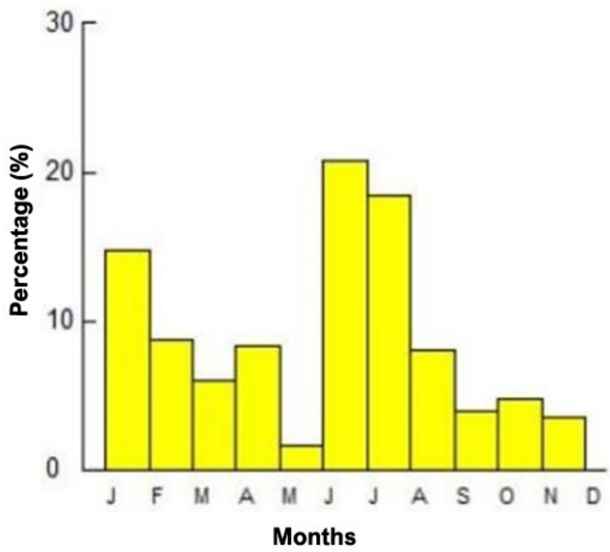

FIGURE 5 Recruitment pattern of *Crossocheilus diplochilus* from Dal Lake.

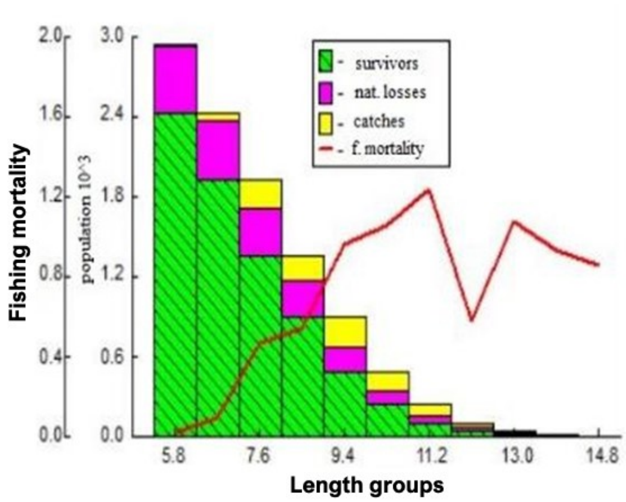

FIGURE 6 Virtual population analysis of *Crossocheilus diplochilus* from Dal Lake.

4 | DISCUSSION

To manage a fish population sustainably, knowledge on the various aspects of population dynamics, especially growth patterns is imperative. The current study utilizes the length frequency data to provide inferences on the growth, recruitment, mortality and exploitation of *C. diplochilus* from Dal Lake.

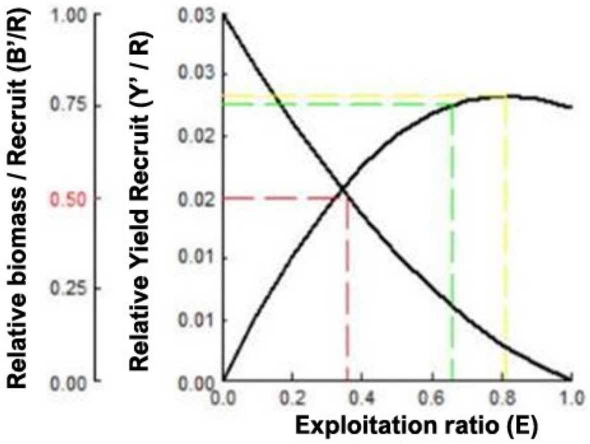

FIGURE 7 Relative yield per recruit and relative biomass per recruit of *Crossocheilus diplochilus* from Dal Lake.

4.1 Length-weight relationship and condition factor

Length-weight relationships (LWRs) are quite vital bioecological tools of fish biology in terms of yielding information about comparative body growth patterns in fishes, estimating biomass, general condition and changes in life history as well as deciphering the trend followed by a fish population during various developmental stages (Le Cren 1951; Arafat and Bakhtiyar 2022). LWRs form the basic data set utilized by multiple fishery stock assessment models (Froese 2006). Fishes are quite sensitive to environmental variations and show pronounced morphological alterations (impact on LWR) in response to changes in various parameters, especially temperature, food availability, habitat, sex, seasonality, diet etc. (Allendorf and Phelps 1980; Sharma *et al.* 2015). During the current study, the total length of *C. diplochilus* ranged from 5.4 cm to 14.8 cm, and the total weight ranged from 1.24 g to 17.19 g. The current range of length and weight is less than what was previously reported by Sharma *et al.* (2014) and Mushtaq *et al.* (2016) but higher than the one reported by Bhat *et al.* (2022).

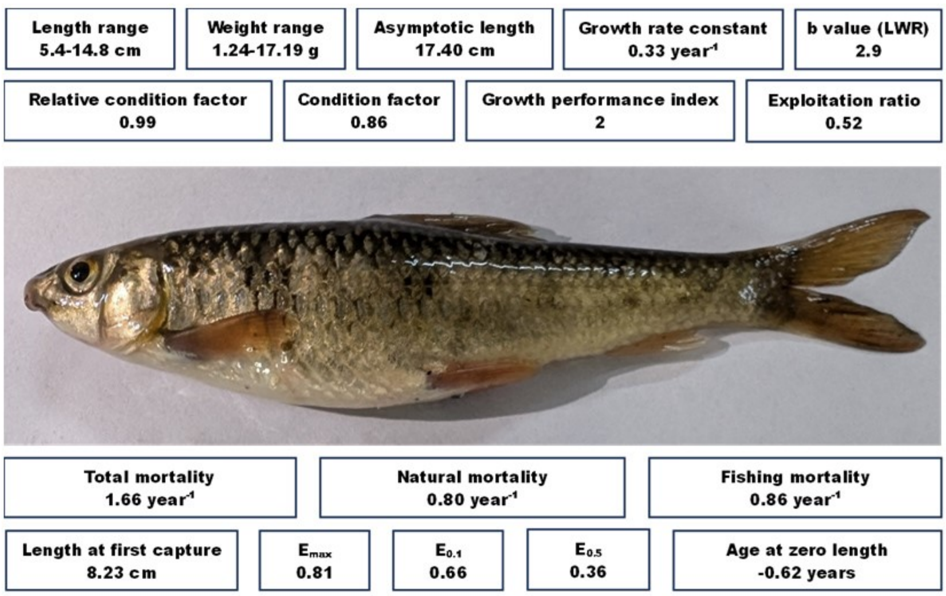

FIGURE 8 Population parameters of *Crossocheilus diplochilus* of Dal Lake.

Sharma *et al.* (2014) reported *C. diplochilus* from the Poonch River with a total length range of 10 cm to 17 cm and body weight range of 12.16 g to 41.22 g. Sidiq *et al.* (2021) reported the size range of *C. diplochilus* from Dal Lake to be 6.9 cm to 13 cm and a body weight range of 3.2 g to 24.0 g whereas, Mushtaq *et al.* (2016) reported a length of 9 cm to 15 cm and a weight of 9.9 g to 39.2 g. Bhat *et al.* (2022) reported the total length range of *C. diplochilus* from Dal Lake to be 7 cm to 12 cm and a weight of 3.3 g to 16.1 g. Yousuf *et al.* (2023) reported length of 9.56 ± 0.22 cm and weight of 10.69 ± 0.64 g for *C. diplochilus* of Manasbal Lake. The variations in the results of the current study and those of the other researchers are primarily due to variations in the water quality, mesh size utilized and the number of sampled specimens.

The LWR parameters (a and b) were calculated by log transformation (log W = log a = b log L) of the LWR equation followed by linear regression, with a and b representing the intercept and slope of the curve respectively. The value of b gives us an idea of the growth pattern of a fish with the ideal value of b = 3, indicating isometric growth whereas the values of b less than or greater than 3 indicates negative and positive allometric growth respectively (Jisr *et al.* 2018). The fish become slimmer with increasing length (negative allometric growth) whereas the fish become heavier with increasing length (positive allometric growth) (Jisr *et al.* 2018). The various factors that impact the b value in fishes are: fish behaviour (active or passive swimmers), variation in environmental variables, gonadal development and physiological growth conditions (Simon *et al.* 2010; Al Nahdi *et al.* 2016). In the current study, the growth coefficient (*b*) was reported to be 2.9, indicating negative allometric growth, reflecting that as the length increases, the fish becomes slender. Various researchers (e.g. Sidiq *et al.* 2021; Bhat *et al.* 2022; Yousuf *et al.* 2023) have also reported negative allometric growth in *C. diplochilus* from different water bodies of Jammu and Kashmir.

In the case of fishes, the condition factor reflects the fitness and well-being and helps in understanding their life cycle thereby contributing to their management (Kumolu-Johnson and Ndimele 2010). It acts as a useful index to monitor the growth rate and feeding intensity of the fish (Anene 2005). The biotic and abiotic factors have a strong influence on this parameter, thus making it a useful index for assessing the status of a water body (Barnham and Baxter 1998). The value of the Fulton condition factor for *C. diplochilus* was reported to be 0.86 for the current study. Bhat *et al.* (2022) reported the condition factor of 1.21 for the *C. diplochilus* of Dal Lake, which is not in conformity with our studies due to the use of a smaller mesh size net in the current study that resulted in a fair proportion of small-sized fish in the catch. Yousuf *et al.* (2023) reported better conditions of fish from Manasbal Lake with an overall condition factor of 1.14, which could be primarily attributed to the better conditions in that lake and the use of a mesh of larger size that eventually resulted in the collection of larger specimens. The drawback of using the Fulton condition factor is that it compares the specimen weight in a length class with the weight of an ideal fish which is growing in accordance to cube law (Le Cren 1951). To overcome this, Le Cren (1951) introduced the relative condition factor. Fishes showing good growth condition show a $K_n \geq 1$ whereas the fishes with a poor growth condition show $K_n < 1$. During the current study the K_n value fluctuated between a minimum of 0.62 and a maximum of 1.68, with an average of 0.99. Such fluctuations in the condition factor could be associated with several factors including the availability of food, water quality and life cycle of the fish (Le Cren 1951).

4.2 Growth parameters

The growth parameters i.e., L_∞, K and t_0 act as fundamental indicators of the population dynamics of a fish species. To set size limits for fishing gears (mesh size) L_∞ tends to be quite useful (Gebremedhin *et al.* 2021). The growth rate constant (von Bertalanffy curvature parameter) computed during the current study is indicative of a moderate growth rate as per Sparre and Venema (1998), who depicted faster growing fish having a $K \geq 1$; moderate growth rate (K = 0.5) and slow growth rate (K = 0.2). The growth parameters are strongly influenced by the catchment of the water body and the climatic conditions of the area (Adeeb *et al.* 2014). Besides growth parameters are also influenced by the size ranges, sampling technique, fishing technique utilized and the data models utilized in the study (Etim *et al.* 1998; Tu *et al.* 2018).

4.3 Mortality and exploitation

The current study revealed the natural mortality was lesser than the fishing mortality. The higher fishing mortality in these fish is attributable to their schooling nature, making them vulnerable to get caught in large groups. Mortality rates may differ within a species inhabiting two different bodies of water due to variability in the fishing activity, growth rate of fish and prey availability (Murugan *et al.* 2014; Rahman *et al.* 2016). The natural mortality of a fish depends directly on the *K* value but inversely on L_∞ (Sparre and Venema 1998). The total mortality (*Z*) is determined using the length converted catch curve, assuming that the particular stock stays in equilibrium, which gets violated when *Z* is underestimated in a declining stock (Hashemi *et al.* 2014). Similar mortality parameters were reported by Yongo *et al.* (2018) and Mutethya *et al.* (2020) in *Lates niloticus* and *Cyprinus carpio* respectively, reporting a higher fishing mortality than natural mortality.

4.4 Recruitment, virtual population and Beverton and Holt analysis

Recruitment infers to the number of individuals that are added to a harvestable stock of fishery, over some time and acts as a vital process to regulate a fish population (Camp *et al.* 2020). *Crossocheilus diplochilus* from Dal Lake shows a continuous process of recruitment, with peaks witnessed in summer months, coinciding with a rise in temperature which leads to higher growth rates. The winter months reported the lowest recruitment due to low ambient temperature (Kindong *et al.* 2018). Higher recruitment in summer months has also been reported by Nissar *et al.* (2024) in *Pethia conchonius* from Dal Lake.

The VPA plots various length groups against fishing mortality, depicting the proportion of losses incurred in a fish stock (due to natural mortality), catches, fishing mortality and proportion of survivors. In the current study, small-sized groups (below the size of 8.0 cm) reported the highest proportion of survivors due to their ability to escape the mesh of the net (Nissar *et al.* 2024). The fishing mortality escalated beyond the length of 8 cm and the catches were highest in the group of 7 cm to 11 cm.

The relative yield-per-recruit and biomass-per-recruit plot estimated the E_{max} of 0.81, $E_{0.1}$ of 0.66 and $E_{0.5}$ with a value of 0.36. The exploitation ratio (*E*) from the current study was 0.52 which is lower than $E_{0.1}$, indicating an underexploited condition of this fish. The M/K value was reported to be within the range suggested by Beverton and Holt (1993), i.e., 1.0 – 2.5. The L_c/L_∞ value was reported to be 0.47, which is less than 0.5, reflective of the presence of juvenile fish in the catch, probably due to the use of smaller mesh net. Similar results have been reported by Nissar *et al.* (2024) in *P. conchonius* from Dal Lake.

5 | CONCLUSIONS

The current study on the population dynamics of *Crossocheilus diplochilus* is the first of its kind that establishes a baseline data on the pattern of its growth, mortality, recruitment and exploitation. The LWR study reflected a negative allometric growth of the fish. The condition factor of the fish indicated slightly poor growth of the fish in the water body, primarily due to excessive pollution of the lake. The fish has a moderate rate of growth, a higher level of fishing mortality but an exploitation ratio lower than $E_{0.1}$. It is an important forage fish of Dal Lake, and plays a vital role as a prey for the aquatic predators (large fish and birds) and in bait fishery. Moreover, the fish has a potential for the ornamental industry due to its golden sheen and colour gradient. The study of various parameters of population dynamics is essential for proper management and to establish the culture of this species.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHORS' CONTRIBUTION

Sinan Nissar: Prepared the main manuscript text, conducted the fieldwork for the collection of fish samples, conducted the lab work, conducted the statistical analysis, reviewed and scrutinized the manuscript. Tabasum Yousuf: Conducted the lab work, reviewed and scrutinized the manuscript. Yahya Bakhtiyar: Research supervision, preparation of manuscript text and data analysis.

DATA AVAILABILITY STATEMENT

The data collected during the current study will be available from the corresponding author on reasonable request.

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