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Length-Weight Relationships and Condition Factor of Five Economically Important Freshwater Fish Species from the Indus Tributary, Suru River, Ladakh Trans-Himalayan Region, India

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ABSTRACT

This study examined the length-weight relationships (LWRs) and condition factor for five economically important freshwater fish species from one of the major Indus Tributary, the Suru river, Kargil Ladakh, namely *Schizothorax richardsonii* (Gray, 1832), *Schizothorax plagiostomus* (Heckel, 1838), *Schizothorax progastus*, *Diptychus maculatus* (Steindachner, 1866), and *Oncorhynchus mykiss* (Walbaum, 1792). In total, 499 specimens of all five fish species were collected using different fishing gears like cast nets. During the current study, *D. maculatus* was the most prevalent fish species whereas *S. richardsonii* comprised the smallest populations. There were significant LWRs in all cases (all $r^2 > 90$). The values of the Fulton condition factor (K) varied from 0.7 to 1.5 while the exponent b values for the studied species ranged from 2.32- 3.16. The b values exhibited both negative and positive allometric growth pattern. *S. plagiostomus* had the largest mean total length value (30.38 ± 3.8cm) while *S. richardsonii* had the smallest mean total length value (17.64 ± 5.5cm). Similarly, *S. richardsonii* also had the lowest mean body weight value (224.90 ± 96.80g). These findings will serve as baseline information for the conservation and management of the above indigenous fish species of Ladakh Trans-Himalayan region which are declining rapidly.

INTRODUCTION

Fish play a critical role in the development of a nation, serving as a major source of essential nutrients, including high-quality protein and lipids (macronutrients), as well as vitamins and minerals (micronutrients), thereby contributing significantly to global food and nutritional security **(FAO, 2020)**. Among agricultural sub-sectors such as forestry and livestock, the fisheries sector has exhibited the fastest growth rate in terms of contribution to gross domestic product (GDP), gaining importance particularly as a substitute for beef. In addition to providing an affordable source of highly nutritious protein for human consumption—even in remote rural areas—fish also supply other vital nutrients necessary for human health **(Maulu *et al.*, 2020; Ahmed *et al.*, 2022)**. Therefore, a deeper understanding of fish biology and ecology is essential for the sustainable management and conservation of fisheries resources.

Like all animals, fish grow in both length and weight throughout their lives. The relationship between these two parameters—the length-weight relationship (LWR)—is

important both practically and scientifically. LWRs are widely used in fisheries biology to provide reliable data on growth patterns and the general health of fish populations, as they vary depending on the environmental conditions of aquatic ecosystems. These relationships are species-specific and can also differ by sex, age, reproductive status, food availability, and geographical location. LWRs are considered essential tools in fish biology and fisheries science because they allow the estimation of a fish's average weight from a given length, through the establishment of a mathematical relationship between the two **(Beyer, 1987; Razeena, 2020)**.

Moreover, LWRs can be used to differentiate small taxonomic units, as population-level variations often occur across different localities **(Le Cren, 1951; Oliva-Paterna *et al.*, 2009; Torres *et al.*, 2012; Azevedo *et al.*, 2018; Mahmoud *et al.*, 2020; Rajathy *et al.*, 2021; Bharti *et al.*, 2023; Zakiya *et al.*, 2024)**. Fisheries researchers make extensive use of LWR parameters ('a' and 'b') to:
(a) transform length-based growth models into weight-based models for stock assessments,
(b) estimate biomass from length data,
(c) evaluate the health or condition of individual fish, and
(d) compare biometric and morphological characteristics across species or populations from different geographic regions or time periods **(Goncalves *et al.*, 1996; Moutopoulos & Stergiou, 2002; Mendes *et al.*, 2004; Torres *et al.*, 2012; Lavergne *et al.*, 2013; Lubich *et al.*, 2021; Dinh *et al.*, 2022)**. These parameters also provide insights into stock composition, longevity, mortality, maturation, reproductive biology, and overall fishery management strategies **(Costa *et al.*, 2014; Jisr *et al.*, 2018; Lubich *et al.*, 2021)**.

The condition factor (K) is another vital biological parameter, offering insight into the health status of individual fish and populations. It plays a key role in conservation and management efforts, as it reflects the fish's ability to survive, grow, and reproduce in its environment **(Sarkar *et al.*, 2009; Ndiaye *et al.*, 2015; Mazumder *et al.*, 2016; Famoofo & Abdul, 2020; Pathak *et al.*, 2022; Chandran *et al.*, 2023)**. As a quantitative indicator, the condition factor is widely used to assess the well-being of fish, based on the assumption that heavier individuals of a given length are in better physiological condition **(Le Cren, 1951; Froese, 2006; Richter, 2007)**. It aids in understanding various biological aspects, such as sexual development, age, food availability, and environmental stress **(Froese & Pauly, 2012)**. The condition factor is also one of the key components in FishBase and supports ecosystem-based fisheries management.

In mountain regions, fishing is a vital source of food and income. Fish contribute significantly to the diets and local economies of hill communities and are key components of aquatic biodiversity. In Ladakh, the fish fauna is dominated by high-altitude species, particularly the snow trout and loaches, which hold both commercial and recreational value. However, catch rates of *Schizothorax richardsonii* (snow trout) have declined significantly in Ladakh compared to other Himalayan regions **(Sivakumar, 2008)**. This decline is attributed to factors such as overfishing, habitat degradation, the introduction of exotic species, and anthropogenic pressures **(Sharma, 1989; Agarwal & Singh, 2009)**, leading to its current classification as a vulnerable species **(IUCN, 2011)**.

In light of this, the present study was undertaken to assess the LWRs and condition factors of five economically important freshwater fish species from the Suru River—a tributary of the Indus River in Kargil, Ladakh. This assessment aims to reveal the growth patterns and overall health of these fish species under current environmental conditions. The Suru River is characterized by a rocky substrate and high- water velocity, factors that influence fish growth and distribution. Despite the availability of global studies on LWRs and condition factors **(Le Cren, 1951; Moutopoulos & Stergiou, 2002; Froese, 2006; Baeck *et al.*, 2012; Mir *et al.*, 2014; Ndiaye *et al.*, 2015; Jisr *et al.*, 2018; Lubich *et al.*, 2020)**, there remains a notable lack of comprehensive data for Himalayan River systems, particularly from the Trans-Himalayan waters of Ladakh. This study aimed to fill that knowledge gap and to provide baseline data critical for the sustainable management and conservation of these valuable freshwater fish species.

MATERIALS AND METHODS

Study area

Ladakh is a union territory in northern India that is divided into two districts: Leh and Kargil. Kargil covers an area of 14036Km^2. Kargil lies between 30 and 35 degrees North latitude and 75 and 77 degrees East West longitude. Kargil is located on the banks of the Suru River and has an average elevation of 2,676 metres (8,780 feet) (Indus). The Suru River is nourished by the Panzella glacier, which is located in the Pensi La region and is roughly 185Km long before entering the Indus River. It is a large perennial Indus tributary that contributes a significant discharge to the Indus River of the Trans-Himalayan Mountains.

Study sites

Suru River flows through Kargil, Ladakh between 33.832917°N and 76.21861°E. For the fish sampling, three different locations were explored (Fig. 1). The upstream (Shafat nallah) site is located at 34°0355 N, 76°1018 E, the middle (farkha sankoo) site is located at 34°1720 N, 75°5754 E, and the downstream (latoo) site is at 34°3521 N, 75°5959 E.

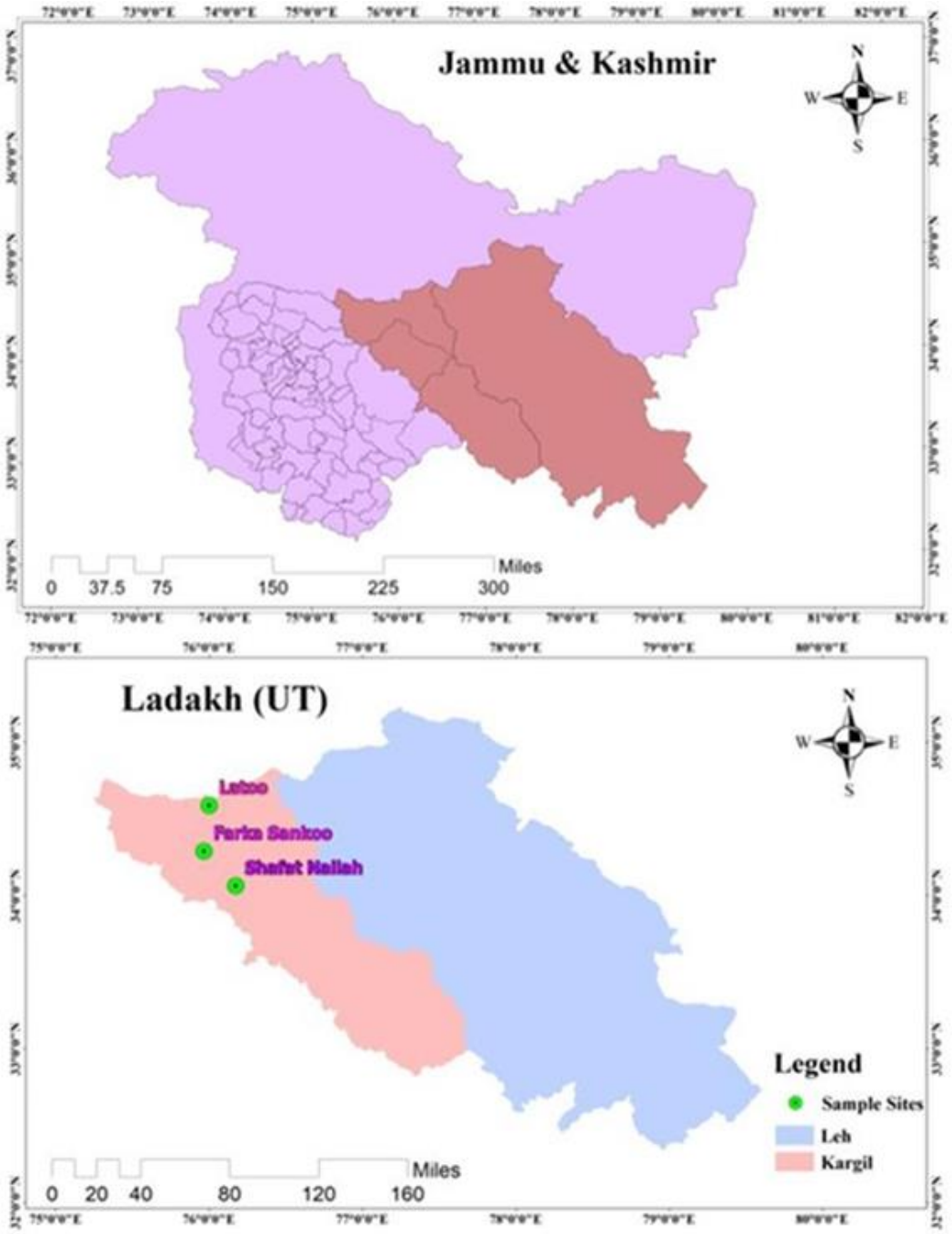

Fig. 1. Map showing collection sites of fish species from Suru River of Kargil, Ladakh Trans Himalayan region

Analysis of LWR and condition factor

A total of three locations along the Suru River, Ladakh, were randomly sampled from April to Oct 2020 using various fishing gear such as cast nets to collect the length weight data of each fish species. Fish were photographed individually and were identified up to species level using standard keys **(Day, 1878; Talwar & Jhingran, 1991; Kullander *et al.*, 1999;**

Jayaram, 1999). A total of 499 specimens of all five fish species were collected, and then surface moisture was removed using tissue paper after cleaning each sample. Each fish was then biometrically measured as follows: Length was ascertained using a digital vernier caliper to the nearest 0.01cm and measured from the tip of snout to the caudal fin end. A digital balance (Shimadzu UX320G) with an accuracy of 0.01g was used to measure the weight.

The relationship between the total weight (W) of the fish (in grams) and its total length (L) (in centimeters) was estimated using the standard length-weight relationship (LWR) equation **(Le Cren, 1951)**:

$$\mathbf{W = aL^b}$$

Where,

W = Total weight of the fish in grams.

L = Total length of the fish in centimeters.

a = Initial growth constant and.

b = Regression co-efficient.

The parameters a and b were calculated using the log-transformed equation:

$$\text{Log (W)} = \log (a) + b \log (L)$$

Where,

a = representing the intercept and

b = indicating the slope of the relationship.

A Student's t-test **(Pauly 1984)** was used to compare the value of b to 3.0 for an isometry test for each species, with a significance level of 95%.

The Fulton's condition factor (K) of fish as expressed by **Bagenal and Tesch (1978)**, was used to quantify the overall well-being of fish, i.e., how healthy they are or how fat they are. In order to estimate them, the following relationship was used:

$$K = 100\ W/L^3$$

Where,

K = condition factor.

W = weight of fish (g)

L = length of fish (cm)

RESULTS

A total of 499 fish specimens were analyzed across three sampling locations, comprising five species: *Schizothorax richardsonii* (42 specimens), *Schizothorax plagiostomus* (127), *Schizothorax progastus* (90), *Diptychus maculatus* (159), and *Oncorhynchus mykiss* (81). Among these, *D. maculatus* was the most abundant species, accounting for the highest number of individuals (159), while *S. richardsonii* was the least represented, with only 42 specimens.

Regarding weight, *O. mykiss* exhibited the highest mean weight (389.60 ± 99.5g), with a weight range between 146.34 and 534.86g. In contrast, *S. richardsonii* had the lowest mean weight (224.90 ± 96.80g), with minimum and maximum weight values of 106.84 g and 388.52g, respectively.

Descriptive statistics and estimated parameters for the length-weight relationships (LWRs) of each species are presented in Table (1). Linear regression analyses revealed statistically significant relationships for all species ($P< 0.05$), with coefficients of determination (r^2) exceeding 0.90 (Table 2). Specifically, *S. plagiostomus* and *O. mykiss* had r^2 values of 0.94, *D. maculatus* 0.95, *S. richardsonii* 0.97, and *S. progastus* 0.98, with an overall mean of 0.95 ± 0.02.

The exponent b values for the LWRs ranged from 2.32 to 3.16 (Table 2). Based on these values, growth patterns varied among species: *S. richardsonii* and *S. plagiostomus* exhibited negative allometric growth ($b < 3$), while *O. mykiss*, *D. maculatus*, and *S. progastus* demonstrated positive allometric growth ($b > 3$).

The condition factor (K) varied significantly among the species, ranging from 0.70 ± 0.13 in *S. richardsonii* to 1.50 ± 0.19 in *O. mykiss* (Table 2). Mean K values were recorded as follows:

- *O. mykiss*: 1.50 ± 0.19
- *S. progastus*: 1.31 ± 0.17
- *S. plagiostomus*: 0.90 ± 0.14
- *D. maculatus*: 1.10 ± 0.18
- *S. richardsonii*: 0.70 ± 0.13

Overall, the average K values for *S. plagiostomus* and *S. richardsonii* were less than 1.0, indicating a relatively poorer condition, while those for *S. progastus*, *D. maculatus*, and *O. mykiss* exceeded 1.0, suggesting better physiological condition and possibly more favorable habitat conditions.

Table 1. Descriptive statistics and estimated parameters of length-weight relationships for five freshwater fish species inhabiting the Indus tributary, Suru River of Ladakh Trans-Himalayan region

Species		Total length (cm)			Weight (g)		
	n	Min	Max	Mean ± SD	Min	Max	Mean ± SD
Schizothorax richardsonii	42	16.2	30.5	17.64 ± 5.5	106.84	388.52	224.90 ± 96.8
Schizothorax plagiostomus	127	16.5	32.3	30.38 ± 3.8	117.65	481.43	328.41 ± 63.1
Schizothorax progastus	90	18.4	31.5	19.89± 5.03	156.88	484.17	288 ± 63.05
Diptychus maculatus	159	15.5	30.2	20.09 ± 6.5	96.68	346.5	238.23 ± 78.17
Onchorhynchus mykiss	81	17	32.5	28.95 ± 4.08	146.34	534.86	389.60 ± 99.5

*n= total number specimens; Min = Minimum; Max = Maximum; SD = Standard deviation

Table 2. Regression parameters, Growth type and condition factor for five freshwater fish species inhabiting the Indus tributary, Suru River of Ladakh Trans- Himalayan region

Species	Regression Parameters					K (Mean± SD)	Growth type
	a	b	95% CI of b	95% CI of a	r^2		
Schizothorax richardsonii	0.039	2.711	2.5515-2.8716	0.0253-0.0629	0.97	0.75 ± 0.13	A −
Schizothorax plagiostomus	0.082	2.327	2.096-2.5586	0.0383-0.1767	0.94	0.90 ± 0.14	A−

*a = intercept slope; b = slope; CI = confidence interval; r^2 = coefficient of determination, K = Fulton condition factor; SD = Standard deviation

DISCUSSION

The LWRs studies of fish play a crucial role in the comparison of fish species from different regions and of fishes that belong to the same taxonomic group **(Famoofo & Abdul, 2020, Lubich *et al.*, 2020)**. Many factors influence fish LWRs, such as physiological, environmental, and nutritional factors in any particular habitats **(Jan *et al.*, 2021, Ondemo *et al.*, 2022, Li *et al.*, 2023; Zakiya *et al.*, 2024)**. In general, fish develop faster as their body length rises; hence length and weight are linked. The body shape and level of fatness determine the value of parameter b in the LWRs of a fish species. Fish with thin elongated bodies will have a 'b' value less than 3, indicating negative allometric growth, whereas fish with thicker bodies will have a 'b' value greater than 3, indicating positive allometric growth, and fish with

a 'b' value equal to 3 indicating isometric growth **(Froese, 2006; Mazumder *et al.*, 2016; Seiyaboh *et al.*, 2016; Jan *et al.*, 2021)**. The LWR for a perfect fish living under ideal conditions remains constant at 3 **(Allen, 1938)**. However, since the fish passes through several developmental stages, the simple cube law fails to hold well throughout their lifespan, and the equilibrium constant varies according to their growth pattern **(Froese, 2006)**.

During the current investigation, it was discovered that the length and weight of all five fish species had a strong association, indicating that the relationships were linear and highly significant. The results of this study revealed that the exponential value 'b' in all five species, *S. richardsonii, S. plagiostomus, S. progastus, D. maculatus,* and *O. mykiss,* was within the expected range of 2 to 4, as reported by **Froese and Pauly (2021)**. The majority of fish specimens of the River Suru and its tributaries are not very large, which may be due to overfishing by the locals, finding it difficult for the species to develop into a significant population or the region's severe environment. The size variations among the fish suggest that the population included both young and mature fish specimens.

In *Schizothorax richardsonii*, a vulnerable indigenous snow trout species, the regression coefficient (b) was found to be 2.711, which is significantly less than 3.0, indicating a negative allometric growth. This suggests that increases in body length are not proportionally matched by increases in weight. Similar findings were reported by **Qadri *et al.* (1983)**, who recorded a 'b' value of 2.448 in specimens from the Sindh Nallah, also indicating a negative allometric growth. Likewise, **Tyagi *et al.* (2014)** documented b values below 3 for *S. richardsonii* from the Teesta and Indus rivers.

Contrary to these findings, other studies have reported b values close to 3 for *S. richardsonii*, suggesting an isometric growth pattern, in which length and weight increase proportionally **(Tyagi *et al.*, 2014)**. Such variation in growth patterns may be attributed to multiple factors, including body size distribution, reproductive maturity, life stage, physiological condition, environmental influences, and the timing of sampling.

For *S. plagiostomus* the b value found in this study were much lower than "3" (2.327), indicating that *S. plagiostomus* in River Suru and its tributaries had a negative allometric development trend. In other words, as the fish grew longer, they became thinner. Our results are in conformity with **Mir *et al.* (2014)**, who also reported a negative allometric growth in *S. plagiostomus* with b value 2.60. In contrary to this, **Bhat *et al.* (2010)** recorded the b value for the same fish from the Lidder River, Kashmir as 2.9467 (isometric growth pattern), which is higher than that observed in the present study. Similar isometric growth pattern was also reported by many other earlier authors in the same fish such as **Khan and Sabah (2013)** (b = 2.86)**, Bashir *et al.* (2016)** (b = 2.926), and **Sheikh and Ahmed (2019)** (b = 3.074).

The value of b = 3.128 for *D. maculatus* in the present study indicates that the increase of body length and weight are related. This is a positive allometric growth pattern and it is different from the b values 2.711 and 2.327 recorded for *S. richardsonii* and *S. plagiostomus,* respectively, in the current investigation. However, our results are in conformity with **Sui *et al.* (2015)**, who reported the same positive allometric growth in the same fish from Ili River, China.

The variations in the b values could be due to differences in ecological conditions, animal physiology, or both **(Le Cren, 1951)**.

The value of regression coefficient 'b' for *O. mykiss* and *S. progastus* was observed to show positive allometric growth during the present study. This suggests that in *O. mykiss* and *S. progastus*, the length growth is related to its weight gain. Different freshwater fish species have shown similar positive allometric growth such as *Mugil cephalus, Labeo rohita,* and *Barbonymus gonionotus* **(Verdiell-Cubedo *et al.*, 2006; Satrawaha & Pilasamorn, 2009; Das *et al.*, 2015)**.

In the present study, differences in observed b values can be attributed to a combination of factors: (i) fish habitat; (ii) sex; (iii) extent of stomach fullness; (iv) number of specimens examined; (v) differences in the observed length ranges of the specimens caught, and (vi) gonadal maturity **(Tesch, 1971; Pauly, 1984; Mendes *et al.*, 2004; Froese, 2006; Famoofo & Abdul, 2020; Ondemo *et al.*, 2022; Li *et al.*, 2023; Zakiya *et al.*, 2024)**, all of which were not taken into account in this study.

Fish condition factor is a quantitative indicator of the health of the fish. In the current study, the mean condition factor evaluated from the equation $K = 100\ W/L^3$ was 1.5 ± 0.19; 1.31 ± 0.17; 0.90 ± 0.14, 0.7 ± 0.13 and 1.1 ± 0.18 in combined sexes for *O. mykiss, S. progastus, S. plagiostomus, S. richardsonii,* and *D. maculatus*, respectively. These values are lower than those recorded by **Bagenal and Tesch (1978)** (2.9–4.8) for matured fresh water fish. The K values for the five fish species in the current investigation were found to be inconsistent with the value of 'K' for *S. richardsonii* and *S. plagiostomus* being < 1.0 while, the 'K' values for *S. progastus, D. maculatus,* and *O. mykiss* were > 1.0. The findings indicated that the fish species with 'K' value < 1.0 were not in an ideal physiological condition in the River Suru of Ladakh Trans Himalayan region; however, fish species with 'K' value > 1.0 indicates that these fish species are in excellent condition. These variations may be due to many environmental and biological variables as well as sampling features, such as size ranges, the number of specimens sampled, etc. The value of K of a fish can vary depending on a number of circumstances, including fish size, feeding frequency, food availability, season, stage of maturity, age, degree of muscular development, sex, quantity of stored fat, and life history **(Bagenal & Tesch, 1978; Jisr *et al.*, 2018; Dinh *et al.*, 2021)**. In the current investigation, none of these factors influences the 'K' value in the fish under study have been considered.

CONCLUSION

This study provides foundational data on the length-weight relationships (LWRs) and condition factors (**K**) of five freshwater food fish species in the Ladakh Trans-Himalayan region. The findings significantly contribute to our understanding of the population dynamics of these species in the Suru River and its tributaries. The study also offers practical insights into the biological status and potential exploitation of these fish resources. Several species demonstrated negative allometric growth and low condition factors, which may reflect suboptimal environmental conditions or pressures such as overexploitation. These findings have important implications for fisheries sustainability and resource management in the region.

To enhance our understanding of the growth patterns, health status, and population structures of fish in this ecosystem, further studies on LWRs and condition factors across more species and seasons are recommended. Such data are essential for informed fisheries management and conservation planning. Importantly, this is the first study to report LWRs and condition factors for these five species in this river system, and it serves as a valuable reference for fisheries scientists, ecologists, and resource managers engaged in the sustainable development and conservation of aquatic biodiversity in the Trans-Himalayan region.

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Author Contribution

IA supervises the study and contributed in conceptualization. IZ wrote the original draft and contributed to the reviewing and editing. All authors helped revise the manuscript, read it, and approve the final version.

Data availability statement

Data are available only upon personal request to the authors.

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