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FEEDING ECOLOGY AND DIGESTIVE ENZYME ACTIVITY OF CHIRRUH SNOWTROUT, *SCHIZOTHORAX ESOCINUS* (CYPRINIFORMES, CYPRINIDAE), FROM THE RIVER JHELUM, KASHMIR

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Feeding ecology and digestive enzyme activity of Chirruh snowtrout, *Schizothorax esocinus* (Cypriniformes, Cyprinidae), from the River Jhelum, Kashmir. Hafiz, Z., Bhat, F. A., Shah, T. H., Abubakar, A., Bhat, B. A., Kumar, A. & Mushtaq, S. T. — We examined the feeding ecology and digestive enzyme activity of Chirruh snowtrout, (*Schizothorax esocinus*, (Heckel, 1838), from three reaches of the Jhelum River (Safakadal, Amira Kadal and Zero Bridge) over 12 months. Gut-content analysis indicated an omnivorous diet dominated by plant material (63.61%) with a substantial animal component (35.25%). Diatoms were the single most abundant category (39.65%), followed by crustaceans (27.70%), macrophytes (12.64%), green algae (6.64%), and blue-green algae (4.68%), with other items comprising 8.69%. Feeding intensity peaked in June–August and was lowest from January–April. Across seasons, mean digestive en-

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zyme activities were α -amylase 110.45 U/L, trypsin 0.96 U mg⁻¹ protein, lipase 57.48 U/L, and alkaline phosphatase 58.98 U mg⁻¹ protein, with trypsin, α -amylase, and lipase showing their highest seasonal values in autumn, while alkaline phosphatase peaked in summer; α -amylase showed its lowest seasonal value in spring. Together, these results clarify trophic strategy and digestive capacity in *S. esocinus* and suggest seasonal tuning of enzymatic function consistent with observed dietary shifts. Findings inform natural resource management and support feed formulation strategies for related aquaculture applications.

Key words: *Schizothorax esocinus*, Food and feeding, Omnivorous feeding behaviour, Digestive enzymes, α -amylase, trypsin, lipase and alkaline phosphatase.

Introduction

The Snowtrouts, specifically *Schizothorax* species, are economically significant indigenous fish in the Himalayan region of India, particularly in the Kashmir Valley. These species hold great potential as a candidate for aquaculture, given their ability to meet the growing demand for fish in the region's large population (Yousuf, 1996; Balkhi, 2007; Petr, 2002; Agarwal et al., 2009; Bhat et al., 2010, 2020). Due to their importance as commercially and economically valuable food sources, Snowtrouts are integral to the local economy (Jhingran, 1982; Yousuf, 1996; Balkhi, 2007; Joshi et al., 2018; Bhat et al., 2010, 2020). However, the introduction of common carp into the Kashmir Valley has resulted in a sharp decline in *Schizothorax* populations, likely due to the prolific breeding habits of the carp and its subsequent dominance in the ecosystem. This has led to a shortage of the widely accepted and culturally significant Snowtrout (Zutshi and Gopal, 2000).

Despite the growing recognition of aquaculture as a viable and profitable industry worldwide, the culture of *Schizothorax* species remains largely experimental. Advancements in aquaculture have focused on enhancing yields and promoting faster growth, often through the substitution of natural food sources with formulated diets. As feed costs now comprise more than half of the operating expenses in many aquaculture operations, a comprehensive understanding of fish nutrition and feeding practices is essential for successful fish farming (Lovell, 1998). Investigating the feeding habits of species is not only crucial for understanding their ecological roles but also for assessing their place within the food web of their ecosystem (Allan & Castillo, 2007). Examining the gut content of fish provides valuable insights into their feeding patterns, while evaluating digestive enzyme activities, such as proteases, carbohydrases, and lipases, can offer a detailed assessment of a species' digestive capacity and nutritional efficiency (Smith, 1980; Palomino, 2018; Buddington, 1985).

The mass production of *Schizothorax* species for aquaculture hinges on the development of appropriate feeding protocols that address their specific nutritional needs. This research aims to fill existing knowledge gaps concerning the feeding biology of *Schizothorax esocinus* (Heckel, 1838), focusing on digestive enzyme activities to enhance our understanding of the species' nutritional requirements and to propose strategies for improving aquaculture practices.

This study aimed to:

(i) Quantify diet composition and seasonal variation in the gut contents of *Schizothorax esocinus* across three urban reaches of the Jhelum River.

(ii) Measure activities of key digestive enzymes (α -amylase, trypsin, lipase, alkaline phosphatase) across seasons and along the gut (anterior–posterior).

(iii) Evaluate implications of feeding ecology and digestive physiology for aquaculture nutrition and management of Chirruh snowtrout (*Schizothorax esocinus*).

Material and Methods

The present investigations on *Schizothorax esocinus* were carried out at the Fisheries Resource Management Laboratory, Faculty of Fisheries, SKUAST-K, Rangil, Ganderbal. The study involved following steps for meeting the various objectives.

Collection of Fish Samples

A total of 30 specimens were obtained monthly ($N = 360$ over 12 months) from fish landing centres associated with three reaches of the River Jhelum in Srinagar, Kashmir namely Safakadal (34.102°N , 74.799°E), Amira Kadal (34.074°N , 74.820°E), and Zero Bridge (34.068°N , 74.831°E). The fish had been captured by local fishermen using cast nets with a mesh size of 15–20 mm as part of their routine fishing activities. Unless stated otherwise, monthly samples were distributed approximately equally among sites (10 ± 2 fish per site per month). Sampling was conducted monthly from January to December 2023. Total length (mm) and body weight (g) of all collected specimens were recorded prior to dissection. Fish of both sexes representing immature and mature stages were included in the study wherever available in catches. Maturity stages were assessed macroscopically based on gonadal appearance during dissection. Samples were transported to Fisheries Resource Management (FRM) laboratory, Faculty of Fisheries, Rangil, in insulated boxes containing ice packs and live samples were carried in plastic boxes filled with river water aerated using battery-operated aerator. At the laboratory, external debris and excess mucus were gently removed from the fish using clean water, and the specimens were blotted dry with absorbent cloth prior to morphometric measurements and dissection. After cleaning, Total length (mm) and body mass (g) were recorded, and sex and maturity were noted where possible. The geographical locations of the sampling sites along the River Jhelum are presented in Figure 1.

The study area is characterized by a temperate Himalayan climate, with marked seasonal variation in water temperature. During the study period, water temperature ranged approximately from $5\text{--}8^\circ \text{C}$ in winter to $22\text{--}26^\circ \text{C}$ in summer. The sampling sites represent moderately flowing urban river stretches with abundant phytoplankton, macrophyte growth, and organic matter input, providing suitable feeding grounds for *Schizothorax esocinus*.

Food and Feeding Habits

A longitudinal cut was made on the ventral side of the fish from just behind the isthmus of the gills posterior to the anal fin. Two transverse cuts were made at each end of the first cut to open the coelom to expose the viscera. Then the digestive tract was separated from other visceral organs with the help of forceps. The length and weight of the gastrointestinal tract were recorded using a digital vernier caliper (accuracy: ± 0.01 mm) and a digital scale (accuracy: ± 0.01 g), respectively.

Gut Content Analysis

For gut content analysis, a longitudinal cut was made across the gut and the contents were transferred into a clean petri dish for further analysis. Weight of gut contents was recorded to the nearest 0.01 g. The number of empty guts was also recorded; however, empty guts were excluded from diet composition analyses and were used only for calculation of the Gut Vacuity Index (GVI). The degree of distension of the stomach was judged and classified as 'gorged', 'full', '3/4 full', '1/2 full', '1/4 full' and 'empty' according to the scale described by Lebedev (1946) traced by eye estimation & the weight noted down to the nearest 0.01 g. The gut contents were analysed to the genus and up to species level wherever possible by identifying the large prey by eye observation and examination of small prey under binocular microscope. Gut content analysis are broadly classified into qualitative and quantitative methods.

Qualitative Analysis

Various gut contents including digested, semi-digested or broken fragments and finely comminuted materials were identified upto genus and wherever possible upto species level depending upon the state of digestion. Standard taxonomical references of Edmondson (1959) were used for identification of the plankton. Oligochaetes and insect larvae were identified with the help of taxonomical studies of Pennak (1978) and Edmondson (1959). Based on frequency of occurrence and relative abundance in the gut contents, food items were qualitatively

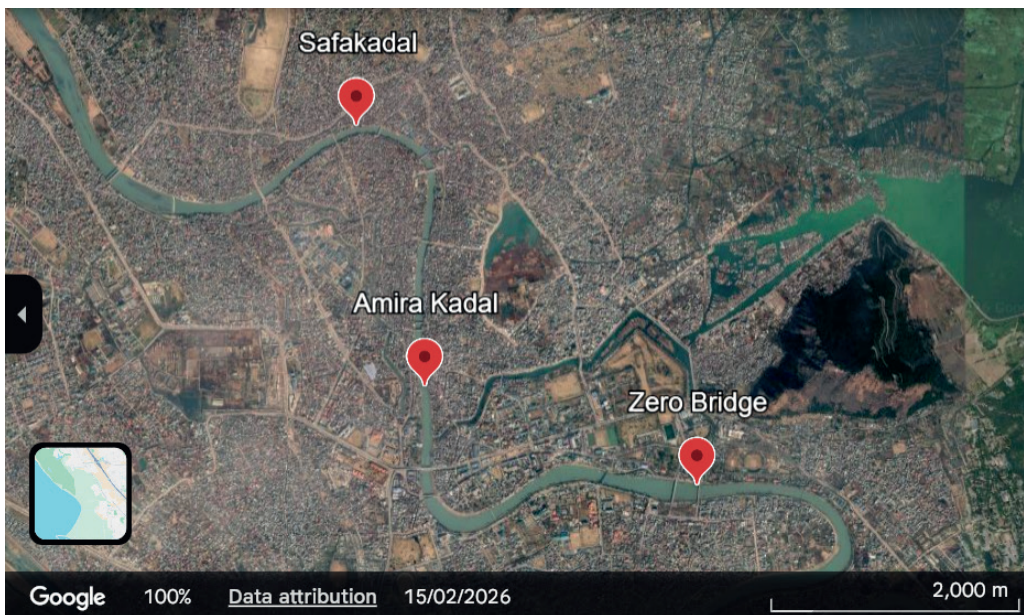


Fig. 1. Satellite imagery showing the three sampling sites along the River Jhelum in Srinagar, Kashmir Himalaya: Safakadal (34.102° N, 74.799° E), Amira Kadal (34.074° N, 74.820° E), and Zero Bridge (34.068° N, 74.831° E). (Source: Google Earth satellite imagery; map annotations and sampling-site locations were added by the authors)

Table 1. **Indices and Formulas**

Index	Formula	Units	Interpretation
RLG (Relative Length of Gut)	$RLG = GL/TL$	Ratio (unit less)	Trophic strategy proxy; >1 often indicates herbivory leaning
RGM (Relative Gut Mass)	$RGM = WG/WF$	Ratio or %	Relative investment in digestive tissue
GaSI (Gastro-somatic Index)	$GaSI = (WG/WF) \times 100$	%	Degree of gut fullness/condition
FI (Fullness Index)	$FI = (W_g/W_p) \times 1000$	%	Short-term feeding intensity
GVI (Gut-vacuity Index)	$GVI = (ES/TS) \times 100$	%	Proportion of empty stomachs
IP (Index of Preponderance)	$IP = [(Vi \times Oi) / \Sigma(Vi \times Oi)] \times 100$	%	Integrated rank of diet categories
ZI (Zihler Index)	$ZI = GL / [10 \times (WF)^{1/3}]$	Ratio (unit less)	Indicates feeding habit from gut-to-body length ratio
Frequency of Occurrence (% O)	$\%O = (Ni/N) \times 100$	%	Percentage occurrence of a food item in examined guts
Percentage Volume (%)	$Percentage\ Volume = (Pi / Pt) \times 100$	%	Relative volumetric contribution of food items

Note: GL — gut length (mm); TL — total length of fish (mm); WG — gut weight (g); WF — body weight of fish (g); ES — number of empty stomach samples; TS — total number of stomach samples; Vi — percentage volume of food item *i*; Oi — percentage occurrence of food item *i*; Ni — number of guts containing food item *i*; N — total number of guts examined; Pi — points allocated to food item *i*; Pt — total points allocated to all food items in the sample.

categorized as very common (>75% occurrence), common (51–75% occurrence), frequent (26–50% occurrence), occasional (10–25% occurrence), and rare (<10% occurrence).

Quantitative Analysis

Gut contents were analyzed using numerical methods [Frequency of Occurrence (%O) and Points method] and by volumetric method (Points volumetric method). The numerical method counted the individual food items in the gut contents, while the volumetric method measured the volume of the food items present in the gut.

Gut morphometric parameters and food analysis indices

Gut morphometric parameters and feeding indices were recorded using standard morphometric and gravimetric procedures. The morphometric parameters and feeding indices used in the present study, along with their respective formulae and interpretations, are summarized in Table 1.

Digestive Enzyme Assay

To estimate digestive enzyme activity, five additional live specimens were obtained monthly from the same fish landing centres and transported to the laboratory, giving a total of 60 specimens over the 12-month study period. The specimens were maintained unfed for 24 hours at 22 ± 2 °C to minimize the influence of recent feeding and to ensure a similar physiological state (Fagbenro, 1990; Furné et al., 2005). Following the fasting period, the fish were humanely euthanized prior to dissection, and the entire gastrointestinal tract was carefully removed for enzyme analysis. Fish used for gut content analysis were processed immediately after collection and were not maintained alive before dissection. The gastrointestinal tract of each of the five fish collected in each month was divided into three equal regions corresponding to the anterior, middle, and posterior portions. The respective regions from the five fish were then pooled separately, such that all anterior portions constituted one pooled anterior sample, all middle portions constituted a second pooled sample, and all posterior portions constituted a third pooled sample. Each pooled regional sample was thoroughly washed with distilled water and homogenized separately using a tissue homogenizer (Remi Motors, Mumbai, India). The homogenates were centrifuged at 3500 rpm for 30 minutes at 4 °C (Fagbenro, 1990). The resulting supernatants were used as crude extracts without further purification (Furné et al., 2005).

α -Amylase, lipase, and alkaline phosphatase (ALP) activities were determined using ready-to-use commercial kits (Coral Clinical Systems; catalogue nos. AA-1102030210, LP-1102180025, and AL-1102020103, respectively) according to the manufacturer's instructions. Absorbance was measured at 405 nm for α -amylase, 340 nm for lipase, and 405 nm for ALP. Trypsin activity was estimated according to Erlanger et al. (1961), using BAPNA (N- α -benzoyl-DL-arginine-p-nitroanilide) as the substrate. Each monthly pooled regional sample was assayed in triplicate as technical replicates at a path length of 1.00 cm using standard cuvettes and at a temperature of 37.0 °C.

For each gut region, monthly enzyme activity values were obtained from the respective pooled sample, and seasonal means and standard deviations were calculated from the monthly values within each season; the reported standard deviations therefore represent temporal variation among months rather than variation among the technical assay replicates.

For trypsin, one unit of activity was defined as the amount of enzyme releasing 1 μ mol of p-nitroaniline per minute under the assay conditions and was expressed as U mg⁻¹ protein. α -Amylase activity was calculated according to the commercial kit procedure and expressed as U/L. Lipase activity was calculated using the corresponding commercial kit calibration procedure and expressed as U/L. Alkaline phosphatase activity was expressed as U mg⁻¹ protein. Protein concentration of the gut homogenates was determined using the Bradford assay (Bio-Rad standard reagent) and was used for normalization of the enzymes expressed on a protein basis.

Calibration curves were generated using kit-supplied standards (p-nitrophenol, maltose, or equivalent), and only the linear range ($r^2 \geq 0.99$) was used for calculations. Each assay run included a reagent blank (without enzyme), a heat-inactivated negative control, and matrix-spike controls to verify recovery, with an acceptable recovery range of 85–115%.

Statistical Analysis

Descriptive statistics were used to summarize diet composition, gut morphometric indices, and digestive enzyme activities across months, seasons, and gut regions. Differences among seasons were assessed using one-way analysis of variance (ANOVA). The assumptions of normality and homogeneity of variance were assessed using the Shapiro–Wilk and Levene’s tests, respectively. Statistical analyses were performed using SPSS, with statistical significance considered at $P < 0.05$. Results are presented as mean $\pm$ standard deviation.

Results

Gut content analysis

Gut content analysis revealed that *Schizothorax esocinus* exhibited an omnivorous feeding habit with plant matter constituting 63.61% and animal matter 35.25% of the total gut contents. Among the plant components, diatoms represented the dominant dietary group (39.65%), followed by macrophytes (12.64%), green algae (6.64%), and blue-green algae (4.68%). The major diatom taxa identified included *Navicula* sp., *Cymbella* sp., *Amphora* sp., *Fragilaria* sp., *Synedra* sp., *Pinnularia* sp., and *Nitzschia* sp. Green algal forms such as *Ulothrix* sp., *Spirogyra* sp., *Pediastrum* sp., *Zygnema* sp., and *Chlorella* sp. were also frequently encountered in the gut contents.

Among the animal components, crustaceans formed the most important dietary group (27.70%), comprising copepods and cladocerans such as *Diaptomus*, *Cyclops*, *Daphnia*, *Moina*, *Bosmina*, and *Chydorus*. Other food items included insect larvae and appendages (2.46%), fish scales and bones (2.70%), rotifers (1.36%), oligochaetes (0.62%), and protozoans (0.38%). Small quantities of sand particles (0.44%) and unidentified matter (0.71%) were also observed in the gut contents. Detailed composition of major dietary groups and representative taxa is presented in Table 2.

The percentage composition of the food items ingested by *S. esocinus* varied seasonally and the gut content analysis revealed the omnivorous feeding behaviour of this species. Seasonal variation in diet composition was statistically significant (one-way ANOVA, $P < 0.05$), indicating differences in the relative contribution of major food categories across seasons.

Frequency of occurrence

The percentage frequency of occurrence (% O) of different food items recovered from the gut was calculated month-wise throughout the year (Fig. 2). Because individual food items could occur simultaneously within the same gut, the percentage occurrence values were not expected to sum to 100%. The results indicated that diatoms were very common during the entire study period except in the months of June, July, and August, where they occurred commonly. Crustaceans were recorded as very common from April to September and occurred commonly from January to March and in October, whereas they appeared frequently during November and December. Macrophytes occurred frequently during January, February, April, May, and

Table 2. Major dietary groups and representative food items identified in the gut of *Schizothorax esocinus*

Category	Sub-category	Representative taxa identified	Percentage contribution (%)
Plant matter	Diatoms (Bacillariophyceae)	<i>Navicula</i> sp., <i>Cymbella</i> sp., <i>Amphora</i> sp., <i>Fragilaria</i> sp., <i>Synedra</i> sp., <i>Pinnularia</i> sp., <i>Nitzschia</i> sp.	39.65
Plant matter	Macrophytes	<i>Utricularia</i> sp., <i>Potamogeton</i> sp., <i>Hydrilla verticellata</i> , <i>Chara</i> sp., <i>Ceratophyllum</i> sp.	12.64
Plant matter	Green algae (Chlorophyceae)	<i>Ulothrix</i> sp., <i>Spirogyra</i> sp., <i>Pediastrum</i> sp., <i>Zygnema</i> sp., <i>Chlorella</i> sp.	6.64
Plant matter	Blue-green algae (Cyanophyceae)	<i>Oscillatoria</i> sp., <i>Spirulina</i> sp., <i>Anabaena</i> sp., <i>Rivularia</i> sp.	4.68
Animal matter	Crustacea	<i>Diaptomus</i> , <i>Cyclops</i> , <i>Daphnia</i> , <i>Moina</i> , <i>Bosmina</i> , <i>Chydorus</i>	27.70
Animal matter	Fish scales and bones	—	2.70
Animal matter	Rotifera	<i>Monostyla</i> sp., <i>Keratella</i> sp., <i>Euchlanis</i> sp.	1.36
Animal matter	Insect larvae and appendages	<i>Chironomus</i> larva, <i>Hexatoma</i> larva	2.46
Animal matter	Oligochaetes	—	0.62
Animal matter	Protozoa	<i>Arcella</i> sp.	0.38
Others	Sand	—	0.44
Others	Unidentified matter	—	0.71

November, while they were common during March, June, and December and very common from July to September.

The occurrence of different food categories throughout the year indicated seasonal variation in food composition in the gut of *S. esocinus*. Diatoms and crustaceans constituted the dominant food items during most months of the study period. Significant seasonal variation was observed in the occurrence frequency of major dietary components (one-way ANOVA, $P < 0.05$).

Feeding intensity

Monthly analysis of feeding intensity demonstrated that the highest feeding intensity was observed during the months of June to August, with the maximum intensity recorded in June. In contrast, lower feeding intensity was recorded from January to April, with the lowest intensity observed in April (Fig. 3). Seasonal variation in feeding intensity indicated increased feeding activity during summer months and comparatively reduced feeding activity during winter months. Feeding intensity varied significantly among seasons, with significantly higher values recorded during summer months compared to winter months (ANOVA, $P < 0.05$).

Gut morphometric and somatic indices

Monthly variations in gut morphometric and somatic indices are presented in Figure 4 (A-D). The gut length of *Schizothorax esocinus* ranged from 174.36 to 848.73 mm, with a mean value of 347.07 ± 115.93 mm. Gut weight varied between 0.17 and 18.91 g, with a mean of 6.73 ± 3.31 g. The Relative Gut Mass (RGM) ranged from 0.01 to 0.13, with a mean value of 0.03 ± 0.02 , whereas the Relative Length of Gut (RLG) ranged from 0.63 to 2.56, with an average value of 1.22 ± 0.33 . The Zihler Index (ZI) varied between 3.05 and 12.75, with a mean value of 5.81 ± 1.56 .

The Gastro-somatic Index (GaSI) ranged from 0.19 to 13.32%, with a mean value of $3.36 \pm 1.96\%$. The Fullness Index (FI) ranged from 0 to 5.61%, with a mean

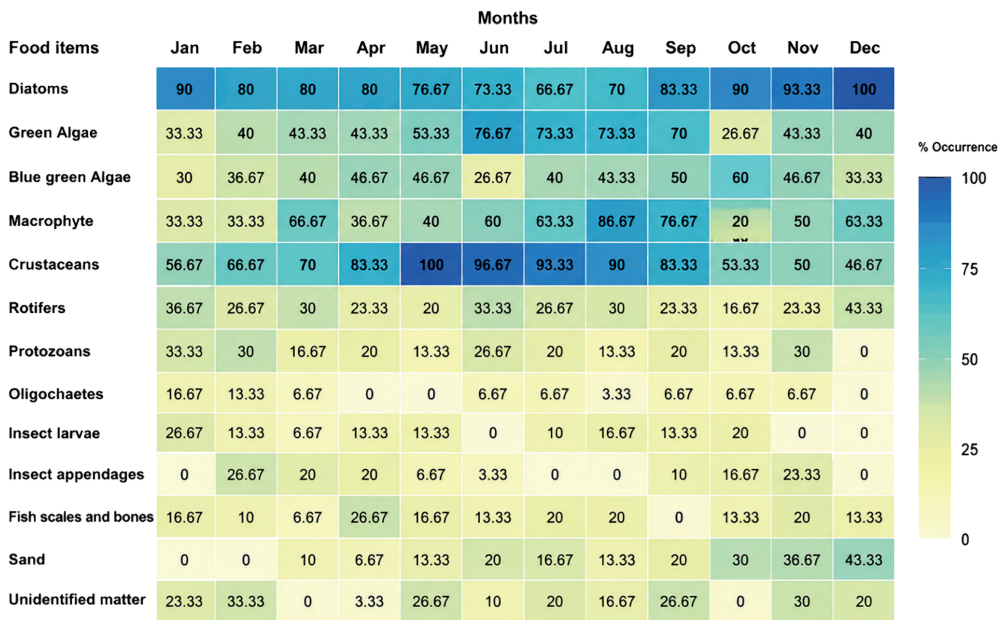


Fig. 2. Monthly percentage frequency of occurrence (% O) of food items in the gut contents of *Schizothorax esocinus*

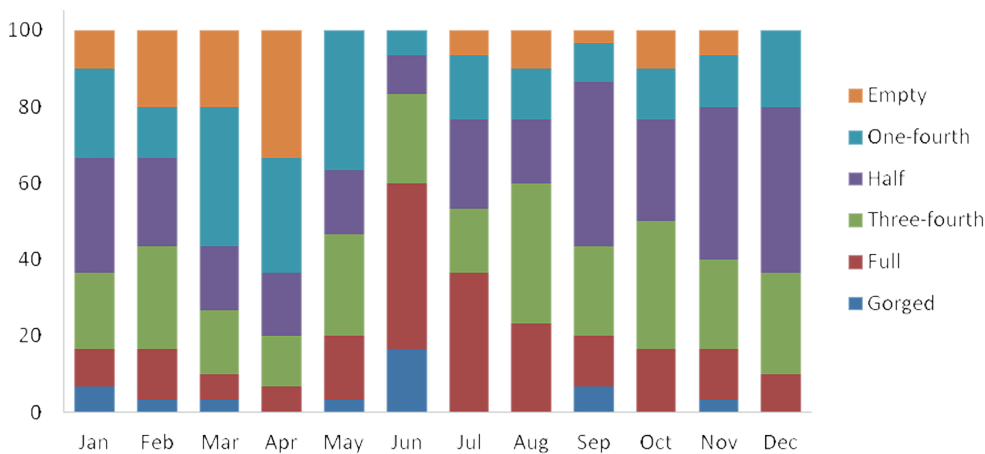


Fig. 3. Monthly variation in feeding intensity (%) of *Schizothorax esocinus* based on stomach fullness categories.

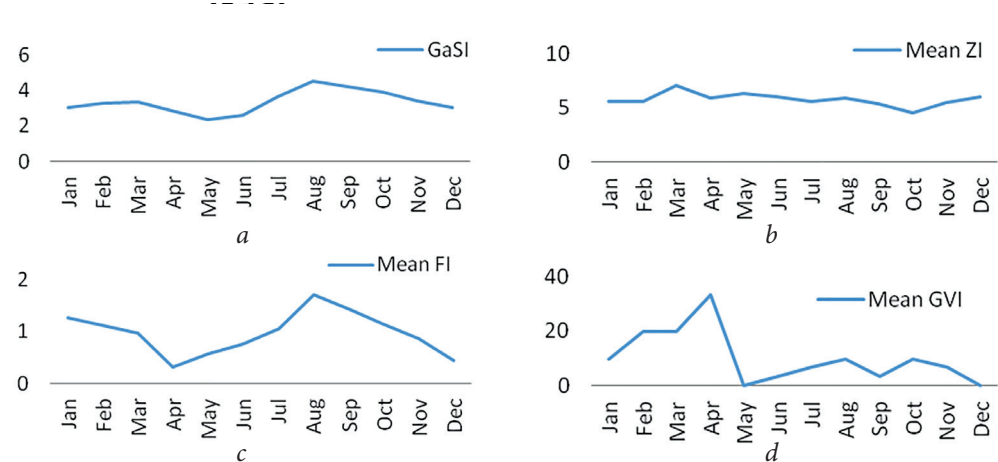


Fig. 4. Monthly variations in Gastro-somatic Index (GaSI) — a, Zihler Index (ZI) — b, Fullness Index (FI) — c, and Gut Vacuity Index (GVI) — c in *Schizothorax esocinus*

Table 3. Descriptive statistical summary of gut morphometric parameters and feeding indices of *S. esocinus*

Dictates	Min	Max	Mean ± S.D
Gut Length (mm)	174.36	848.73	347.07 ± 115.93
Gut Weight (g)	0.17	18.91	6.73 ± 3.31
RGM	0.01	0.13	0.03 ± 0.02
RLG	0.63	2.56	1.22 ± 0.33
ZI	3.05	12.75	5.81 ± 1.56
GaSI (%)	0.19	13.32	3.36 ± 1.96
FI (%)	0	5.61	1.01 ± 1.13
GVI (%)	0	33.33	10.28 ± 9.80

value of $1.01 \pm 1.13\%$, while the Gut Vacuity Index (GVI) ranged from 0 to 33.33%, with a mean value of $10.28 \pm 9.80\%$. Elevated GaSI and FI values along with lower GVI values were observed during warmer months, indicating comparatively higher feeding activity during this period. Seasonal variation in GaSI, FI, and GVI values was statistically significant (one-way ANOVA, $P < 0.05$), whereas variations in RLG and RGM remained comparatively stable throughout the study period. The descriptive statistical summary of gut morphometric parameters and feeding indices of *Schizothorax esocinus* is presented in Table 3.

Digestive Enzyme Activity

The evaluation of digestive enzymes in the anterior, middle, and posterior portions of the gut of *Schizothorax esocinus* indicated seasonal variation in enzymatic activity (Table 4). Enzyme activity measurements were obtained monthly from the three separately pooled gut regions, with each regional pool comprising the corresponding gut portions from five fish; seasonal means and standard deviations were calculated from the monthly observations. The maximum mean value of trypsin activity ($1.47 \pm 0.95 \text{ U mg}^{-1} \text{ protein}$) was recorded during July, whereas the minimum value ($0.59 \pm 0.53 \text{ U mg}^{-1} \text{ protein}$) was observed in January (one-way ANOVA, $P < 0.05$).

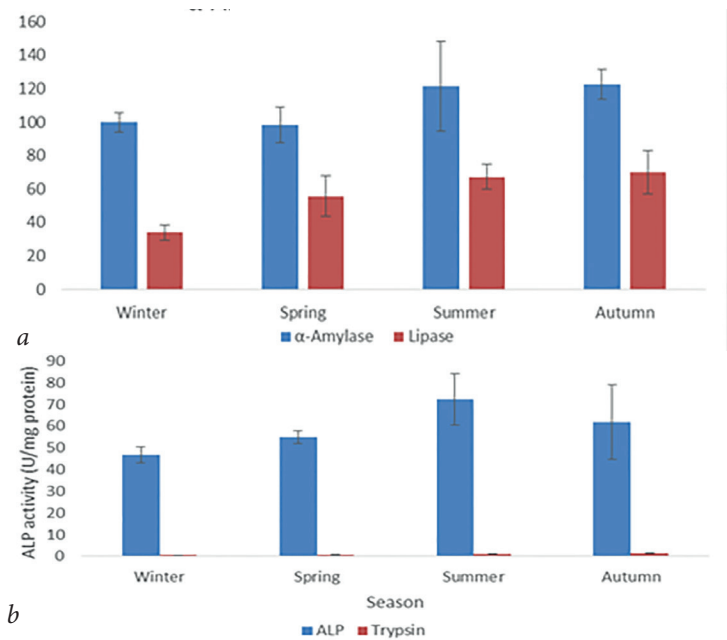


Fig. 5. Seasonal variation in digestive enzyme activities in the gastrointestinal tract of *Schizothorax esocinus*: *a* — α -Amylase and lipase activities (U/L); *b* — alkaline phosphatase (ALP) and trypsin activities (U mg⁻¹ protein)

Table 4. Seasonal enzyme activities across gut regions

Enzyme	Region	Winter	Spring	Summer	Autumn
Trypsin (U mg ⁻¹)	Anterior region	1.16 ± 0.04	1.46 ± 0.30	2.12 ± 0.37	2.34 ± 0.19
	Middle region	0.66 ± 0.03	0.71 ± 0.06	1.08 ± 0.47	1.35 ± 0.34
	Posterior region	0.052 ± 0.03	0.113 ± 0.10	0.20 ± 0.14	0.29 ± 0.03
α -Amylase (U/L)	Anterior region	155.22 ± 7.04	153.75 ± 13.44	153.87 ± 38.15	197.90 ± 13.21
	Middle region	113.72 ± 7.11	111.50 ± 14.07	169.83 ± 12.01	125.60 ± 7.27
	Posterior region	30.30 ± 2.25	29.15 ± 4.71	40.07 ± 14.90	44.48 ± 6.87
Lipase (U/L)	Anterior region	50.53 ± 6.98	82.61 ± 17.52	91.08 ± 6.94	91.14 ± 14.09
	Middle region	37.53 ± 8.02	69.58 ± 15.73	82.14 ± 9.17	84.72 ± 13.32
	Posterior region	13.72 ± 2.12	24.17 ± 11.60	28.64 ± 7.58	33.84 ± 10.97
ALP (U mg ⁻¹)	Anterior region	82.26 ± 1.56	96.39 ± 6.94	126.15 ± 18.95	108.31 ± 21.27
	Middle region	51.12 ± 10.33	59.41 ± 7.84	73.39 ± 22.61	65.26 ± 23.15
	Posterior region	7.38 ± 1.01	9.03 ± 1.72	17.40 ± 4.54	11.66 ± 6.15

The overall mean trypsin activity recorded during the study period was 0.96 ± 0.34 U mg⁻¹ protein. The highest mean α -amylase activity (144.06 ± 81.44 U/L) was recorded during August, while the lowest activity (88.32 ± 60.15 U/L) was observed in May (one-way ANOVA, $P < 0.05$). The overall mean α -amylase activity was 110.45 ± 17.77 U/L. Lipase activity showed maximum mean values during September (78.18 ± 32.94 U/L) and minimum values during December (28.71 ± 13.43 U/L), with an overall mean value of 57.48 ± 17.53 U/L. The maximum mean alkaline phosphatase (ALP) activity (82.23 ± 57.37 U mg⁻¹ protein) was recorded during August, whereas the minimum activity (43.18 ± 38.64 U mg⁻¹ protein) was observed during Decem-

ber (one-way ANOVA, $P < 0.05$). The overall mean ALP activity during the study period was 58.98 ± 13.36 U mg^{-1} proteins. When enzyme activities were averaged across the three gut regions, trypsin, α -amylase, and lipase showed their highest seasonal mean values in autumn, whereas alkaline phosphatase reached its highest seasonal mean in summer. The lowest seasonal mean values occurred in winter for trypsin, lipase, and alkaline phosphatase, while α -amylase showed its lowest seasonal mean in spring. Among the three pooled gut regions, enzyme activities were generally higher in the anterior region, followed by the middle and posterior regions of the gastrointestinal tract. Seasonal variation in digestive enzyme activities is illustrated in Figure 5.

Discussion

Feeding Ecology and Trophic Behaviour

The gut content composition of *Schizothorax esocinus* observed during the present study indicates an omnivorous feeding habit with a predominance of plant matter and a substantial contribution of animal matter. Diatoms formed the major component of the diet throughout the study period, followed by crustaceans, macrophytes, green algae, and blue-green algae. Similar observations have been reported by Bhat et al. (2014), who recorded a mixed feeding pattern in *S. esocinus* from Dal Lake, Kashmir. Wani (2021) also reported omnivorous feeding behaviour in *Cyprinus carpio* var. *communis* and *S. niger* from Dal Lake, Kashmir, where plant matter constituted a major proportion of the gut contents. Jan and Das (1970) described the diet of *S. esocinus* as comprising protozoans, rotifers, zooplankton, insect remains, fish scales, fish eggs, green algae, diatoms, macrophytes, detritus, and sand, which is consistent with the present observations.

The predominance of diatoms and macrophytes in the gut suggests that *S. esocinus* utilizes abundant periphytic and benthic food resources available in the River Jhelum ecosystem. Earlier studies by Qureshi et al. (2014) and Naik et al. (2015) categorized *S. esocinus* as a predominantly herbivorous bottom feeder. However, the present investigation demonstrated considerable ingestion of animal matter, particularly crustaceans, indicating trophic flexibility and omnivorous feeding behaviour. The observed variation in dietary composition may be influenced by habitat conditions, seasonal availability of food organisms, and ecological alterations within the riverine environment. Such trophic adaptability may enable *S. esocinus* to efficiently exploit available food resources under varying environmental conditions.

Frequency of Occurrence

The dominance of diatoms in the frequency of occurrence analysis throughout most months of the year indicates their importance as a principal food resource for *Schizothorax esocinus*. Similar observations were reported by Shekhar et al. (1993), who stated that Bacillariophyceae constituted the dominant dietary component of food in *Schizothorax* species during most months of the study period. The relatively lower occurrence of diatoms during June, July, and August may be attributed to reduced production of these organisms caused by increased water velocity and water level

following snowmelt in the catchment areas, as suggested by Shekhar et al. (1993). Jan et al. (2018) also reported that diatoms formed an essential component of food in *S. plagiostomus* during all months of the year. Crustaceans were observed throughout the study period with higher occurrence during warmer months, indicating increased availability and active feeding during this period. Similar findings were reported by Naik et al. (2015) and Kausar et al. (2012), who observed substantial proportions of animal matter and crustaceans in the gut contents of *Schizothorax* species and *Cyprinus carpio* var. *communis*.

The seasonal variation in the occurrence of different food categories suggests that *S. esocinus* exhibits flexible feeding behaviour in response to changes in environmental conditions and food availability within the River Jhelum ecosystem.

Seasonal Feeding Intensity

The seasonal variation in feeding intensity observed in *Schizothorax esocinus* suggests increased feeding activity during the summer months and reduced feeding during winter. The highest feeding intensity recorded between June and August may be associated with increased metabolic activity, greater availability of food organisms, and favourable environmental conditions during warmer months. The observed seasonal variation in feeding intensity is consistent with the findings of Ouakka et al. (2017), who reported pronounced seasonal fluctuations in feeding activity of *Sardina pilchardus*. The present findings also support the observations of Ikusemiju and Olaniyan (1977) and Sarker et al. (1980), who suggested that the degree of stomach repletion may serve as an indirect indicator of prey availability and overall trophic conditions within the aquatic environment. Reduced feeding intensity during winter months may be attributed to lower metabolic activity in fish along with decreased productivity of food organisms during colder conditions. Nikolsky (1963) reported that seasonal rhythms in feeding are closely linked to variations in food supply and environmental conditions. Similarly, Shekhar et al. (1993) suggested that reduced winter feeding in *Schizothorax* species may result from decreased autogenic food production and lower allogenic inflow during this period. The increased feeding intensity observed during summer indicates active food utilization and may also reflect enhanced energetic requirements associated with growth and post-spawning recovery.

Gut Morphometry and Feeding Adaptations

The gut morphometric and somatic indices recorded during the present study further support the omnivorous feeding habit of *Schizothorax esocinus*. The observed RLG, RGM, and ZI values indicate an intermediate gut morphology characteristic of fishes consuming both plant and animal matter. Elevated GaSI and FI values, together with reduced GVI values during warmer months, suggest increased feeding activity and greater gut fullness during this period. The increasing trend in GaSI and FI values from summer onwards may indicate enhanced food consumption associated with post-spawning recovery and increased metabolic activity.

Conversely, the declining trends observed in GaSI and FI values approaching the breeding season may reflect reduced appetite and altered feeding behaviour dur-

ing reproductive phases. Seasonal fluctuations in gut indices therefore appear closely associated with physiological condition, feeding activity, and environmental changes. The gut morphometric characteristics observed in *S. esocinus* demonstrate adaptive flexibility in utilizing a mixed diet and support the trophic observations obtained through gut content analysis.

Digestive Enzyme Activity and Nutritional Implications

The digestive enzyme profile observed in *Schizothorax esocinus* indicates an efficient capacity for the digestion of proteins, carbohydrates, and lipids. The presence of appreciable activities of trypsin, α -amylase, lipase, and alkaline phosphatase suggests that the species possesses a well-developed digestive system capable of utilizing a wide variety of dietary components. The comparatively higher activities of digestive enzymes during summer and early autumn may be associated with increased feeding activity, elevated metabolic rates, and greater food availability during warmer months. Seasonal fluctuations in enzymatic activity therefore appear to correspond closely with the feeding intensity and dietary composition observed during the present study.

Higher enzymatic activity in the anterior region of the gut compared to the middle and posterior regions indicates that major digestive processes predominantly occur in the proximal portion of the alimentary canal. Similar regional variation in digestive enzyme distribution has been reported in several omnivorous freshwater fishes.

Trypsin activity reflects the protein digestive capacity of the species, whereas α -amylase activity indicates the ability to digest carbohydrate-rich food components such as algae and plant matter. The observed lipase activity demonstrates the utilization of lipid-containing food resources, while alkaline phosphatase activity suggests active intestinal metabolic and absorptive functions.

The enzymatic versatility observed in *S. esocinus* supports the omnivorous feeding behaviour revealed through gut content analysis and indicates considerable trophic adaptability. Such digestive flexibility may be advantageous under fluctuating environmental conditions and variable food availability within the River Jhelum ecosystem. A limitation of the enzyme analysis is that the additional specimens were maintained at 22 ± 2 °C for 24 h before dissection, irrespective of the season. This difference in holding temperature may have influenced digestive enzyme activity; therefore, the measured seasonal patterns should be interpreted with this methodological limitation in mind. From an aquaculture perspective, understanding the digestive physiology of *S. esocinus* may contribute to the development of suitable feeding strategies and nutritionally balanced diets for captive rearing and conservation-oriented culture practices.

Conclusion

The present study demonstrated that *Schizothorax esocinus* exhibits an omnivorous feeding habit characterized by substantial consumption of both plant and animal matter, with diatoms and crustaceans forming the major dietary components. Sea-

sonal variation in feeding intensity, gut morphometric indices, and digestive enzyme activities indicated pronounced changes in feeding behaviour and digestive physiology throughout the year. The observed activities of trypsin, α -amylase, lipase, and alkaline phosphatase confirmed the species' ability to efficiently digest a wide range of dietary substrates, reflecting considerable trophic adaptability. Seasonal enzyme activity was generally highest in autumn for trypsin, α -amylase, and lipase, whereas alkaline phosphatase showed its highest activity in summer; these patterns broadly corresponded with seasonal variation in feeding intensity and metabolic activity.

The findings of the present investigation provide important baseline information on the feeding ecology and digestive physiology of *S. esocinus* from the River Jhelum, Kashmir. Such information may contribute to the development of effective nutritional strategies, improved aquaculture practices, and sustainable management approaches for this economically important indigenous fish species. Further studies focusing on seasonal environmental variation, nutrient utilization efficiency, and controlled feeding trials may provide additional insights into the nutritional biology and aquaculture potential of *S. esocinus*.

Ethics statement. Fish specimens were obtained from local fishermen at established fish landing centres, where they had been captured as part of routine fishing activities. No institutional animal ethics approval or collection permit was obtained for the acquisition of these specimens. The additional specimens used for digestive enzyme analysis were maintained alive for 24 h under controlled laboratory conditions and were humanely euthanized prior to dissection.

Author contributions. Z.H. conceptualized and designed the study, conducted field sampling and laboratory analyses, curated the data, and prepared the original draft of the manuscript. F.A.B. and T.H.S. supervised the project, contributed to methodology development, and participated in the review and editing of the manuscript. A.A. and A.K. contributed to the writing, review, and editing of the manuscript. B.A.B. contributed to data visualization, statistical analysis, and editing of the manuscript, S.T.M. did the proofreading of the whole draft to be made suitable for publishing.

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