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Feeding ecology of the endangered indigenous ornamental fish *Botia striata* (Rao, 1920) in the Koyna River, Western Ghats, India

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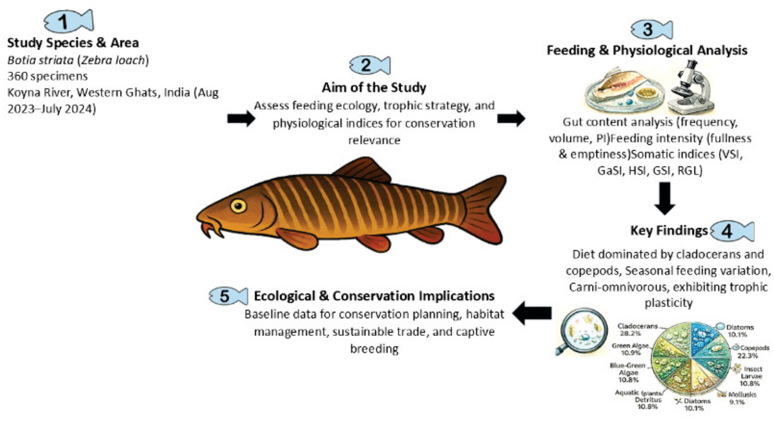
Abstract

Aim: This study examines the feeding ecology and trophic biology of endangered ornamental fish *Botia striata* in the Koyna River, Western Ghats, India. The objective was to quantify diet composition, feeding intensity, and somatic indices to elucidate ecological adaptability and inform conservation, sustainable trade, and captive breeding strategies.

Methodology: A total of 360 specimens were collected monthly from August 2023 to July 2024. Morphometric measurements were taken, followed by gut content analysis using frequency of occurrence, volumetric, and preponderance index methods. Feeding intensity was assessed through fullness and emptiness indices, while nutritional and reproductive status were evaluated using VSI, GaSI, HSI, GSI, and RGL.

Results: Feeding intensity varied seasonally, with empty guts (23.83%) and full guts (19.44%) predominating. Diet comprised aquatic plants/detritus, diatoms, green and blue-green algae, cladocerans, copepods, insect larvae, molluscs, and other zooplankton. Volume-wise, cladocerans (28.22%) and copepods (22.32%) dominated. The preponderance index identified cladocerans as the principal food item. The mean somatic indices indicated balanced energy storage and reproductive condition.



Interpretation: *B. striata* is a carni-omnivorous generalist, exhibiting trophic plasticity and seasonal feeding variation linked to reproduction and environmental factors. The findings support its ecological resilience and provide a baseline for conservation planning, habitat management, and aquaculture development.

Key words: *Botia striata,* Conservation, Feeding ecology, Ornamental fish, Western Ghats

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Introduction

The genus Botia (family Botiidae) comprises approximately 20 recognised fish species, commonly known as Indian loaches, which are valued in the ornamental fish trade due to their striking colouration, agile movements, and bottom-dwelling habits (Dey *et al.,* 2015). The idiosyncratic morphological characteristic of the Botia genus is the presence of two sharp suborbital spines, which are used as a defence mechanism and erected at the time of danger and threat. Additionally, individuals of this genus exhibit a unique ability to produce a "cracking" sound during feeding activity (Raffinger and Ladich, 2009). In India, this genus is represented by nine species, showing substantial diversity in the subcontinent (Kottelat, 2004). *Botia striata*, commonly referred to as the zebra loach or candy stripe loach, has garnered significant conservation concern, and in the Western Ghats of India, it is classified as endangered (Dahanukar *et al.,* 2004; 2011; Keskar *et al.,* 2015; 2017). Despite being an endangered species, the loach remains a significant component of India's ornamental fish trade, with reported trade volumes exceeding 382,575 numbers, and is ranked as the second-most traded aquarium fish in terms of volume (Raghavan *et al.,* 2013).

Food is an essential requirement for all living organisms, providing energy necessary to support various biological processes, including growth, development, and reproduction. Therefore, a comprehensive understanding of the dietary patterns and feeding behaviour of fish is a fundamental basis for their overall biological information, encompassing critical aspects such as growth dynamics, reproductive strategies, and migratory patterns of fish (Golikatte and Bhat, 2011; Alam *et al.,* 2015). The feeding habits of fish are influenced by various factors, including diurnal cycles, seasonal variations, body size and developmental stage, ecological conditions, and availability of food resources (Hynes, 1950; Alam *et al.,* 2020). The study helps to understand the dietary requirements of fish species and evaluate the productivity of water bodies (Rahman, 2005; Lawson and Aguda, 2010; Omondi, 2013; Tripathi *et al.,* 2013). The gut content enhances understanding of feeding patterns and dietary assessments, which are fundamental to effective fisheries management. It provides critical information on dietary composition, feeding preferences, and trophic interactions, enabling a quantitative assessment of food habits that inform sustainable fisheries practices. It offers valuable insights into seasonal and ontogenetic changes in fish feeding behaviour (Akinwumi, 2003) and prey selection, ontogenetic shifts, and conservation strategies (Chipps and Garvey, 2007).

Similarly, dietary information helps to determine dominant prey species and the relative importance of various food sources, enabling researchers to quantify individual prey consumption rates (Zacharia, 2017). The quantitative and qualitative assessment of gut content provides insight into dietary composition and trophic interactions (Cortés, 1997; Baker *et al.,* 2014). The composition of fish diets is significantly influenced by environmental conditions and ecological factors (Fagbenro *et al.,* 2000; Hajisamae *et al.,* 2003; Saikia, 2015). A widely adopted metric for evaluating fish feeding habits is the index of relative importance (IRI), which is applied to analyse the stomach content (Saikia, 2015) and determine the integrity of weight or volume of prey in relation to their numerical abundance (Pinkas, 1971). A comprehensive understanding of feeding ecology of fish, particularly through gut content analysis, Gastrosomatic index (GaSI), and relative gut length (RGL), is fundamental for effective aquaculture and fisheries management (Gupta, 2016).

The gastrosomatic index (GaSI) is widely used to assess seasonal variations in feeding intensity and serves as an indirect indicator of spawning periods in fishes (Alam *et al*., 2016; Dadzie et al., 2000). The relative gut length (RGL) is commonly employed to classify feeding strategies, distinguishing herbivorous, carnivorous, omnivorous, herbi-omnivorous, and carni-omnivorous species (Dasgupta, 2004). Gonadosomatic index (GSI) and hepatosomatic index (HSI) are important metrics for evaluating reproductive cycles and physiological condition, with GSI extensively used to determine spawning frequency and reproductive seasonality (Arruda *et al*., 1993; Islam *et al*., 2008; Ghaffari *et al*., 2011; Kingdom and Allison, 2011; Jan *et al*., 2014).

The liver plays a key role in vitellogenin production, making HSI a reliable indicator of ovarian development, energy reserves, and recent feeding activity (Tyler and Dunns, 1976; Jan and Jan, 2017). The viscerosomatic index (VSI) reflects the nutritional status of fish and generally increases with higher dietary lipid intake (Rasmussen *et al*., 2000; Chaiyapechara *et al.*, 2003). Together, VSI and HSI provide valuable insights into metabolic processes, digestion efficiency, and nutrient assimilation in fishes (Krogdahl *et al*., 2005; Samad *et al*., 2025).

In recent years, research on freshwater ornamental fishes of the Western Ghats has primarily emphasised taxonomy, distribution, population structure, and exploitation in the aquarium trade, while studies on functional ecology remain limited (Dahanukar *et al.,* 2004; Raghavan *et al.,* 2013). Specifically, for *Botia striata*, despite its endangered status and high commercial importance, scientific investigations have largely focused on its conservation status, morphometric relationships, and fishing pressure, rather than its ecological functioning (Keskar *et al.,* 2015; Dahanukar *et al.,* 2017). Available studies on loaches and other cobitid hill-stream fishes during the last five years are mostly restricted to short-term or qualitative gut content observations, lacking comprehensive seasonal coverage and integration of feeding intensity and physiological indices (Agrawal and Tyagi, 1969; Nagar and Sharma, 2016; Gupta, 2016). Consequently, critical information on the diet composition, energy allocation, and coordination of reproductive processes in *B. striata* under natural conditions remains poorly understood, highlighting the need for integrated trophic and physiological studies on this endangered ornamental species. The novelty of the present study lies in its integrated, year-long evaluation of feeding ecology of *B. striata* under natural conditions, which has not been previously reported. Unlike previous studies that were limited to short-term or qualitative dietary assessments, this research combines quantitative gut content analysis with feeding intensity measures and multiple somatic indices to provide a comprehensive understanding of trophic plasticity and energy allocation. This work establishes the first ecological baseline for *B. striata* from the Western Ghats, thereby advancing knowledge beyond descriptive ecology and directly supporting conservation management, habitat protection and the development of species-specific captive feeding and breeding protocols.

Materials and Methods

Sample collection: The fish specimens of *Botia striata* for the present study were collected from the Koyna River, Satara, situated at 17.33996°N, 73.95691°E Maharashtra (India), which is a significant river system within the Western Ghats of India. A total of 360 fish specimens were collected by twelve field expeditions each month from August 2023 to July 2024. The collected specimens were immediately preserved in an insulated ice box to maintain their integrity during transportation and transported to the Division of Aquaculture, ICAR-Central Institute of Fisheries Education, Mumbai (Maharashtra) for morphometric measurements, including total length (cm) and weight (g).

Sample identification: The collected fish specimens were identified as *B. striata* (Rao, 1920) based on the key diagnostic morphological characteristics described for loaches (Fig. 1). The species exhibits a laterally compressed head and body, varying from elongated to fusiform in shape, and possess a characteristic suborbital spine extending posterior to the eye socket (Dey *et al.,* 2015). Three pairs of barbels are present, including one subterminal pair near the inner mouth region, and the body is covered with minute cycloid scales (Anna Mercy *et al.,* 2007). Individuals are predominantly benthic in habit and display distinct dark bands and blotches on a lighter body background. The pectoral fins are relatively elongated in comparison to snout length, and the caudal peduncle is nearly square in cross-section, consistent with standard taxonomic descriptions (Talwar and Jhingran, 1991).

Dissection and measurement of organs: Following the morphometric measurement, the internal organs of each specimen were meticulously dissected using precision tools, including scissors, forceps, needles, brushes, etc. The digestive tract was carefully excised and preserved in a labelled vial containing 10% formalin solution for subsequent analysis, including dietary assessment and analysis of gut content. The length of the digestive tract was measured with a digital slide callipers to ensure precise morphometric evaluation.

Observation of gut condition: The gut condition was visually examined and categorized into five distinct levels: 'full,' '¾ full,' '½ full,' '¼ full,' and 'empty' (Jayabalan and Ramamoorthi, 1985). The stomach of the fish was separated from the digestive system and weighed alongside the liver on an electronic balance. The gut contents of the studied fish were analysed under a binocular microscope (Nikon SMZ1270) at 8X magnification for identification up to generic level. The evaluation of indices contributes significantly to understand fish physiology, particularly in relation to the production of digestive enzymes, thereby advancing broader research efforts in aquatic nutrition and health.

Somatic indices: Somatic indices and feeding parameters were analysed to assess feeding intensity, dietary composition, and physiological condition of fish. Gut fullness was evaluated visually, and the fullness index (FI) was calculated based on stomach condition following the method of Dadzie *et al.* (2000),

Fig. 1: Experimental fish, Zebra loach, *Botia striata* (Rao, 1920), collected from the Koyna River, Western Ghats, Maharashtra, India.

while the stomach emptiness index (CV) was determined according to Preciado *et al.* (2014). For dietary analysis, the stomach were dissected, and the aliquot of ingested content was collected in pre-rinsed glass vials and examined under a light microscope (XSP L101). Diet composition was quantified following the frequency of occurrence method by Hynes (1950), with food items identified following Hyslop (1980). The relative importance of dietary components was assessed by calculating the preponderance index (PI), based on the percentage volume and frequency of occurrence (Natarajan and Jhingran, 1963); Soni and Ujjania (2018). The viscerosomatic index (VSI) was estimated to evaluate visceral mass relative to body weight following Igejongbo and Olufade (2022). Feeding intensity over time was further assessed by gastrosomatic index (GaSI), calculated according to Desai (1970) and Verma (2015). The hepatosomatic index (HSI) was determined to assess the liver condition using the formula proposed by Rajaguru (1992). Reproductive investment in relation to feeding activity was evaluated by gonadosomatic index (GSI), following the method of Strum (1978) and Afonso-Dias *et al.* (2005). Additionally, the relative gut length (RGL), expressed as the ratio of gut length to total body length, was calculated by the method of Al-Hussaini (1949) to infer feeding strategy.

Statistical analyses: The data were systematically calculated, with all relevant graphs and tables generated to facilitate comprehensive interpretation using Microsoft Excel (2021).

Result and Discussion

The analysis of gut condition in *B. striata* revealed pronounced variability in feeding intensity throughout the study period, reflecting the dynamic feeding behaviour typical of hill-stream and benthic fishes. The distribution of gut fullness categories showed that empty stomach were most prevalent (23.83%), followed by full and three-quarter full stomachs (19.44%), half-full (19.16%), and quarter-full (18.06%). The observed range of the fullness index (3.33-43.33%) and stomach emptiness index (6.67-40.00%) indicates marked temporal fluctuations in feeding activity (Table 1). Such variability is widely recognised as an adaptive response in lotic systems, where prey availability, flow regimes, and habitat heterogeneity vary seasonally, influencing feeding periodicity and intensity (Saikia, 2015; Alam *et al.,* 2020).

The predominance of empty and partially filled stomachs suggests intermittent feeding behaviour rather than continuous feeding behaviour. Recent studies have demonstrated that reduced gut fullness in freshwater fish is often associated with reproductive energy allocation and behavioural shifts during gonadal maturation, rather than solely reflecting food scarcity (Jan *et al.,* 2014; Alam *et al.,* 2016; Jan and Jan, 2017). This interpretation is supported by relatively high proportion of full and nearly full stomach observed outside peak reproductive phases, indicating compensatory feeding when energetic demands are lower (Arai, 2023). Comparable feeding intensity patterns have been documented in riverine and benthic fishes inhabiting dynamic environments, including *Sphyraena* spp. and other small-bodied freshwater fishes, where feeding activity fluctuates in synchrony with physiological condition and environmental cues (Osman *et al.,* 2019; Meshram *et al.,* 2022). Gut content analysis demonstrated that *B. striata* utilises a wide range of dietary resources, reflecting a flexible trophic strategy. Aquatic plants and detritus constituted the most frequently occurring dietary component (24.13%), followed by diatoms (18.32%), green algae (15.70%), cyanobacteria (11.44%), and euglenoids (8.48%). However, volumetric analysis revealed a contrasting pattern, with animal prey being the dominant proportion of ingested feed. Cladocerans accounted for the highest volume (28.22%), followed by copepods (22.32%), insect larvae and molluscs (15.25%), and rotifers (11.93%) (Table 2). This divergence between frequency of occurrence and volumetric contribution indicates that while plant material and detritus are ingested regularly, microcrustaceans and benthic invertebrates represent

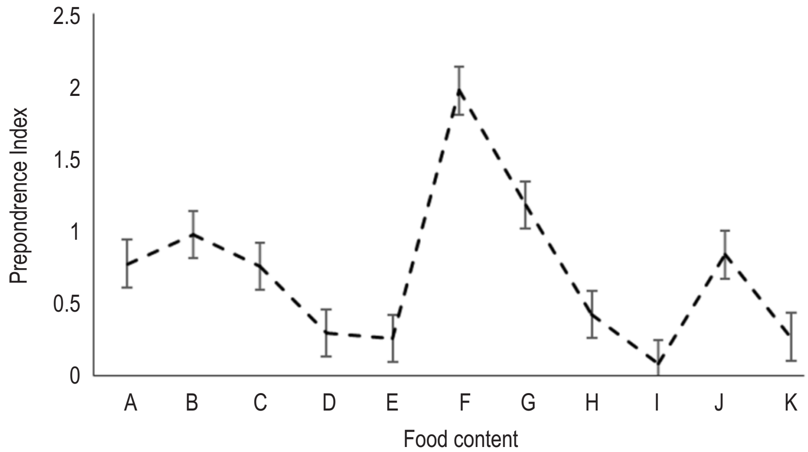

Fig. 2: Preponderance index of various dietary components identified in the gut content analysis.

Table 1: Gut condition of *Botia striata* (Rao, 1920) from the Koyna River

Gut condition	Minimum-Maximum (No.)	Mean (No.)
Full	1.0-13.0	5.83 (19.44 %)
¾ Full	3.0-9.0	5.83 (19.44 %)
½ Full	2.0-9.0	5.75 (19.16 %)
¼ Full	1.0-11.0	5.42 (18.06 %)
Empty	2.0-12.0	7.17 (23.83 %)
FI (%)	3.33-43.33	19.44 %
CV (%)	6.67-40.00	23.89 %

the primary energetic components of the diet.

The preponderance index further reinforced this trophic pattern by identifying cladocerans as the principal food item, followed by copepods, diatoms, and insect larvae (Fig. 2). Recent trophic ecology studies have highlighted the nutritional importance of microcrustaceans, which provide high-quality protein and lipid resources essential for growth and reproduction in small freshwater fishes (Baker *et al.,* 2014; Saikia, 2015). Similar dietary dominance of microcrustaceans has been reported in cobitid and benthic fishes from Indian rivers, confirming a carni-omnivorous feeding strategy with selective reliance on animal prey, supplemented by algal and detrital matter (Gupta, 2016; Nagar and Sharma, 2016; Lanthaimeilu and Bhattacharjee, 2018).

The consistent presence of algal groups and detritus suggests trophic plasticity, enabling *B. striata* to maintain feeding continuity under fluctuating prey availability, a key adaptive trait in hill-stream ecosystems. Somatic indices provided physiological support for the observed feeding patterns and trophic strategy. The viscero-somatic index ranged from 6.25 to 12.22 (mean 8.21 ± 0.11), indicating effective digestion and nutrient assimilation without excessive visceral fat accumulation (Table 3). The gastrosomatic index exhibited a narrow range, reflecting relatively stable feeding activity across seasons. The hepatosomatic index remained low and consistent, suggesting balanced hepatic energy reserves and efficient metabolic regulation. Recent studies have demonstrated that stable HSI values are indicative of efficient energy transfer from liver reserves to gonadal development during reproductive phases, rather than metabolic stress (Jan and Jan, 2017; Samad *et al.,* 2025).

The gonadosomatic index values confirmed active reproductive investment, and the observed inverse relationship between feeding intensity and gonadal development aligns with contemporary evidence showing that feeding activity often decline during peak reproductive phases due to hormonal regulation and behavioural prioritisation of spawning activities (Islam *et al.,* 2008; Alam *et al.,* 2016; Lv *et al.,* 2025). The relative gut length ranged from 0.57 to 0.97, with a mean value of 0.76, which is characteristic of carni-omnivorous fish (Table 3). Such gut morphology reflects adaptation to diets dominated by animal prey while retaining the capacity to process plant material when required. Similar RGL values have been reported in recent

Table 2: Occurrence and volume of food components in the gut of *Botia striata* (Rao, 1920) during the study period

Food contents	Occurrence (%)	Rank	Volume (%)	Rank	PI	Rank
Aquatic plants and detritus	21.8-28.3 (24.125)	I	2.8-3.6 (3.208)	IX	0.774	V
Bacillariophyceae (Diatoms)	16.9-20.1 (18.317)	II	5.0-5.7 (5.308)	VI	0.973	III
Chlorophyceae (Green algae)	14.5-16.7 (15.700)	III	4.4-5.1 (4.800)	VII	0.754	VI
Cyanophyceae (Blue-green algae)	10.4-12.7 (11.442)	IV	2.2-2.9 (2.592)	XI	0.296	VIII
Euglenophyceae	7.7-9.2 (8.483)	V	2.8-3.3 (3.058)	X	0.259	IX
Cladocera (Water fleas)	6.2-7.6 (6.975)	VI	27.2-29.5 (28.217)	I	1.970	I
Insect larvae and molluscs	5.0-6.1 (5.475)	VII	14.5-15.7 (15.250)	III	0.836	IV
Copepoda (Micro crustaceans)	4.6-5.9 (5.275)	VIII	21.4-23.7 (22.317)	II	1.178	II
Rotifera (Tiny zooplankton)	3.0-4.3 (3.542)	IX	11.2-12.5 (11.933)	IV	0.422	VII
Protozoa (Microorganisms)	2.0-2.7 (2.400)	XI	3.0-3.8 (3.442)	VIII	0.083	XI
Miscellaneous	2.9-3.6 (3.217)	X	7.8-8.7 (8.300)	V	0.267	X

PI is Preponderance Index, and in parentheses is the mean value

Table 3: Biological or somatic indices of fish *Botia striata* (Rao, 1920) from the Koyna River (mean ± SE)

Biological indices				
VSI	**GaSI**	**HSI**	**GSI**	**RGL**
6.250- 12.220 (8.207±0.107)	1.203-1.230 (1.221±0.007)	0.974-0.987 (0.982±0.001)	1.491-1.515 (1.506±0.006)	0.572-0.968 (0.764±0.007)

VSI-Viscerosomatic Index; GaSI-Gastro-somatic Index; HSI-Hepatosomatic Index; GSI-Gonadosomatic Index and RGL-Relative Gut Length studies on omnivorous freshwater fishes exhibiting flexible feeding strategies (Koundal *et al.,* 2013; Lanthaimeilu and Bhattacharjee, 2018; Kuhn *et al.,* 2024).

This study presents the integrated, year-long assessment of feeding ecology and physiological condition of the endangered Western Ghats loach *B. striata.* The combined analysis of gut contents and somatic indices establishes the species as a carni-omnivorous generalist with pronounced trophic plasticity and seasonal feeding variation linked to reproductive activity. The ecological baseline generated here fills a critical knowledge gap for this heavily exploited ornamental fish. These findings provide valuable guidance for conservation planning, habitat management, and development of species-specific captive feeding and breeding strategies, which are essential for long-term sustainability.

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Authors' contribution: V.K. Ujjania: Conducted experiments, collected and analysed data, and drafted the manuscript; **P.B. Sawant:** Conceptualised the study, designed experiments, supervised research, and edited the manuscript; **S. Munilkumar, G. Biswas, S. Debroy, K. Rasal and D. Sarma:** Provided assistance with experimentation and technical support; **A.K. Jaiswar and B. Kushwaha:** Supervised manuscript editing and formatting. **N.C. Ujjania:** Guided statistical analysis, data interpretation and manuscript drafting. **G. Sravani:** Assisted in sampling and experimentation.

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Ethical approval: This research was conducted within the framework of the approved project proposal (No. CIFE-03-2025), titled "All India Network Project on Ornamental Fish Breeding and Culture." All experimental procedures involving fish were carried out in accordance with ethical guidelines and received prior approval from the Institutional Animal Ethics Committee (IAEC) of ICAR–Central Institute of Fisheries Education, Mumbai (Registration No. 524/GO/ReBi/S/02/CPCSEA, dated: June 09, 2025).

Conflict of interest: The authors declare that they have no conflict of interest.

Data availability: The data that support the findings of this study are available on request from the Corresponding author.

Consent to publish: All authors agree to publish the paper in *Journal of Environmental Biology.*

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