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Cover: Freshly emerged Footman Moth *Nepita conferta* from the cocoon on a brightly painted wall in the Nilgiris. Digital art on Procreate. © Aakanksha Komanduri.

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COMMUNICATION

Assemblage structure and diversity of ichthyofauna in a low-order stream of the Pamba River in the Western Ghats of southern Kerala, India

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Abstract: This study investigates the assemblage structure and diversity of ichthyofauna in the second-order stream Chorakakki, a tributary of the Pamba River in the Western Ghats of southern Kerala, India. Monthly surveys conducted between January 2019 and June 2021 documented 20 ichthyofaunal species belonging to three orders, six families, and 14 genera. The stream exhibited diverse physico-chemical characteristics, including an average width of 6.17 ± 1.8 m, depth of 0.71 ± 0.28 m, a current velocity of 2.01 ± 0.19 m/s, water temperature of 27.3 ± 0.8°C, dissolved oxygen of 7.8 ± 0.8 mg/L, and slightly acidic pH (6.04 ± 0.23). Stream substrate composition varied, comprising bedrock, boulders, cobbles, pebbles, gravel, sand and silt, which created diverse mesohabitats supporting species-specific preferences. The ichthyofaunal community was dominated by *Garra mullya* (42.63%) and *Mesonoemacheilus triangularis* (25.48%). Habitat preferences were evident, with *Haludaria fasciata* frequenting pools and Balitoridae members inhabiting riffles. Diversity indices such as Margalef's (2.85), Shannon's (1.67), Dominance (0.27), and Evenness (0.26) revealed moderate species richness and uneven species distribution. The presence of 'Vulnerable' *Schistura denisonii* and 'Critically Endangered' *Homaloptera montana* underscores the conservation importance of the investigated stream. In addition to highlighting the significance of low-order streams in maintaining a variety of freshwater fish species, this study offers insightful information for Western Ghats conservation planning and management.

Keywords: Abundance distribution, conservation, habitat preference, mesohabitat, physico-chemical properties, stream substrates, rheophilic species, threat status.

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Author contributions: RT—conceptualisation and research design, field data collection, data compilation and analysis, and manuscript drafting. RTK—Methodological guidance, taxonomic support, species verification, manuscript review and revision, and supervision.

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INTRODUCTION

Low-order streams, characterised by their small size and limited discharge, are vital components of freshwater ecosystems. These streams typically originate in mountainous or forested catchments and significantly contribute to the biodiversity of river systems and their riparian networks, supporting both permanent resident species and seasonal migrants that utilize headwaters during specific life stages or seasons (Shrestha 1993; Dudgeon 2000; Meyer et al. 2007; Richardson & Sato 2015; Zbinden & Matthews 2017). Headwater streams, as the origin points of freshwater networks, offer unique and sensitive habitats that support specialist and often endemic species, contribute to evolutionary diversification, and are critical for various life stages of numerous freshwater taxa, yet remain highly vulnerable to degradation due to their small size, catchment dependence, and ease of physical alteration (Johnson & Douglass 2009; Lapointe et al. 2014; Richardson 2019). Globally, ecologically sensitive and biodiverse stream systems are increasingly threatened by a range of anthropogenic pressures, such as habitat loss, hydrological modifications, land-use change, invasive species, and pollution (Wohl 2017; Grzybowski & Lewczuk 2019).

In the Indian context, rivers of the Western Ghats and their headwater streams are increasingly affected by a range of anthropogenic pressures across their catchments, including pollution from large-scale pilgrimage, intensive agriculture, and unregulated land-use changes. These stressors contribute to the growing vulnerability of stream fish communities in the region, particularly due to habitat degradation, deforestation, dam construction, and the impacts of climate change (Arunachalam 2000; Johnson & Arunachalam 2010; Abraham & Kelkar 2012; Shilly et al. 2016).

The aquatic ecosystems in the state of Kerala region, particularly the lower-order streams, exhibit diverse flow patterns, substrate types, and water chemistry. These factors create microenvironments that support a wide range of fish fauna. However, these ecosystems remain understudied in comparison to larger rivers. The ichthyofaunal diversity is a crucial indicator of ecosystem health and vitality. The studies of Hora (1921, 1937, 1941) and Hora & Misra (1938) focused particularly on the freshwater fish fauna of the Western Ghats. The variety of ichthyofauna seen in the high range of Travancore was documented by Silas (1951). Gopi (2000) and Easa & Shaji (2003) have provided comprehensive analyses of ichthyofaunal diversity in Kerala. Devi et al. (2005) listed 88 fish species from the Anamalai Hill ranges. The biodiversity status of the low-order streams of the Pamba River in the Western Ghats has not yet been studied adequately. In southern Kerala, however, significant streams and rivers have been the subject of in-depth research on ichthyofaunal diversity (Jancy & Jobiraj 2017; Arunkumar & Arunachalam 2018; Salu & Ambili 2019). Vishnu et al. (2023) listed 35 fish species from a perennial tributary of the Achankovil River in Kerala.

The Pamba River, one of the longest rivers in Kerala, is fed by numerous low-order streams that collectively shape its hydrology and biodiversity. The specific contributions of these tributaries, particularly in terms of ichthyofaunal diversity, remain underexplored. Understanding the dynamics of low-order streams is essential for conserving the unique biodiversity of the Western Ghats, a global biodiversity hotspot. The current study is aimed at examining the fish assemblage structure in a low-order stream of the Pamba River, by emphasising habitat preference and threat status under the current ecological conditions. The study of such streams is crucial to identify and mitigate threats to aquatic biodiversity, including habitat degradation and climate change. It may aid in the effective management and sustainable use of these aquatic resources.

MATERIALS AND METHODS

Study area

Chorakakki, situated within the Ranni forest division of Kerala, India, is a second-order tributary of the Pamba River (Image 1). Positioned at an altitude of 163 m within the Western Ghats, its geographic coordinates are approximately 9.304° N & 77.054° E. This perennial stream encompasses various mesohabitat units, including rapids, glides, pools, riffles, runs, and waterfalls. The study examined the assemblage structure of fishes in a specific 200 m section of the stream from January 2019–June 2021, every month. Both fish sampling and habitat assessments were carried out within this same 200 m stretch. This location was selected to minimise variability. To capture variations in mesohabitat structure, a total of eight sampling sites were established at intervals of approximately 20–30 m along the 200 m stream section.

Assessing the physico-chemical and biological parameters

Water samples were collected in sterilised 1L bottles

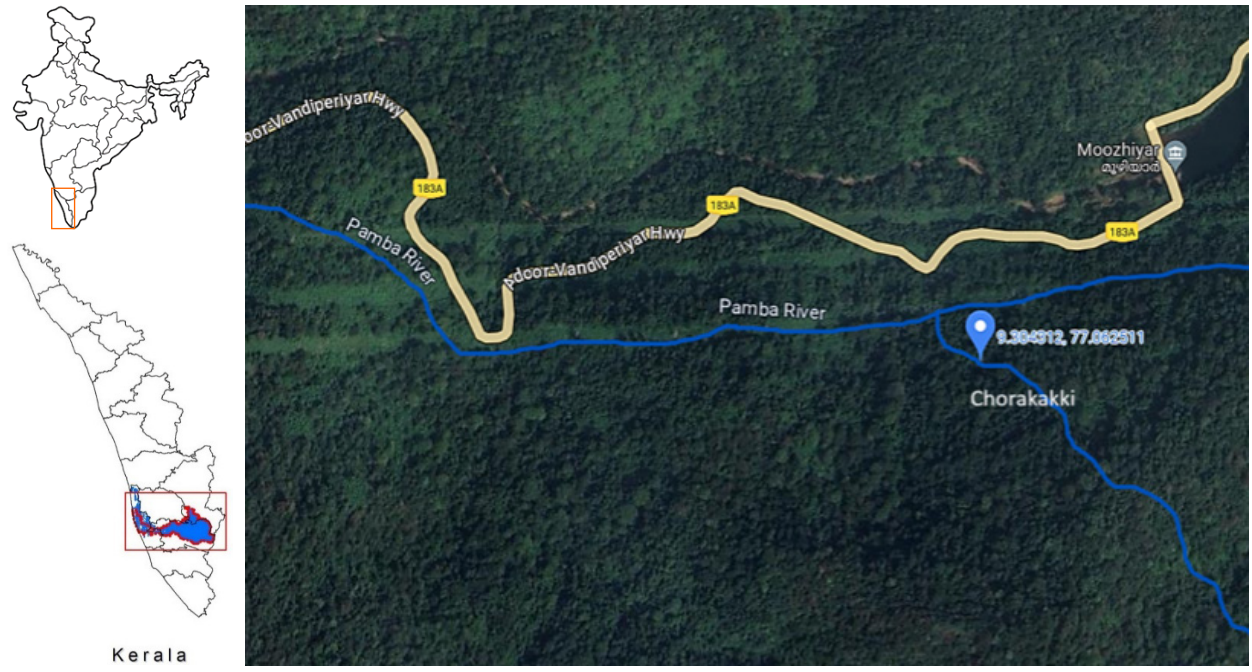

Image 1. Satellite map from GoogleMaps ® displaying the location of the studied low-order stream of the Pamba River in the Western Ghats of southern Kerala, India

after cleaning with distilled water. Water temperature was measured on-site using an HM Digital Water Tester (Model: AP-1), and pH was determined with a pen-type pH meter (Model: PH-009 IA). The Winkler method was used to estimate dissolved oxygen (mg/L). Additionally, stream substrate types, instream cover (%), and bank stability were visually assessed. Riparian shade was measured with a spherical crown densiometer, while current velocity was measured using a pygmy-type current meter (No. 4010, M/S National Instruments Corporation, Roorkee). Stream width and depth were recorded using a measuring tape and a graduated wading rod, respectively. Bank stability was assessed using visual qualitative habitat assessment based on erosion, bank collapse, and vegetation cover.

The physico-chemical parameters were recorded monthly to capture consistent environmental conditions across sampling sites. This approach aimed to provide a baseline understanding of the stream's characteristics without seasonal biases.

Assessing the assemblage structure of the ichthyofaunal community

Fish surveys and identification were conducted utilising non-destructive sampling techniques tailored to the characteristics of the stream, including its order, flow regime, instream cover, habitat/channel unit, and presence of aquatic vegetation. Scoop nets (mesh size 2 mm) and cast nets (mesh size 14 mm, length 2.33 m, nylon webbing) were employed for fish sampling, with captured specimens preserved in 10% Formalin for subsequent investigations. During the sampling process, the abundance of each species was meticulously documented. Additionally, relative abundance was calculated for each species, providing a standardised measure of their prevalence within the ecosystem. To confirm the identity of preserved specimens, standard reference manuals such as Talwar & Jhingran (1991) and Jayaram (2010) were used. Drawing upon available scientific literature, including notable works by Dahanukar et al. (2004), Kurup et al. (2004), and Radhakrishnan & Kurup (2010), a thorough review was conducted to evaluate the current status of fish populations within the southern Kerala region of India (on a regional level). The conservation status of all identified species was cross-checked with the latest regional assessments, and the regional status was prioritised to reflect local ecological contexts and conservation priorities.

The assemblage structure of ichthyofauna was thoroughly analysed using various univariate indices (Margalef Index, Dominance Index, Shannon Index, and Evenness Index), each offering unique insights into the ecological information of the studied ecosystem.

Species octave curves and rank abundance curves (RACs) were employed to predict, model, and elucidate the distribution of species abundance within the studied stream. These analytical approaches were conducted utilising Paleontological Statistics (PAST) software version 4.03.

RESULTS

The stream exhibited varying physico-chemical and biological characteristics across its stretch (Table 1). The average stream width was 6.17 ± 1.8 m, with a maximum width of 8.2 m. The average depth was 0.71 ± 0.28 m, reaching a maximum of 1.2 m. Stream velocity averaged 2.01 ± 0.19 m/s, while water temperature and dissolved oxygen were 27.3 ± 0.8°C and 7.8 ± 0.8 mg/L, respectively. The pH was slightly acidic, with an average value of 6.04 ± 0.23. Riparian shade covered approximately 39.71 ± 9.99% of the stream.

The surveyed stream exhibited notable diversity, hosting 20 ichthyofaunal species, belonging to three orders, six families, and 14 genera (Table 2). Stream substrate composition and mesohabitat types positively influenced the distribution of fish species. Deep pools, boulder edges, and overhangs served as critical habitats for the stream inhabitants. Riffles were primarily observed in the surveyed stream, which supported rheophilic species due to its fast-flowing and oxygen-rich conditions. *Garra mullya* was the most abundant species (42.63), followed by *Mesonoemacheilus triangularis* (25.48), indicating its ecological importance in the ecosystem. Within the order Cypriniformes, species such as *Haludaria fasciata* and *Rasbora daniconius* preferred pool habitats. While species from the family Balitoridae were exclusively associated with riffle habitats. Bagrid members *Mystus malabaricus* and *M. montanus* were found in lower abundance and primarily inhabited

Table 1. Major physico-chemical and biological parameters recorded from the low-order stream of the Pamba River in the Western Ghats of southern Kerala, India.

Variable	Description
Stream width	6.17 ± 1.8 m (8.2 m maximum)
Stream depth	0.71 ± 0.28 m (1.2 m maximum)
Stream velocity	2.01 ± 0.19 m/s
Water temperature	27.3 ± 0.8 °C
Dissolved oxygen	7.8 ± 0.8 mg/L
pH	6.04 ± 0.23
Substrate types	Bedrock, boulder, cobble, pebble, gravel, sand and silt
Instream cover	Deep pool, boulder edge, overhangs, aquatic macrophytes and leaf litter
Bank stability	Good
Riparian shade	39.71 ± 9.99%

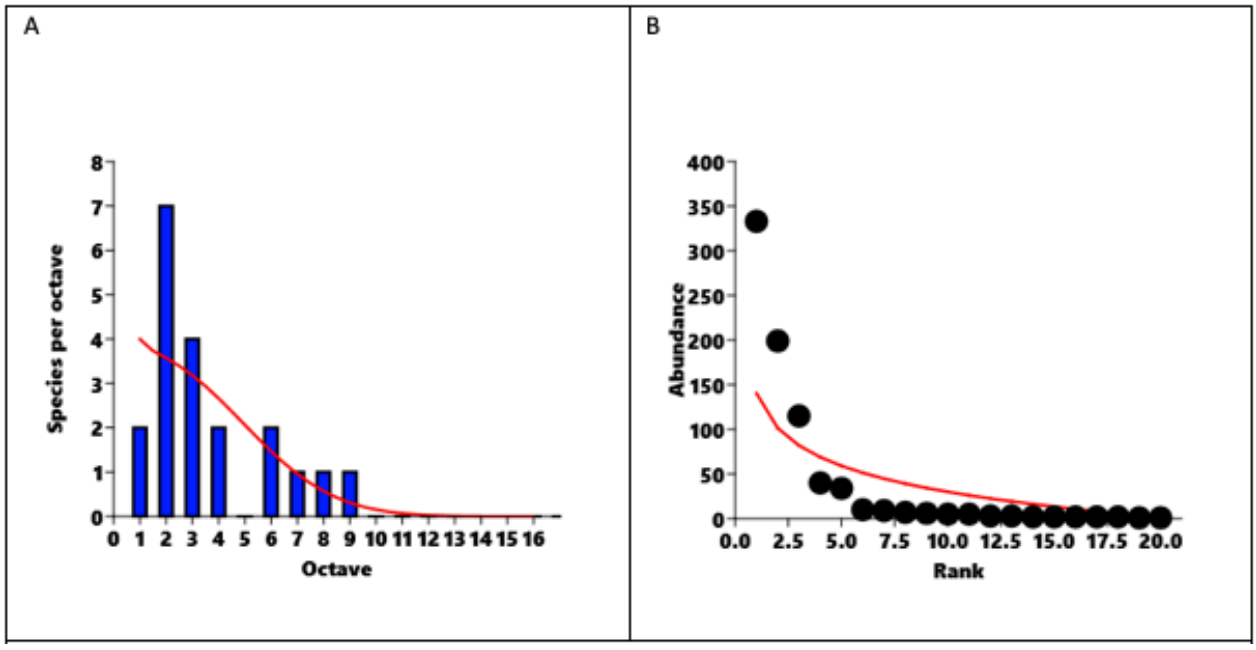

Figure 1. Freshwater fish species composition and abundance distribution in a low-order stream of the Pamba River, Western Ghats, Kerala, India: A—species octave | B—rank abundance curves.

Table 2. List of freshwater fish species recorded from the low-order stream of the Pamba River in the Western Ghats of southern Kerala, India. The species mentioned also include their preferred habitat/channel unit, relative abundance, and threat status.

	Species	Habitat/Channel unit preferred	Relative abundance	Threat status (Regional)
	Order: Cypriniformes			
	Family: Cyprinidae			
1	*Haludaria fasciata* (Jerdon, 1849)	Pool	5.12	LC
2	*Barilius bakeri* (Day, 1865)	Pool, Run	14.72	LC
3	*B. barna* (Hamilton, 1822)	Pool, Run	0.25	LC
4	*B. bendelisis* (Hamilton, 1807)	Pool, Run	0.896	LC
5	*B. gatensis* (Valenciennes, 1844)	Pool, Run	1.15	LC
6	*Devario aequipinnatus* (McClelland, 1839)	Pool, Run	0.64	LC
7	*D. malabaricus* (Jerdon, 1849)	Pool, Run	0.25	LC
8	*Rasbora daniconius* (Hamilton, 1822)	Pool	4.35	LC
9	*Garra mullya* (Sykes, 1839)	Pool, Riffle, Run	42.63	LC
10	*G. menoni* (Rema Devi & Indra, 1984)	Pool, Riffle, Run	0.25	VU
11	*Amblypharyngodon* sp.	Pool	0.76	DD
	Family: Balitoridae			
12	*Bhavania australis* (Jerdon, 1849)	Riffle	1.28	NT
13	*Homaloptera montana* (Herre, 1945)	Riffle	0.25	CR
14	*Travancoria jonesi* (Hora, 1941)	Riffle	0.38	EN
	Family: Nemacheilidae			
15	*Mesonoemacheilus triangularis* (Day, 1865)	Pool, Riffle, Run	25.48	LC
16	*Schistura denisonii* (Day, 1867)	Pool	0.64	VU
	Order: Siluriformes			
	Family: Bagridae			
17	*Mystus malabaricus* (Jerdon, 1849)	Pool	0.12	DD
18	*M. montanus* (Jerdon, 1849)	Pool	0.12	DD
	Family: Sisoridae			
19	*Glyptothorax* sp.	Rapid, Riffle	0.25	DD
	Order: Anabantiformes			
	Family: Channidae			
20	*Channa gachua* (Hamilton, 1822)	Pool, Riffle	0.38	VU

Threat status: EN—Endangered | VU—Vulnerable | NT—Near Threatened | LC—Least Concern | CR—Critically Endangered | DD—Data Deficient.

pools. The presence of *Channa gachua* in the stream indicates the presence of labyrinth fish, though they are not very abundant. Among the noted ichthyofauna, *Garra menoni*, *Schistura denisonii*, and *Channa gachua* were categorised (based on regional-level assessments) as 'Vulnerable'. While *Homaloptera montana* formed the 'Critically Endangered' (CR) category (Dahanukar et al. (2004); Kurup et al. (2004); Radhakrishnan & Kurup (2010).

Figures 1 & 2 show the fish species composition and the diversity indices of the ichthyofauna in the stream under investigation. The species octave curves (Figure 1A) demonstrate a varied distribution of species abundance across different octaves, indicating an uneven distribution within the community. Similarly, the steep decline observed in the rank abundance curve (Figure 1B) suggests an uneven abundance distribution among species.

This indicates a low evenness in the fish community, with a few dominant species overshadowing many others with lower abundances. The Margalef Index, representing species richness, was 2.853, while the

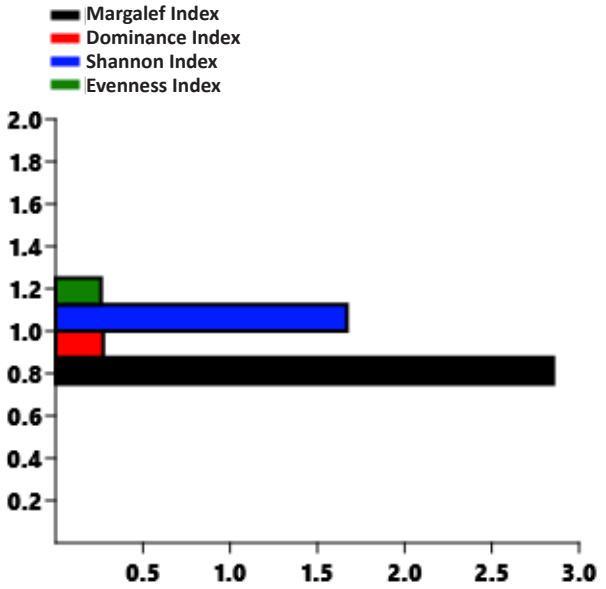

Figure 2. Diversity indices of freshwater fish in a low-order stream of the Pamba River, Western Ghats, Kerala, India.

Dominance Index (D), indicating dominant species abundance, was 0.273. The Evenness Index was 0.26, revealing a disparity in species distribution. The Shannon Index, representing richness and evenness, was 1.67 (Figure 2).

DISCUSSION

The low-order stream under study offers important insights into its ecological dynamics and ichthyofaunal community structure. Environmental factors at local scales and regional scales affect fish communities (Angermeier & Winston 2015); transient upstream habitats generally tend to have lower diversity and richness when compared to diverse downstream habitats (Pease et al. 2012; Bahuguna 2020). In this study, the stream exhibited varying physico-chemical and biological characteristics across its stretch. Parameters such as current velocity, substrate composition, and riparian vegetation played a crucial role in shaping the assemblage structure. For example, substrate diversity provided microhabitats that supported species with specific ecological preferences, as noted by Magalhaes et al. (2002). Nsor & Obodai (2016) further emphasized the significance of habitat heterogeneity in sustaining ichthyofaunal diversity, a pattern corroborated by our observations in the Chorakakki stream. The substantial diversity found in the low-order stream of the Pamba River draws attention to the distinct ecological dynamics of low-order streams, which generally have fewer species than main river courses. Studies focusing on the diversity of fish communities within the low-order stream systems of the Pamba River remain scarce, despite the availability of numerous studies examining major tributaries and the main channels (Radhakrishnan 2006; Radhakrishnan & Kurup 2010; Renjithkumar et al. 2011; Benno 2018). *Garra mullya* formed the most prevalent species in the respective stream reach, followed by *Mesonoemacheilus triangularis*, demonstrating the ecological significance of these species in determining the composition of the community. Both species are known to exhibit specific microhabitat preferences and strong associations with key stream features such as substrate type, flow, and proximity to cover. These habitat selection patterns reflect species-specific morphological, physiological, and trophic adaptations in the respective stream (Thomas & Thomas 2024). Hillstream loaches from the families Balitoridae, Nemacheilidae, and Sisoridae thrive in low-order streams because of their adaptation to the swift currents and diverse stream habitats that may provide a range of food resources (plants to insects). These hillstream specialists exhibit rheophily, utilising specialised morphological and behavioural adaptations to withstand extreme hydrological forces, as described by Lujan & Conway (2015). According to Crawford et al. (2020), rheophilic hillstream loaches from southern and southeastern Asia, particularly those in the family Balitoridae, demonstrate diverse pelvic girdle morphologies, reflecting adaptations for effective locomotion in fast-flowing waters. The prevalence of rheophilic fish in lowland rivers is also supported by Aarts et al. (2004); Puijenbroek et al. (2019); Liu et al. (2021); Stoffers et al. (2021). The calculated diversity indices and species abundance distribution analysis further corroborate these findings, with the Margalef Index indicating moderate species richness, while the Dominance Index and Evenness Index reflect disparities in the species abundance distribution. Several studies have highlighted the role of physical habitat structure in shaping fish distribution, abundance, and community composition in the southern Western Ghats (Johnson & Arunachalam 2010; Arunkumar & Arunachalam 2018). Presence of a diverse and unique fish assemblage, particularly species sensitive to habitat disturbance, suggests that the sampled stream section remains relatively undisturbed and ecologically intact (Sarkar et al. 2017; Mandal 2018).

As mentioned earlier, headwater streams face mounting threats from hydrological alterations, land-use changes, pollution, and riparian degradation, all of which

impact aquatic biodiversity and ecosystem services. In the southern Western Ghats, as per our previous study (Thomas & Thomas 2023), streams are increasingly affected by agricultural activities, loss of riparian cover, hydrologic disruption, and pilgrimage-related tourism. These anthropogenic stressors alter stream morphology, destabilise pool-riffle patterns, and shift fish community structure, favouring tolerant generalist species over habitat-sensitive specialists.

In contrast, the current study stream supports a relatively intact fish assemblage, indicating favourable habitat conditions. These findings reinforce the need for proactive conservation efforts—such as regulating religious tourism, restricting destructive land-use practices, and restoring riparian buffers—to safeguard the ecological integrity of headwater streams in the Western Ghats. The documentation of species richness, abundance, and threat status provides valuable insights for conservation planning and management efforts aimed at preserving the unique biodiversity of this ecosystem in the Western Ghats.

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